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Human Research in Technology Design

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Abstract. Modern technology design processes in intelligent societies are different from the classic electromechanical technology design processes. Future technology design must be based as much on human research as on natural scientific thinking. Today one can find technologies such as social media applications which are created with minimal technical effort. Thus, understanding the human dimension of technologies is becoming much more important today than in the time of electromechanical technologies. The change in focus motivates to pay attention to the foundational differences between natural science and human research in technology design. The differences between the two traditions have been discussed over the last century, but today the differences between human research and natural science get new forms in designing intelligent technologies.

Keywords: Designing, Human research, Natural science

1 Introduction

Human research is becoming increasingly more important in technology design. Designing traditional electromechanical technologies is based on natural scientific and mathematical thinking [1]. Over the years scientific design and engineering has reached its present forms. However, information technology is different in many respects from the traditional electromechanical technologies because its essence is in intelligent information processes [2-3]. Solving problems of intelligence on the basis of mere natural scientific thinking is no longer optimal, and the foundations of the design processes must be rethought.

The invention of the Turing machine meant a revolution from electromechanical thinking to intelligent technologies and it also gave the basic model for intelligent technologies [4-5]. Turing's mathematical model showed how human thinking can be used in designing intelligent machines. Later, the discussion was expanded into can machines think like people [4-7], and it became evident that machines can capture some aspects of human thinking and for this reason they can carry out intelligence demanding tasks.

Intelligent technologies take part in human work processes. Intelligent machines can be used to free people to other tasks, and they can improve human performance in existing tasks. Information technology has greatly changed work processes in offices since the early 1950's. However, in the future, development will be even more dramatic as the intellectual complexity of machine run tasks shall essentially increase [3].

Expertise on people and understanding their actions and their lives are presuppositions for constructing a intelligent information society. It will be essential to construct technical systems which can take care of intelligence demanding tasks. Designing such systems, however, requires understanding the action of new systems, what they are supposed to carry out, and how they are should do what they do. As the intelligent processes normally require human information processing, it is evident that human research is a necessary component in designing intelligent technologies.

Designing future intelligent technologies shall thus be linked much more intensively to human research than was necessary in the times of electromechanical technologies. However, human research is meta-scientifically different from traditional natural scientific design thinking and thus it is good to consider that the foundational problems of adding human research into future design thinking requires specific meta-scientific analysis.

Foundationally, integration of human research-based design thinking with traditional natural scientific technology design has its roots deep in the last century European philosophy. The traditional has been divided into Continental and Anglo-Saxon (American and Scandinavian) thinking [7] [8] . The same difference can also be found in the differences between logical empiricism and positivism on the one hand, and phenomenology, existentialism and critical philosophy on the other. Behind the division one can also see the differences between natural sciences and human sociocultural inspired research traditions.

The two traditions, i.e., natural science and human research, have lived separate lives for a century. The difference was already present in Kant's famous remark about heaven above his head and moral law inside himself [9]. However, the new design culture required for developing intelligent technologies and intelligent society should find ways to unify the two ways of thinking. Therefore, it will be essential to find out how the two traditions can be unified in future design processes.

2 Design thinking

Design processes can be studied as human thinking [10-11]. When designing, designers try to create something new. Thinking is the mental process which creates these new pieces of information. Thought processes are typical and unique to the human mind and they have been studied in concepts of different research disciplines from psychology to logic and philosophy.

Psychologically, design thinking is based on the contents of information in the minds of the designers. Thoughts are in forms of mental representations. The information in representations is in the form of concepts, emotional schemas, pictures, propositions, stories, and tacit or subconscious intuitive information [11] [12]. Designing people have vast external memories of information from private notes, press articles and television documentaries, to books, company databases and the internet.

Human research and scientific knowledge also belong to the pool of knowledge individual designers and design groups use in developing new technologies.

Understanding design processes requires analysis of the information required for the analysis of concrete design thinking. The power of human thinking can be found in its selectivity and power to manipulate information. People concentrate on issues they see relevant for their design goals. In order to be able to mentally represent the things, they have to have information about these issues. The analysis of mentally represented information enables researchers to reflectively think design processes.

The selectivity of human thinking has two sides. On the one hand, people can focus on important issues. They can find relevant topics and they are able to integrate all the necessary knowledge to reach the design goals. However, selectivity can also fixate people in illusionary mental contents [13]. There are situations in which people simply do not see the relevant issues and their meaning. For hundreds of years, people looked how masts of ships rose firstly from the horizon, but they did not understand that the phenomenon was a sign of the earth's form [14].

One explanation for concentrating on irrelevant issues in design thinking is the lack of knowledge. It is easy to believe in credos instead of being aware of research knowledge. The difference is clear, research always presents valid and tested reasons for why some solutions should work. If no one in a design group has a certain relevant piece of information, this often leads to design errors. This is why it is essential to form the teams of designers such that the group has the relevant skills.

The challenge with human research as a component of technical design thinking is, on its deepest level, the meta-scientific difference between human research and natural science [7] [15-16]. When natural science argumentation is based on causal laws in human research, it is important to understand human intentions. Causal explanation, for example, presupposes that explaining phenomenon emerges before the phenomenon to be explained, while in intentional explaining, the future goal explains what happens now [17]. These differences in the meta-scientific position makes it necessary to consider the foundations of human research applied in design discourse and processes.

A critical difference between science and human research is the notion of meaning, or mental contents. In socio-cultural and parts of psychological research, the information content of thoughts is relevant. The human mind creates mental representations of the external world. In design, the representational contents entail such issues as information contents of design tasks, design problems, concepts, propositions, elements of technologies, and possible solution models. Researchers interested in design thinking should be able to explicate the mental contents of design processes [9] [11]. This can be done, for example, by means of focusing on major research documents in the field such as textbooks and documentary analysis. Here, a philosophical discourse is applied to investigate No fact or theory in research can have an infinitely long chain of supporting argumentation. It is always necessary to stop argumentation at some stage, and for this reason all scientific ideas have their presuppositions or hidden assumptions [11] Hidden assumptions may be explicit or implicit, theoretical or intuitive, but they exist, and there is no single idea in research which does not entail tacit assumptions. We must accept that no percept, no inference or argumentative chain can be free of assumptions, presumptions, or intuitions. Everything cannot be doubted and accepting something without doubt means accepting its certainty on the ground of suppositions.

It is hard to accept that science is always built on preconditions. Social pressures towards the scientific community, scientific self-image, and the need to differentiate scientific knowledge from lay-thinking, pseudoscience, and charlatanism obviously motivates researchers to separate science from all common sense and intuition. Unfortunately, the acceptance of a strict separation would be incorrect and fatal for the practical application of scientific knowledge, scientific self-correction, and hence, it would slow down scientific progress.

Ernst Nagel [18], for example, wrote:

> "[F]inally, should the formula (i.e., the scientific practice, P. S.) be read as claiming that the practice of scientific method effectively eliminates every form of personal bias or source of error, which might otherwise impair the outcome of the inquiry, and more generally that it assures the truth of every conclusion reached by inquiries employing the method. But no such assurances can in fact be given."

A reason for unwillingness to acknowledge the necessity of preconditions is that the necessity of tacit assumption apparently threatens the credibility of science. If scientific ideas lay on assumption, it is easy to claim that everything in science is wrong. However, the truth of preconditions cannot be resolved on the grounds that they are preconditions. It is possible to have correct assumptions, which eventually prove to be true. In principle, preconditions can be correct or incorrect [11]. The problem is that no one knows if the preconditions are true or false. It is incorrect to think that preconditions are automatically wrong. One cannot say that scientific knowledge or human research is false. If one could, all the scientific knowledge would be false. Actually, all knowledge would be without values. However, scientific ideas form huge coherent webs of information and they are valid because their claims have the best argumentative support [11].

Tacit assumptions are also normal in design thinking, because today design relies on science. Design concepts and solutions entail their presuppositions. Even big companies can fall as a consequence of having adopted mistaken assumptions about markets or technologies. Nokia mobile phones underestimated the importance of the graphic user interface and swiftly lost its dominant market position. It assumed that it would not be so important to develop smartphones, but the markets proved the company had had incorrect intuitions.

Human research is not less intuitive than science. However, these two fields of learning are very different and for this reason the underlying systems of intuitions are very different. Nokia's misconception could have been solved if only the company had paid attention to how human text-related verbal memory and pictorial memory work. This is commonplace knowledge among memory researchers [19], but the company was so technology driven that no-one paid attention to this piece of human research knowledge, even though graphic user interfaces were everyday design solutions in computers. This example illustrates how important it is to get human research as a part of design discourses, and therefore it makes sense to further investigate design to meta-science of design thinking based on human research.

All conceptual, theoretical, and methodological ideas must meet in facts. Facts form "the centre of gravity" in modern research and design thinking. Indeed, in facts, thoughts meet reality. Facts have dual commitments . On the one hand they depend on the conceptual structure of the experiment, given concepts and design models or philosophical observations. Especially, it is important to see how human research facts can be integrated to support the design solutions.

Design solutions must be justified. Designers should have good reason for why the solution should work [11]. The reasons must be based on scientific research as research is the best guarantee for the validity of used knowledge. Validity is important as false assumption and false information, in actual products, cause harms and accidents of different types. Good examples are the space shuttle Challenger, Chernobyl, Bhopal, and the Boeing 727 MAX. Actually, errors of different types in design thinking are based on using invalid information in design decisions.

The complexity of modern technologies makes it understandable that relativity small lapses of attention thinking can have catastrophic consequences. The passenger ship “Estonia”, which sank in 1994 taking the lives of over 800 people, is a good example [20]. It began to sink twenty years before the actual accident because designers had made seriously mistaken solutions. The complexity of modern work life is an important cause for accumulating failures with devastating final outcomes.

3 Explaining

Explaining is the method of connecting individual phenomena in both research and design with researched knowledge. In the nineteen sixties, the basic models of explaining in science were developed and they still have their role in design thinking. Nevertheless, the discussion in the sixties was more concerned on the nature of scientific knowledge rather than the role of science in design practices.

The modern conception of explaining relies on the strictly logical use of regularities and invariances. The best-known individual schema for the logic of explanation was developed by Hempel [21]. According to this covering law model, explanation is based on covering laws and individual phenomena can be explained as examples of the covering law. Thus, the explanation for a broken pipeline in winter could be the law that the volume of frozen water is larger than the volume of liquid water. Thus, icy water breaks unprotected pipelines.

The covering law model is logically consistent, and it can be used in several different types of explanatory problems. With inessential variations, the model can also be used in predicting, i.e., in explaining future and past events. Thus, we can thus know that all unprotected pipelines full of water will break in the future as they have done in the past.

However, the covering law model has problems within human research. It is seldom applied in practical psychology. Explaining and prediction in human research uses intuitive practices related to the covering law model. Researchers make their explanatory conclusions on the grounds of general principles and particular occurrences. It seems clear that Hempel's logical schema expresses something essential about the intuitions of researchers in explaining. The tacit logic of explaining is certainly very close to the covering law model because the model would be very counterintuitive it had never reached its position.

In spite of the undeniable success, Hempel's classic theory of explanation has also met with numerous problems. Especially difficult has been explaining human action. It is very unclear how far the covering law model can be applied to social and historical phenomena. The model has acquired even less success among humanistic researchers. Dray showed its implausibility in historical explanation [22]. If historians should explain Royal succession in Britain, how could they use causal laws? They could find numerous particular occurrences such as how the parliament feels. However, there are no general causal laws of the form: Each time parliament feels itself threatened, it wants to make changes to the settlement rules of the crown. Historical events are often singular and therefore, it would make much sense to think that there are covering laws in historical issues.

History is not the only critical research field for traditional thinking. The challenge of other fields of humanistic research may be even more problematic. In thinking laws and ethics, the covering laws model is inadequate, because causal explanation does not have any real relevance in these fields of learning. Causal analysis does not tell us why van Gogh used colours as he did. Causal analysis is impotent even when verb valences or systems of laws are considered. Causal analysis is by and large irrelevant in humanistic research. Instead, attention in explaining should be improved by moving the focus of explanations from causal laws to human research and analysis of intentions.

4 Analysis of actions in human research

Human research has a different topic, structure and methodology from traditional natural science inspired research. Human research, also often referred to as human science or Geisteswissenaschaften [23-24] is research targeted to understand cultural, ethical, legal and historical phenomena. It essentially refers to understanding why people act as they act or how they should act to reach their goals, and in the end, the best possible quality of life [25-26]. Important intellectual movements in this respect were phenomenology, hermeneutics, and existentialism. Also, humanists and psychological researchers have developed the analysis in this field.

The core of understanding is in deep encoding of how people experience and act in different situations. This means answers to the question why people act as they act. The questions in human research are often idiosyncratic. Why the Norwegian royal family escaped from their country during the war or why British royals kept themselves in Britain? In a larger perspective, researchers can look for explanations for social phenomena as well. For example, why people follow sport events and are ready to pay to watch them? Thus, understanding means explication of the the meanings and motivations people have for acting in some particular manner.

Classical analyses of actions have been externalist or behaviourist . This means that actions have been described on an external level. However, in modern human research, the notion of action should be studied in internal and representational terms. Decisive in analysing action is mental contents or information contents of human mental representations [6] [27] [28]. The explanation of actions requires understanding how people represent and experience situations, and why they represent it in the way they do represent them. In short, this can be called mental contents. Thus, it makes sense to redesign the analysis of understanding on modern concepts.

Understanding – saying why it makes sense to have a specific kind of action on the grounds of mental content. Napoleon mistakenly assumed that he could win the war against Russia as he had won practically all wars. He did not understand how different the circumstances in Russia were compared to central Europe or Egypt [29]. In a way, Napoleon made an induction error by thinking that the past success can safeguard future success irrespective of the prevailing circumstances [30].Thus, understanding means understanding of the relevant actors' mental contents in a particular case.

The analysis of mental contents can be based on qualitative methods developed at the end of the previous century [31-32]. The methods from protocol to documentary analysis can be used to explicate the mental contents of individuals and group mental representations. Thus, the classical analysis of understanding, and the analysis of actions can be given a new form on the grounds of qualitative, cognitive, and emotional psychology.

Human research has its role in modern technology design because it can make it understandable. People organise their actions around technologies. Numerous people will act similarly and use the same technology for similar purposes. Surgeons in different operation rooms apply minimally invasive surgery technologies. They share the same form of life in the way they act [26]. Understanding the structure of the form of life enables a researcher to improve the technical artefacts and work models typical for this particular form of life. The analysis of thought models and other representational content elements typical to this, or to any social form of life, is essential in designing and developing new technologies. Thus, modern analysis of understanding gets an important role in innovating new technologies.

Technologies have always been for people to use and for this reason human research has its role in technology development. The differences between natural scientific and human research are difficult to overcome. If human research is applied in natural scientific issues, it does not provide sufficient analytical power to discuss substance. However, natural science is equally impotent in solving issues relevant in the human dimension of technology. This is why it is essential to think how the two world views can be unified in the practice of design thinking.

5 Explanatory discourses and frameworks

Design problems differ from scientific problems. The designer's task is to construct artefacts, information structures or technologies to help users reach a given goal in their life. For example, when designing any technology, the artefact helps people reach their practical goals without causing risks and satisfies the users' needs in their lives [1]. This is why design problems commonly arise from the recognition of a need that people wish to satisfy.

The logical connection between science and design is built on the notion of truth. Deontological propositions can be considered to have a truth value if there is a possible world in which they are true. Only impossible propositions are false in a deontological sense. This rather obscure claim simply means that designed technologies can work if they can be realized, and they can be realized if the principles upon which they are built are true when the technology is used.

In contemporary engineering, basic sciences such as mathematics, physics and chemistry provide conceptual and empirical tools that make design possible [1]. History has shown that science is a prerequisite of modern innovations. Einstein, for example, understood the intimate connection between matter and energy. He also realised that it was possible to create a chain reaction when newly freed electrons meet new nuclei. This theoretical phenomenon was later applied by Fermi in nuclear power stations and Oppenheimer's group in creating the atom bomb. Here, basic natural science created tools for very complicated engineering thinking and applications. In the same way, social sciences can create important visions for political and social thinking.

Human visual and pictorial memory is superior compared to human verbal memory [19]. This simple psychological fact explains why graphic user interfaces are in general better than alphanumeric. It is easier for people to remember interaction relevant issues. Chemistry does not have the power of expression to help in solving such issues. It is thus necessary to organise the design discourse. In that, a good conceptual tool is the explanatory framework [33].

Explanation should be based on science and scientific principles (Figure 1). When designing for life, it is essential to search for explanatory solutions. The main challenge is to unify design problems, scientific truths, and explanatory grounds in a sense-making manner. In practice, design is not one single discourse but depending on the design problem, different types of discourses come into focus. Natural sciences are required in solving such technical problems as consumption of power or weight of the product. Human research is essential in usability, user experience, and organisational issues.

One method of keeping things in good order is to organise a different discourse to separate explanatory frameworks. This is the way to unify design questions with relevant knowledge to generate argumentatively grounded solutions.

Problem * Relevant knowledge => Solutions

Fig. 1. Explanatory framework

In this model of general explanatory framework (Figure 1), a designer binds the interaction problem and relevant scientific knowledge to each other and generates a solution [26] [31]. Each design thought sequence of this type can be seen as a separate explanatory framework, but scientifically grounded design processes are generally characterised by this schema.

Each explanatory framework activates its own discourse. Surgical equipment is used in an operating theatre. It is one discourse to create sufficient lighting, another to make the required screens so well organised that operating doctors can get all the knowledge they need without effort. A third problem is to develop collaborations between the operating personnel so smooth that the operating people can effectively work to save the patients. Solving the problems requires its own design discourse with different research knowledge.

Each design discourse must be linked with scientific information. Problems must be solved, whether designers have scientific knowledge or not. If they do not have the relevant framework knowledge to make proper design solutions, they have to use their intuitions. The have to think a support for the solutions on the grounds of their common-sense knowledge. This may be due to the facts that the knowledge does not exist, or because designers do not have the required knowledge. Ideally, all design problems should be solved on the grounds of the best human research or scientific knowledge that exists.

6 Human research and natural science in technology design

Explanatory frameworks provide a meta-scientific model how one can organise the different scientific and human research discourses relevant in solving different problems. Technologies are combinations of human actions and tools to reach the goals of these actions. For this reason, each technology must concentrate on both people and the technical artefacts they use. Design groups must organise themselves following the problem they have to solve and the discourse they have to organise for solving the particular problem.

Natural science provides knowledge about natural phenomena. These phenomena include chemical, physical, and biological phenomena. Typical examples of the first kind are fire, combustion, or chemical reactions. Physical phenomena can be friction, thermodynamics, or the behaviour of planets. Finally, biology is about living organisms' birth, death, growth, or phenomena typical to population ecology. All of these natural scientific phenomena can be used in solving design problems of their kind in developing new technologies.

Natural sciences have their own principles and methods. They use observation and experimentation of collecting well founded facts. Natural scientific phenomena are determined and regular [32]. Therefore, it has become possible to find very strongly founded and regular principles, called laws, typical for natural scientific phenomena.

The task of engineering is to organise a physical object in a purposeful manner following the natural laws [1]. Thus, design means organising things in the way that they can serve for the given human purposes. This goal is as valid with bridges and buildings as well as with modern AI technical artefacts. Often mathematical knowledge is required in developing engineering solutions of different types and for this reason this field of research is seen as a natural science.

The predictability of natural science helps in technology design, as it makes it easier to use this information in supporting design decisions. It is not necessary to rely on only trial and error and traditional type thinking. It is possible to use mathematical and physical knowledge, for example, to be sure that constructions do not collapse. Thus, the laws of nature support the design of physical products.

However, human research is different. The laws of physics and chemistry very seldom provide important information for supporting design decisions. For example, the position of a technical artefact in human life must be analysed in concepts of human research. There is no law of physics that could inform us about the ethical consequences of social media or AI applications in governance. Physics, chemistry, or biology do not have concepts or laws to analyse and design issues relevant for human individuals and social action.

In most of the electromechanical technology human factors are easy and commonsense issues. People walk on the street, and to analyse this action sufficiently accurately for engineering design is not difficult. However, the complexity of technologies has increased, and it is no longer possible to solve design problems intuitively. Cockpits of fighter airplanes, for example, were already so complex that it was necessary to develop a new research area called human factors [26]. This area later became usability, and serious work in it required in-depth human research knowledge. When ICT-consumer electronics got into the mass production state, it became necessary to apply human research into issues of how people feel about these products, and finally, with the development of intelligent technologies, it has become essential to start thinking about the holistic and social issues such as ethics and the required social actions to regulate the human side of human technology interaction.

A sign of transformation from electromechanical technologies to human research relevant technologies is the service industry. Knowledge of platforms and other basic information , but the creative technology development problems are human problems. The human dimension is the moving part, as it is possible to build on one single platform and it is possible to build an unlimited number of services for human actions.

Technology design is thus no longer a discussion on technical artefact and physics. It is essential to also study human capacity and willingness to use technical artefacts, and especially, the functions of new technologies in human life [26]. Ethics is no longer a less essential an issue than electronics in design discussions. Consequently, the focus of philosophical thinking will move from natural scientific and positivist discourse to psychosocial and “Geistewissenschaftliche” or human research-oriented discourses.

Today, two major traditions inside scientific research, natural science and Geisteswissenschaft should be unified. Natural science analyses natural phenomena and Geisteswissenschaft focusses on mental and cultural systems. Sociohistorical and psychological approaches to what happens in the human mind, and consequently in actions and their systems, provides a natural scientific thinking completing research direction to mind.

The term Geist or spirit may appear strange today. However, if we think of the vast cognitive research which has penetrated into all the major domains of human research, it is clear that the word Geist is today expressed in such concepts as information, representation and cognition [6] [35]. to get a conception of modern cognitively oriented human research). One can thus take the issues and the ideas of Geisteswissechaft under scrutiny inside modern cognitive science and cognitive research.

The long dispute between logical empiricism and positivism with human research can be understood by analysing the foundational intuitions of the two traditions. Causal natural science and intentional and understanding human research look at technology and technology design from different perspectives. Very roughly, one can argue that the first is effective in providing support for artefact design, while the latter opens the human dimension of technologies in all of its complexities. Thus, in future technology design it is possible to see the two directions as complementary rather than controversial.

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