Technology in Society 45 (2016) 1–7

Contents lists available at ScienceDirect

Technology in Society

journal homepage: www.elsevier.com/locate/techsoc

Issues and opinions

The synergy of creativity and critical thinking in engineering design: The role of interdisciplinary augmentation and the fine arts

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ARTICLE INFO

Article history:
Received 29 September 2014
Received in revised form
20 November 2015
Accepted 24 November 2015
Available online 23 January 2016

Keywords:
Design
Interaction
Quality
Criticality
Creativity
Aesthetics

ABSTRACT

Analysis of the impact of interaction and experience on quality components such as “usability”, “producibility”, “reliability”, “sustainability” and “aesthetics” is presented using the case of engineering design, a discipline that traditionally has an image of being a strictly calculated, rigid framework. It has been widely recognised that engineering design encompasses two ways of thinking—creative and critical. A central argument that the synergy of creativity and criticality is significantly enhanced by connecting true interdisciplinary augmentation with the fine arts is discussed along with reflecting on the importance of such an approach in higher education.

1. Introduction

An ultimate goal of engineering design—a discipline in which scientific knowledge is applied to solve problems of interest to society—is to enable the sustainable realisation of a product. A “product” is something that is first designed, and then brought to such condition and quality to serve a specified purpose. This generic definition can be developed further to classify products into primary, intermediate and finished categories. “Primary” products include various raw materials for which there are defined quality specifications, extraction techniques and purposes, such as further processing to become a semi-finished product of an increased quality and value. Typical examples include coal, oxygen, wheat and iron ore. “Intermediate” products include everything that can be classified in between these two extremes, for example, hot rolled steel wire, paper sheets, a microchip, ceramic tiles, a city's infrastructure and a polyester fabric, etc. The “finished” category includes products such as a pencil, an airplane, a screwdriver, a computer and an instruction manual, all of which are designed to satisfy some of society's needs.

A product has to be designed to have a specified level of quality. While there are quite extensive treatises discussing the concept of “quality”, the website <http://spuzic.yolasite.com/quality.php> [1] outlines a widely accepted definition. In this current paper, the focus is on the impact of interactions and experiences on quality components such as “usability”, “producibility”, “reliability”, “sustainability” and “aesthetics”. Moreover, these aspects are discussed using the case of engineering design, a discipline that traditionally has an image of being a strictly calculated, rigid framework.

Engineering design, typically defined as “a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints” [2], is a very creative activity. It differs from design in the fine (free) arts in that it introduces higher order logical (rational) components. The perceptions of the logic and aesthetics of a design are significantly affected by the emotional

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http://dx.doi.org/10.1016/j.techsoc.2015.11.005
0160-791X/

state of the person contemplating them: these emotional states, recently defined and measured in neuroscientific research, are still far from sufficiently understood [3].

While there is general consensus that the fine arts defy rational explanation, few, if any, would propose that the fine arts should be eliminated from our lives. Arguably, human existence would be impoverished without music, humour, movies and other arts, and the same can be said about the effect of the fine arts on the education process. Therefore, emotions and aesthetics, both concepts that are quite different from 'rational' thinking, should not be ignored. Interestingly, these phenomena appear to be in discernible consonance with several highly rational scientific and engineering principles.

Firstly, the idea of significant digits has incorporated the rule of introducing an additional, final, guessed digit at the end of any technically defined reading. Inasmuch as its value is limited within the scale resolution of the instrumentation used, this digit will be affected by something beyond rational explanation. Secondly, the Heisenberg uncertainty principle indicates that basically everything in the universe is affected, at least to some extent, by certain unpredictable agents [4]. As a consequence, any decision is associated with some incalculable outcome. Finally, as a way of reacting to this uncertainty, the evolution of life forms continuously displays an infinite variety of mutations. Perhaps some emotions (such as curiosity and boredom) and aesthetic positions (such as disliking and favouring) reflect such reactions at the level of the human mind. The growing evidence [2–16] indicates that too strong a separation of scientific knowledge from non-scientific aspects (pertaining to matters that are not scientifically rigorous, for example, the fine arts) can lead to the encaging of the learner's intellect.

With the advent of information processors, humans are set free from tedious rational iterations, derivations and even estimates of aspects such as reliability, confidence limits and correlations. Misconceptions such as "[k]nowledge cannot, as such, be stored in computers; it can only be stored in the human brain. There is no knowledge without someone knowing it" [6] have been overridden by recognition of the potential of human–computer interactions. The human–computer interface lies at the crossroads of many engineering and scientific disciplines. The perception of interaction between artificial intelligence and manned systems gives rise to radical advances in our knowledge growth, sharing and applications [17].

In this paper, the effects of these interactions are contemplated by solving some problems within the technical discipline of long steel products "rolling system design" (RSD), known as "roll pass design". The rolling system (and pass) design discipline is outlined by Oduguwa and Roy [15] and Lundberg [16]. This example is chosen as one of this paper's authors launched his career in this profession: any other technical discipline could serve equally well. The authors aimed to explore an activity that results in producing the highest volume of metallic products, while being an activity that continues to outstrip our scientific understanding of its practice. It was intended, therefore, to use a case where rigid technical rational decisions are *conditio sine qua non*, despite being a case in which many shades of decision-making are inevitably vague.

2. The product to be designed

Tools in general can be classified as products that fall in the final or the intermediate category. This depends on the actual purpose of a tool; for example, kitchen shears are a final product. Hot rolling mill shears, however, are intermediate tools that require the blades to be replaced for each particular intermediate shape that is to be processed. Analogously, an instruction manual for a newly purchased car or for using a kitchen roller press would be readily seen as a final product, while the instructions for a rolling system (pass) design would not.

At this point it is useful to reflect on the significance of Taguchi's definition of the losses to society resulting from poor quality. Taguchi explained that loss of quality does not exclusively imply a sudden plummet, for example, at an instance of roll (tool) fracture. Instead, "loss" progressively increases as variation increases from the intended condition. This kind of loss needs to be considered in the context of product significance. The poor quality of a single kitchen roller press (including an instruction manual) for making tortillas would certainly generate lower costs compared to poorly designed rolls and the associated rolling system (pass) design in a hot rolling mill.

Increasing evidence of global warming and resource decline is prompting further rationalisations in large systems such as the steel industry. In addition to environmental pollution, the steel industry is a large consumer not only of fuel but also of fresh water. A conservative estimate [18] indicates that the production of one tonne of steel product requires nearly 90 tonnes of fresh water. In the last two years, Australia alone produced over 10 million tonnes of steel, which corresponds to nearly 900 million tonnes of fresh water sent to the sea. This is more than 40% of the yearly water consumption in Adelaide, South Australia. The Government of South Australia ("the driest state in the driest continent on earth") has issued a document titled *Water Proofing Adelaide* (a strategy plan for the period to 2025), which also seeks rationalisation in industrial consumption of water [19].

The foreseeable long-term global views imply increasing requirements for quality steel-related products. Over 80% of steel products have at some stage been processed by hot rolling at 900–1200 °C [20]. This has prompted considerable research and development activities in scientific, engineering and other public domains [15,16,20].

The complexity of a rolling mill system requires the process design to be accompanied by appropriate documentation—knowledge sources—which today is typically made available by virtue of information processing and communication networks. Even though the entire production process might be well computerised and automated, the operators are expected to monitor and correct the product quality variations: for this, they need to be provided with instructive, easily consumed information and knowledge. These resources are prepared and delivered by the rolling system designers.

In this rather complex scenario, the task of the rolling system designers includes satisfying socially important aspects of quality that are usually denominated as usability, producibility, reliability and sustainability. The product of rolling system design is a comprehensive set of documentation that includes principle and practical input in instruction manuals, process schemes and norms, quality (and safety) standards and all other technical documentation needed to actualise a production process in a rolling mill. Is there also a need to consider the aesthetics component? We argue that the answer to this question is: "Yes".

3. Quality aspects of rolling system design

In principle, the usability, producibility, reliability, sustainability and aesthetics of rolling system design are related to knowledge storing, sharing or transfer, and use. There is an obvious need to devise the most efficient modes for such purposes. Figs. 1 and 2 illustrate how a complex schedule of the rolling sequence can be presented. It is worth mentioning that this scheme still presents only a small fraction of the complete process. It is obvious that an attempt was made to produce an explanatory scheme that enables