Human-Centered Design as an Integrating Discipline

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ABSTRACT

What is research today? Good research has to be indexed within appropriate mechanisms to be visible, considered and finally useful. These mechanisms are based on quantitative research methods and codes that are often very academic. Consequently, they impose rigorous constraints on the way results should be obtained and presented. In addition, everything people learn in academia needs to be graded. This leads to standard packaging of what should be learned and results in making people executants and not creators nor inventors. In other words, this academic standardization precludes freedom for innovation. This paper proposes Human-Centered Design (HCD) as a solution to override these limitations and roadblocks. HCD involves expertise, experience, participation, modeling and simulation, complexity analysis and qualitative research. What is education today? Education is organized in silos with little attempt to integrate individual academic disciplines. Large system integration is almost never learned in engineering schools, and Human-Systems Integration (HSI) even less. Instead, real-life problem-solving requires integration skills. What is design research? We often hear that design has nothing to do with research, and conversely. Putting design and research together, as complementary disciplines, contributes to combine creativity, rigorous demonstration and validation. This is somehow what HCD is about.

Keywords: Qualitative research, real-life problem solving, human-centered design, critical thinking, complexity, creativity, tangibility, integration, socio-technical changes.

1. INTRODUCTION

This article results from a long thinking process assorted with constant observation of socio-technical world evolution. Seven years ago, I started the development of a Ph.D. program in Human-Centered Design (HCD) at Florida Institute of Technology. Five students already graduated, and fifteen others are currently studying in this program. Two years ago, I started a Masters program in HCD. Success of these graduate programs led us to think about an undergraduate program in HCD. But, what is HCD? Why has HCD become such an important topic? Why is HCD different from other connected disciplines in engineering, science and arts? Why is HCD useful in research, education and real life problem solving?

This paper addresses three points that will be further developed in the next section: (1) technology evolution; (2) robotics and jobs evolution; (3) culture, research, education and design. It will discuss compromises among standard comfort, critical thinking and risk taking. It will also address the concept of situation, discuss reductionism and complexity, and demonstration. Measure rigor will be addressed in terms of accuracy and uncertainty, as well as consistency and tangibility. Rigor will be both opposed and associated to creativity. Creativity can be understood as an integration process. HCD is interdisciplinary and therefore requires a common frame of reference, educated common sense, meaning and trust. Creativity can be individual in the form of storytelling, and collective in the form of participatory ideation (Figure 1). Finally, I will present the shift from STEM[1] to STEAM[2] as a great opportunity to depart from current education silos, frame creativity and better understand interdisciplinary necessity of HCD as a discipline integrating technology, organizations and people. In conclusion, I will address socio-technical changes, autonomy and coordination, and ultimately rehabilitating the art of making meaningful things.

Figure 1. A participatory design ideation session.

2. CURRENT SOCIO-TECHNICAL EVOLUTION

Technology Evolution

During the 20th century, we built machines from pieces of metal, wood and other tangible materials (Boy, 2014). We integrated them mechanically, making mechanical engineering a leading discipline. At the end of the century, we embedded electronic and software systems into mechanical machines and other constructions. Machines started to have (artificial) behaviors generated by software. We automated machines. Automation existed for a long time. The clock is certainly one of the oldest automata. However, what we called automation at

[1] Science, Technology, Engineering and Mathematics.

[2] Science, Technology, Engineering, Arts and Mathematics.

the end of the 20th century in term of automation has a totally different order of magnitude. People have moved from doing to thinking, making work more cognitive, and less physical. I already explained this evolution elsewhere (Boy, 2013). We have gone from hardware to software.

Since the beginning of the 21st century (i.e., during the last fifteen years), we inverted this design and development process. Almost everything that we design and further develop starts as a piece of software, and later on becomes an integrated piece of interactive hardware. Most projects starts as PowerPoint presentations, which are already software that we incrementally "automate." In other words, we develop system functions since the very beginning of the design process. We are also able to show behaviors using modeling and simulation tools. Human factors can be anticipated by observing potential users in Human-In-The-Loop Simulations (HITLS). We often do not need to develop hardware until clear design decisions have been made. We are going from software to hardware. We even can 3D print software models (Figure 1).

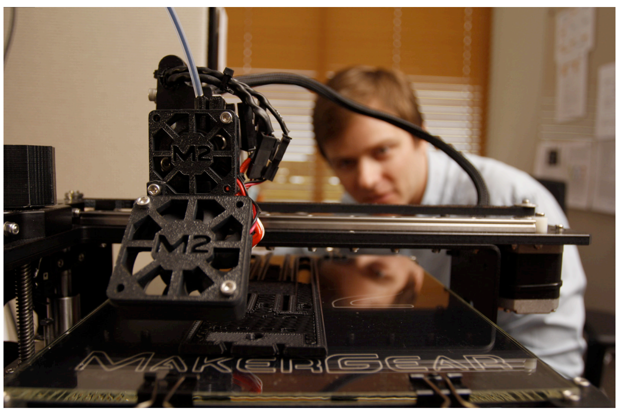

Figure 1. 3D printer in action.

This technological change in design and development is crucial. We do not think design and engineering in the same way as we did during the 20th century. Most importantly, systemic integration can be done much earlier than before. For a long time, integration was done almost at the end of the development process. Today in many cases, we can do it from the beginning of the design process. This enables us to effectively integrate human factors within and across all system elements during their life cycle. HSI is an essential enabler to systems engineering practice (Boy, 2017). Of course, we need to make sure that modeling and simulation provides tangible outcome (Boy, 2016). We will further describe the tangibility issue in this paper.

Robotics and Jobs Evolution

Whether at home, at work or during travel, people never stop using software. Software is everywhere, in smart phones, cars, and various kinds of appliances for example. We live "connected" with digital systems or with other people through digital systems. At the beginning of the 20th century, elevators were operated by grooms. Then they became automated. We automated metros and trains. Today, cars and trucks can be driven by software, and unmanned aerial vehicles can fly by themselves. 3D physics is being progressively mastered. What about jobs? If robots do most jobs that people are doing now, what will they do in the future? These important questions should be addressed in education and training, and most importantly emergent topics, such as sustainable sources of energy, data science (including 3D printing) and transportation harmonization.

Since robots will do things that people used to do, what would be the role of people in the future? The concept of work will necessarily change, and consequently what young people will need to learn will need to change accordingly. For example, an important factor that is dramatically emerging is ecology (i.e., care of our planet Earth). Even if some geologists can question global warming, the influence of carbon production has a noticeable influence on climate. We then need to take care of such things. Technology can be used to further find solutions to this end, and new ways of living should be investigated. I am afraid that current ways of doing research will provide satisfactory solutions in the short term but totally ignore the long term. We then need to develop human-centered design everywhere we design new systems to both investigate and find good solutions for our planet Earth. In other words, let's use robots and more generally technology to harmoniously satisfy natural needs and constraints, instead of damaging natural resources to produce technology for the only sake of making money. Consequently, schools and universities need to reconfigure curricula to adapt these upcoming changes, and help students to choose new careers.

Culture, Research, Education and Design

Research has its codes and practices with respect to current culture. Education is culture-dependent. Design attempts to create new artifacts and therefore new cultures. Research, education and design relate to culture. Culture is to people what water is to fish. We are not usually aware of it until we get out of it! Consequently, people usually have difficulties with culture changes. HCD proposes methods and tools to handle these changes. More specifically, HCD takes a holistic view. It enables to investigate and "co-design" Technology, Organizations and People (Figure 2). Of course, we do not design people, but we design jobs and potential human activities. As a matter of fact, when we design new technology, new organizational setups and human activities emerge, progressively replacing old ones.

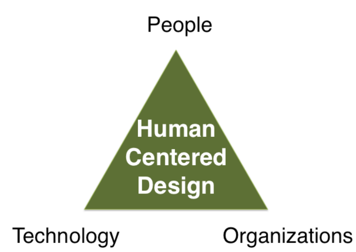

Figure 2. The TOP model.

HCD and systems engineering (SE) lead to human-systems integration (HSI) (Boy & Narkevicius, 2013). HSI is both a process and a product. HCD and SE are interdisciplinary fields. They deal with complex systems, such as biological systems, communication systems, business systems, aerospace systems and social systems. Complexity is certainly one of the most important topics in the early 21st century. It has to be addressed at school much earlier than before. If 20th century engineering focused on disciplines such as linear algebra, HCD started to focus on system science, which includes understanding of systems of systems, emergent properties of complex systems, HSI, organization design and management, modeling and simulation, and life-critical systems.

HCD and SE should address and harmonize innovation and standardization, which are basically opposite concepts. Successful innovation tends to break standards. Standards can be good when technology, organizations and human activities are stabilized. Many questions have to be answered, such as: How do we measure rigorously relevance and appropriateness of new designs? What does make a new socio-technical solution acceptable?

3. STANDARD COMFORT, CRITICAL THINKING AND RISK TAKING

Comfort of Standards

What is research today? Good research has to be indexed within appropriate mechanisms to be visible, considered and finally useful. These mechanisms are based on quantitative research methods and codes that are often very academic (i.e., theoretical compared to real-word requirements and needs). Consequently, they impose rigorous constraints on the way results should be obtained and presented. In addition, everything people learn in academia needs to be graded. This leads to standard packaging of what should be learned and results in making people executants and not creators not inventors. In other words, this academic standardization precludes freedom for innovation.

In human factors for example, the use of statistics is common practice to this end. More specifically, the use of p-values requires a number of subjects or entities to make sure results are valid and credible. In the real world, this kind of approach is most of the time impossible because of cost and relevance. Being a reviewer of scientific journals and advanced conferences all over the world, I see many submissions that present research work with right syntax (i.e., the right number of subjects and corresponding appropriate methodology), but wrong semantics (i.e., authors use students instead of professional pilots). Reason is that students are cheap and convenient, but they do not have appropriate knowledge and skills required in the demonstration. Consequently, results are not useful at all. What a waste of time!

Most importantly, this is a wrong dogmatic approach to do research. Indeed, testing cockpit designs requires a few well-chosen professional pilots who will find advantages and drawbacks of socio-technical solutions being developed. Design is inherently iterative and qualitative. Therefore, these professional pilots should be design team members. This is the participatory component of HCD. Participatory design forces working with real stakeholders (e.g., experts, experienced people, all possible kinds of end users) who will be involved during the whole life cycle of a product.

Critical Thinking and Cooperation

What is education today? Education is organized in silos with little attempt to integrate academic disciplines. Large system integration is almost never learned in engineering schools, and human-systems integration even less. Instead, real-life problem solving requires integration skills. In the real life, we typically have messy problems to solve. They are not well stated; we then need to learn how to state problems. At school, we learn how to solve problems that are well stated by professors. It is time to learn problem stating, which is inter-disciplinary education.

It is impossible to learn, teach and handle HSI without practice on complex real-world projects. Simple stand-alone academic exercises are not enough. Inter-disciplinary work should be more promoted and more importantly valued. Specialization is what our education systems mainly value, and very rarely high-level general knowledge and skills. What most people miss is capacity of integration. More generally, we absolutely need to develop creativity, out-of-box thinking and the pleasure of abduction. Most of education systems train technicians and not inventors, nor creators.

It is time to put together science, technology and art, based on today culture and needs rather than low-level discipline dichotomized elements. This is what Florida Institute of Technology's School of Human-Centered Design, Innovation and Art (SHCDIA) is doing. SHCDIA is a graduate school, where students are learning by designing new things. They learn how to cooperate to make the world better on real projects and problems that society and industry requires us to solve. They associate participatory design techniques to explore how various disciplines can contribute to improve human-systems integration.

Risk Taking and Knowledge Design

What is design research? We often hear that design has nothing to do with research, and conversely. Research is strongly based on rigorous demonstration and validation of initial claims. It is mainly considered as quantitative. Design is synthesis and integration of existing materials that requires creative and innovative thinking. It involves risk taking and therefore abductive inference.

Design is mainly considered as qualitative. Consequently, putting design and research together, as complementary disciplines, contributes to combine creativity, demonstration and validation. This is somehow what HCD is about. Design contributes to the production of artifacts that could be useful to and usable by people. Research and analysis contributes to the production of knowledge that enables explanation and/or prediction of facts and events and most importantly assures usability and functionality of the result.

Consequently, design research can be considered a discipline that contributes to the production of design knowledge useful to and usable for the production of artifacts. Therefore, a circular definition emerges. On one side, design can be considered as research. On the other side, research can be considered as "knowledge design." Consequently, system design can be seen as knowledge design (Figure 3).

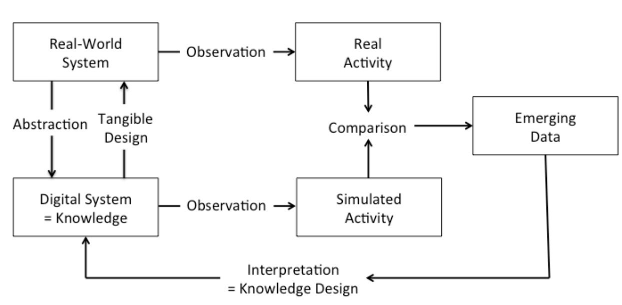

Figure 3. System design as knowledge design.

Today, making a system in the real world is staring by an abstraction that leads to a digital system (i.e., a software that is implemented on a computer). In return, the digital system enables to design the real tangible system. When concepts and physical objects have been put together enough to make something tangible, in both physical and figurative senses (Boy, 2016), activity can be observed. Consequently, we can generate two sets of data: real activity and simulated activity, which in turn have to be compared to further interpret discrepancies and fits. The former suggest modification of the digital system. The latter suggest validation of the digital system. The beauty of this approach is in the concomitant knowledge design process that superimpose on top of the incremental system design process.

4. OBSERVATION, COMPLEXITY AND DEMONSTRATION

Basic engineering and science disciplines have their own ways to model and measure their constructs. These modes and measures are typically quantitative. The holistic HCD approach cannot derive global credible quantitative metrics to support the validation of complex systems being developed. Parts can be quantitatively evaluated, but HSI assessment remains highly qualitative, often based on expertise and experience. Experts and experienced people know where to look to detect problems and assess solutions. They have learned the concept of situation. They know the separability issue in complex systems. Finally, they know how to articulate a demonstration that a system is good to go or not (i.e., how to deal with the certification issue).

The Concept of Situation

The concept of situation (Boy, 2015) can be defined as: location; set or combination of circumstances; state of affairs; condition; case; position; post of employment; job. It can be also defined as a set of fact, events and conditions that affect somebody or something at a particular time and in a particular place. Situation may refer to a dynamic set of states including multiple derivatives, in the mathematical sense. Let's try to construct a model of the various kinds of situations (Figure 4).

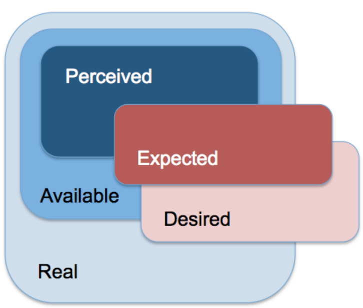

Figure 4. Various kinds of situations.

Ideally, the real world is characterized by an infinite number of highly interconnected states. This is what we call the "real situation". It may happen that some of these states are not available to us. For example, many states describing aircraft engine health are not directly available to pilots. States available to a human observer define the "available situation" (e.g., aircraft engine health states available to pilots). Note that the "available situation" is typically part of the "real situation". In addition, the "available situation" may not be totally perceived by the observer. What he/she perceives is called the "perceived situation". Of course, the "perceived situation" is part of the "available situation", but is also directed by what is being expected.

The "desired" situation typically expresses a goal-driven behavior (e.g., we want to get to this point). The "expected" situation expresses an event-driven behavior (i.e., we anticipate a set of states to happen). When people expect something to happen very strongly, they may be confused and mix the "perceived situation" with the "expected situation" (i.e., this is usually related to cultural context, distraction and focus of attention). There is huge difference between monitoring activities and control activities. People involved in a control activity are goal-driven. Their situation awareness process is directed by the task they need to perform (Boy, 2015). Conversely, people who only have to monitor a process (and who do not have to act on it) need to use, and sometimes construct in real time, an artificial monitoring process that may be difficult, boring and sometimes meaningless. In this second case, the situation awareness process has many chances not to be accomplished correctly.

Finally, the "perceived situation" is not necessarily a vector of some available states, but a model or image that emerges from a specific combination of these states, incrementally modified over time. This is called experience acquisition. Human operators build their own mental models or mental images of the real situation. This mental image depends on people, cultural context, current people's activity and other factors that are specific to the domain being studied.

Consequently, human operators subjects, who are not familiar with situations in laboratory setups, may lead to false interpretations in the long term. For this reason, human-centered design formative evaluations dealing with complex systems require training, minimal experience acquisition and longer involvement of human operator subjects. At SHCDIA for example, we choose to design new systems using realistic aircraft simulators and professional pilots.

Real and available situations are categorized under the concept of extrinsic situations. Expected and desired situations characterize the concept of intrinsic situation. Perceived situations belong to both concepts of extrinsic and intrinsic situations. Extrinsic situations are related to the complexity of human operator's environment. Intrinsic situations are related to the complexity of human operators' capabilities. Both types of complexity could be expressed in terms of number of states and interconnections among these states. In both cases, appropriate models need to be developed.

This ontological account of the "situation" concept assumes a single agent perspective. Within a multi-agent perspective, an additional dimension should be added, the shared situation (i.e., a situation shared by several agents, people or machines). More specifically, shared situation awareness deals with intersubjectivity, that is "the sharing of subjective states by two or more individuals" (Scheff, T. et al., 2006).

Reductionism and Complexity

The concept of separability was developed in physiology where some parts of the human body can be separated from the whole body and other cannot. For example, you cannot extract the brain, study it, work on it, and put it back. This does not work.

Conversely, you can replace a hand or even the heart of a person. More generally, some parts of the human body can be modeled using block diagrams. Interconnections complexity of others does not allow this reductionism. Therefore, people need to learn what can be reduced to simpler models and what cannot. During the 20th century, reductionism was an admitted practice in engineering. I personally learned to simplify real-world problems in order to solve tractable problems. This is why stating problems is a real endeavor that consists in making sense of a complex situation by choosing meaningful parameters and relationships among them that represent it.

We have learned in mathematics that transposing a complex situation into a simplified situation may lead to catastrophes (Thom, 1989). For example, radiography is a good example of such reductionism, where 3D situations are transformed into 2D situations (or images). Medical doctors have learned how to interpret 2D X-ray images to detect anomalies in belly organs. Today, medical doctors easily manipulate 3D scans and do not have these problems of catastrophes, in Thom's sense. More generally, HCD can greatly help by providing appropriate visualization solutions. In addition, technology such as head-mounted displays provides 4D solutions (i.e., 3D and motion).

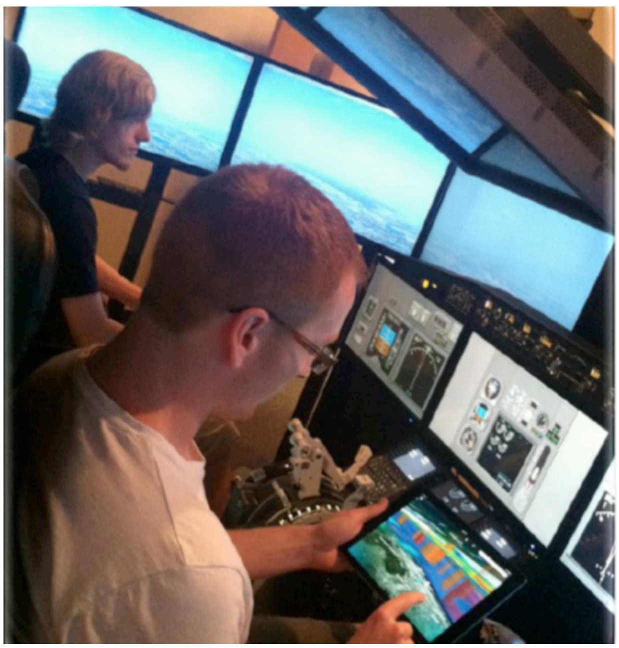

Figure 5. OWSAS tablet currently designed using HITLS and agile development in realistic aircraft cockpits.

A good example of a 4D solution is the Onboard Weather Situation Awareness System (OWSAS) that is currently designed and developed at SHCDIA using an agile approach on a commercial aircraft simulator with professional pilots (Boulnois & Boy, 2016). Agile development enables team collaboration, flexibility for later modification (i.e., architectures evolve), verify, validate and upgrade requirements at each iteration, induce collaboration and transparency among stakeholders. OWSAS is incrementally developed using HITLS (i.e., human-systems integration progressively emerges from experience). We constantly perform activity analyses that feed cognitive and physical function analyses (Boy, 1998). OWSAS enables aircraft pilots to strategically anticipate weather issues far away from problematic or dangerous zones by manipulating evolving 3D data (i.e., 4D data) and figuring out the best track to avoid these zones (Figure 5).

Demonstration, validation, verification and certification

Anytime a design process ends up in a prototype, it needs to be demonstrated a further validated. Validation is a question of verification that expected requirements have been met. Some of these requirements can be quantified; other cannot and need to be assessed qualitatively.

Every week, I give an assignment to my graduate students. They mainly have to provide their understanding of the lecture I gave that week, and their analysis and interpretation of one or several papers on the topic being learned. One of my students explicitly asked me to grade him with a quantitative score. I replied to him by asking him to have a face-to-face meeting. During that meeting, I asked him three questions to verify if he understood the concepts presented in the recent lectures and readings. I explained to him that I preferred to check his own understanding of these concepts. This is rather a more qualitative assessment of taught concepts and methods than a dry quantitative score. During that meeting, he recognized that he better understood concepts included in my three questions.

Verification consists in testing with respect to regulatory and technical standards. In aeronautics, it is commonly called flight test engineering. It leads to technology acceptance. Verification typically leads to certification or accreditation, which is the confirmation that expected requirements have been met. Verification processes are always based on scenarios, test protocols and criteria. Scenarios are meaningful models of situations (i.e., meaningful reductions of complex situations). Criteria are also meaningful metrics that can be either qualitative or quantitative, depending on maturity of what we attempt to assess. Certification is the ultimate verification that enables giving the "ready-to-be-used" stamp.

5. CREDIBILITY, RIGOR AND CREATIVITY

Credibility of a new product or technology includes and mixes rigor and creativity. Rigor is a matter of accuracy and uncertainty management using appropriate metrics. A product becomes credible when it is consistent and tangible to a large set of people. Creativity contributes to credibility when integration of its components is well done.

Accuracy and Uncertainty

"Are you sure that your design solution will work and be sustainable?" I always use Alan Kay's statement to answer this question: "The best way to predict the future is to invent it." Even if historical knowledge is always useful to anticipate possible future, accurate (mathematical) prediction based on past experience is impossible in the long term. Prediction is an event-driven process that leads to short-term reactive behavior. Conversely, we can anticipate possible futures and test these claims. Of course, we need to take risks. This is what research is about. It is a goal-driven process that involves longer-term intentional behavior. Modeling and simulation is a good way to assess possible futures.

Industry managers have always the problem to reduce and cope with uncertainty. Planning enables reducing uncertainty. Flexibility enables coping with uncertainty. Today, we can develop prototypes that can be tested very quickly during the design process. Prototypes enable design teams to progressively reduce uncertainty. Reducing uncertainty in the design of complex systems consists in continuously adjusting the balance between stability and flexibility in order to secure successful performance (Boy & Grote, 2009).

Prototyping supports agile system development. That is the spiral approach of designing, prototyping, human-in-the-loop testing, activity observation and analysis, and back to design until a satisfactory solution is found. An important question is: how is human activity analysis performed? This requires defining metrics. How accurate should they be? This is a matter of finding representative parameters or indices that can be assessed from human activity observation. Both choice and assessment of such metrics are a matter of rigorous expertise and experience. This is why good design requires great experience, expertise, inter-disciplinary knowledge and anticipation of visionary possible futures.

Consistency and Tangibility

Rigor in design is less a matter of accurate mathematical predictions than testing prototypes with respect to consistency and tangibility. Consistency can be tested at four levels: lexical, syntactic, semantic and pragmatic. Testing lexical consistency is about verifying that a concept is denoted by a single term (i.e., there might be synonyms to denote a concept, but they should not lead to ambiguities). A term can be any textual description, icon, symbol or physical device that affords to “manipulate” a concept (e.g., the word “File” or a file icon on a computer screen enables a user to manipulate a software file, in a similar way as a real file, which is a physical object as opposed to its metaphor on a computer screen). Testing syntactic consistency is about verifying how terms are organized together to express meaningful concepts (i.e., a complex concept being a combination of several other concepts). As in literature where writers combine words using a given syntax to provide a meaningful story, designers combine systems (systems of systems) using a given syntax to enable a meaningful job. Using MS Word for example (Figure 6), when users select “File” on a computer screen, they can see the first item in the menu “New Blank Document”, which is syntactically consistent with the use of MS PowerPoint.

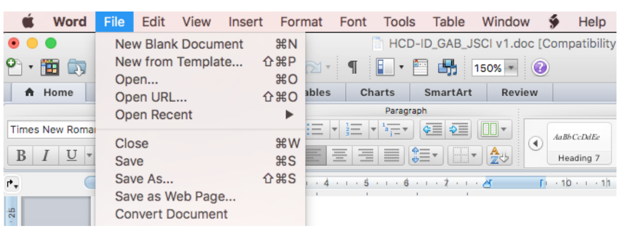

Figure 6. Consistent syntax of text processing applications.

Semantic consistency is about verifying that a term denotes only one concept. Indeed, if a term denotes two concepts, there is a semantic inconsistency. For example, if the term “Table” denotes the concept of a physical table with four legs and the table of content of a book, there is a semantic inconsistency. In natural language, this possibility requires contextualization in order to override this kind of ambiguity. Pragmatic consistency is about verifying that a term is understood in the culture where the underlying concept is used. For example, if you design systems in a country where driving on the right hand side of the road, it will not be pragmatically consistent in a country using British road rules.

Figure 6. SHCDIA experimental space suit test.

More systems today are software-based. Predominance of software requires verifying tangibility more than before. Tangibility can be physical in the sense of grabbing, holding and physically manipulating an object. For example, it is often better to manipulate a rotary selector to fix the sound of your car radio than to select a button on a computer screen while you are driving. You better feel what you are doing physically. More specifically, when a space suit is being designed physical tangibility testing requires a real-world space suit used in a simulated environment on the Earth first (Figure 6).

Tangibility can also be figurative in the sense of grabbing, understanding and cognitively using a concept. For example, if I try to convince you and you are not totally convinced by my argument, you will tell me, “what you are saying is not tangible!” This means that you do not believe in my argumentation. You cannot grab the concept I am talking about. Extending this explanation, nuclear managers who need constant high-level and low-level awareness in order to make appropriate decisions require a crisis management support system, such as the system that was developed at SHCDIA using Fukushima disaster data (Stephane, 2013). Figurative tangibility issues emerged from the use of visualization of real-world geographical data (Google Earth style) and superimposed artificial reality objects, such as CAD-CAM installations and analytical reports (Figure 7).

Figure 7. Mixing real-world geographical data and artificial reality data to enhance problem solving and decision making.

Creativity and Integration

Dealing with accuracy and uncertainty as well as testing consistency and tangibility of systems being designed requires creativity to find, correct and refine appropriate solutions. Creativity can be seen as synthesis and integration. When a painter wants to create a new color, say “a variation of

Orange". He or she will mix (integrate) a little bit of Red together with a little bit of Yellow. If the Orange that is obtained is too red, then he or she will integrate more yellow until the right (desired) variation of orange is created.

Integration is often done too late in industry today. Creativity as integration applies very well to human-centered design practice. Integration should be thought and done from the beginning of the design process. As already said, we start by generating ideas and concepts using software tools today, using PowerPoint for example and then more sophisticated modeling and simulation tools later on. Current information technology enables us to create various kinds of things, and test their consistency and tangibility very early during the design process.

6. CONCLUSIONS

This paper analyzed how human-centered design (HCD) is an integrating discipline that should be learned at school and practiced in socio-technical life together with core STEM disciplines.

Creativity to Override Education Silos

During the 20th century, we learned disciplines in isolation one from each other. We learned in silos. Integration was supposed to be done later. Even if I strongly recognize that we need to learn core disciplines such as mathematics, physics and literature in depth, we should provide young learners with meaningful concepts of integration. In other words, creativity should be put at the same level of core disciplines.

For example, Newton invented differential calculus that cannot be learned and practiced with knowing what a derivative is. In mathematics, we learn that speed "v" is equal to "dx/dt", which is a variation of distance "dx" divided by a variation of time "dt". However today, if we watch the speed indicator on the car that we are driving, we immediately see and sense the concept of derivative (Figure 8). It is very difficult to fully understand a concept until we understand it cognitively (figurative tangibility) and embody it (physical tangibility). Appropriate visualization improves physical tangibility.

Figure 8. Speed indicators.

STEM learning and practice require inclusion of Arts, making STEAM. Why? STEM education is very dry for many your learners, and should be irrigated by more meaningful perspectives and integrating perspectives (i.e., include creativity in STEM curricula). In addition, engineering education and training currently leads the production of technicians who are not creators, inventors and innovators. It is time to shift to STEAM education for good. HCD enables this shift.

An HCD approach to enhance children's collaboration and facilitate learning using tangible cubes was developed at SHCDIA (Almukadi, 2017). MathVocab was designed in the form of tangible interactive cubes that children could manipulate to learn words or simple calculations (Figure 9). Both physical tangibility and figurative tangibility were tested and enabled to improve the MathVocab system. More generally, this Ph.D. work showed that children learn better when abstract concepts can be manipulated in a tangible way. It is also clear that data science and advanced visualization techniques can greatly enhance both system design and knowledge design (i.e., learning).

Figure 9. MathVocal at work in a classroom.

Socio-Technical Changes

We have seen that, since the beginning of the 21st century, software enables us to generate not only new technological solutions that can be tested very early during the design process, but also technology that progressively replace most jobs that people were and are still doing. For example, trucks have already become autonomous in many situations and will be fully autonomous in the near future. Truck driver jobs will then become obsolete. At this point, we can see that the role of HCD is to extend human-systems integration to the anticipation of new roles for people. More specifically, human-robot interaction and integration has become a reality.

We then will have to interact with machines that have some levels of autonomy. These levels of autonomy will need to be categorized, as we did for levels of automation (Parasuraman, Sheridan & Wickens, 2000). In addition, we will need to relate autonomy with system maturity from three viewpoints: technology maturity, maturity of practice (i.e., what people can perceive, accept and manage), and organizational maturity (i.e., the more machines will be autonomous, the more coordination rules we will need to be developed and used). Schools will need to upgrade their curricula to integrate these new factors.

Rehabilitating the Art of Making Meaningful Things

Education and research should associate theoretical learning and hands-on practice toward creating more meaningful things. Instead of remaining in the comfort of standards, students should take critical thinking more seriously and learn from experts and experienced people the process of abduction. Umberto Eco, in *Il superuomo di massa*, wrote (Eco, 1976): "There is no difference (at the highest level) between the *cold* *speculative intelligence* and *artist's intuition*. There is something artistic in scientific discovery and something scientific in what naive people call 'artist's genius intuitions.' What they have in common is the happiness of *Abduction*."

In other words, creativity and scientific methods should go together in the education and training of engineering designers of tomorrow. HCD enables the shift from STEM to STEAM where qualitative research becomes essential. Real life problem solving requires focusing on consistency and tangibility, especially today, when almost everything starts on a computer. We then need to define qualitative metrics that enable us to perform meaningful assessments. We need to better learn how to observe real world systems and their environment, become familiar with their complexity, and finally demonstrate their relevance from human and societal points of view. We cannot do this without motivation and enthusiasm.

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