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UP: A unified paradigm to compare computer-based and paper-based supporting tools for collective co-located preliminary engineering design activities

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Abstract: Are Computer Supported Cooperative Work in Design (CSCWD) media worth to be used or do we need to maintain the traditional paper-based ones? Several studies exist, but address heterogeneous functions and criteria, and are not comparable. This contribution introduces an exploratory study toward a Unified Paradigm of evaluation (UP). UP aims to ease the set-up of comparable design studies to evaluate if CSCWD are worth to be used in respect of actual supports. The most adapted paradigm to provide a valuable answer prescribes ethnographic qualitative descriptive studies between a traditional paper-based and a CSCWD media. A scenario centered on a common function is presented (isofunctional comparison). The criterion assessed is effectiveness, expressed as the combination of efficacy and usefulness. Efficacy is measurable through objective factors. Usefulness is measurable through subjective factors. In order to confront studies involving different people, we suggest that individual characteristics should be properly considered.

Key words: Disruptive Innovation, Design methods and tools, Design observations paradigm, Computer Supported Cooperative Work in Design, Design research.

1- Introduction

A disruptive innovation [C1] is an innovation that disrupts an existing market, displacing an earlier technology. For example, with the introduction of engine-propelled cars, the use of horses as mean of transportation was progressively dismissed. The introduction of a new product with a disruptive technology can cause the decline of an existing product.

We define as “**transitional phase**” when one technology emerges, trying to substitute another one in use (Figure 1). During the transitional phase, the two technologies are evaluated for sake of comparison. However, the products incarnating those different technologies are generally extremely dissimilar, making the comparison difficult. As an example, while passing from horses to cars for human transportation, how horses were compared to cars? How is it possible to compare heterogeneous products or services? (From now on in the paper, with product we mean the

technology embedded in a product or as well in a service or a process).

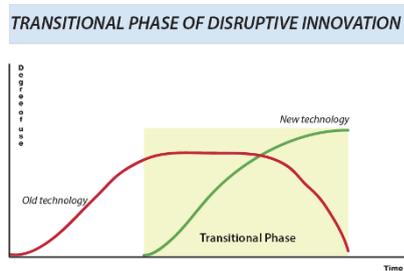


Figure 1: The transitional phase of disruptive innovation (derived from [HT2])

Considering two products, each one has a set of functions. A function can be measured through a criterion. A criterion is a standard to compare and judge individual things. A criterion could have sub-criteria. A possible strategy is to find a relationship between equivalent functions of both products to compare them through common criteria. Watt’s horsepower is an immediate and bright example of a criterion used to compare a common function of horses and cars, the production of Power.

Section 2 introduces a Unified Paradigm (UP) of evaluation. Section 3 explains the reasons for applying UP to the transitional phase, from paper-based toward computer-based media, for supporting co-located collective preliminary engineering design activities during the early design phase. Section 4 provides a state of the art for what concern different comparative studies and their associated criteria, proposing a common evaluative procedure. Section 5 shows an example of isofunctional comparison, between paper-based and computer-based supportive media. Section 6 critically reflects on our contribution and highlights its limits. Finally Section 7 summarizes our conclusions and perspectives.

2- UP: a Unified Paradigm for evaluation.

We introduce the notion of Unified Paradigm (UP) of evaluation. UP represents a model for comparing the functions of a product, during its transitional phase. We describe it mathematically, for the sake of comprehension and interoperability, because UP can and should be applied independently from the nature of the products compared.

We have two entities: an *OLD_PRODUCT* that needs to be compared with a *NEW_PRODUCT*. The more similar the two products compared are, the more similar *OLD_PRODUCT* and *NEW_PRODUCT* are, to the point to be equivalent.

If we define:

$$OLD_PRODUCT = \{x: P(x)\},$$

$$NEW_PRODUCT = \{y: P(y)\},$$

with $P(t)$ as $\{t: t \text{ is a function of the product}\}$,

we obtain two sets representing the functions of each product; they can have equal or different cardinality.

When a comparable set of functions is identified, we have a subset $COMMON_F \sim COMMON_F_OLD_PRODUCT \sim COMMON_F_NEW_PRODUCT$ (\sim means equivalent). The subsets have the same cardinality, containing the same functions, and so being equivalent.

$COMMON_F_OLD_PRODUCT \subseteq OLD_PRODUCT$ and $COMMON_F_NEW_PRODUCT \subseteq NEW_PRODUCT$.

A bijection $f: COMMON_F_OLD_PRODUCT \rightarrow COMMON_F_NEW_PRODUCT$ exists. This bijection represents an “**isofunctional**” comparison.

We define also

$$UNCOMMON_F_OLD_PRODUCT = OLD_PRODUCT - COMMON_F_OLD_PRODUCT$$

and

$$UNCOMMON_F_NEW_PRODUCT = NEW_PRODUCT - COMMON_F_NEW_PRODUCT$$

They represent the functions for which the only possible comparison is in term of possession, so that one product has that function and the other does not. We define this as a “**heterofunctional**” comparison.

If the subsets of comparable functions contain all the functions of the product, they become improper subsets, and the uncommon functions sets are \emptyset .

A criterion is associated to one or more common functions (more than one quality can be measured through the same criterion), building a set of common criteria *COMMON_CRITERIA*. Criteria are function-dependent; hence a relevant criterion for one function can become irrelevant for another one. The number of people, a car or a horse can load, may be fundamental as a mean of transport, while loose importance when considering the hectares they could respectively work in one day.

The faster the subsets *COMMON_F_OLD_PRODUCT* and *COMMON_F_NEW_PRODUCT* are identified, and a common consensus rises around them, the faster a set of common criteria *COMMON_CRITERIA* can be used to compare (or not) a product to a previous one.

Venn diagram in figure 2 represents our model.

3- Co-located collective computer supported tools for engineering preliminary design activities.

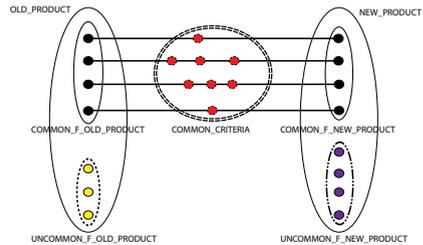


Figure 2: UP: Unified Paradigm of evaluation

We want to apply UP to the transitional phase from paper-based supporting tools toward computer-based supported tools, for co-located collective preliminary engineering design activities during the early design phase. Why this choice?

Engineering preliminary design is a collaborative multidisciplinary process conducted by a design team [G1], allowing it to be more effective and responsive to the challenges of the markets [S2]. This explains our interest for collective design activities.

Design activities, which are identified as design process, are extremely heterogeneous. According to several authors (as resumed by [S1]), the design process can be divided into a detailed phase where production, components architecture, and materials are discussed and an early one, or conceptual design phase [S1]. The early stage of the design process is dominated by the generation of ideas, which are subsequently evaluated against general requirements' criteria. [GK1]. As outlined by [PB1], [WS1] and [ML1], among others, early design phase is the most impactful in terms of performances and costs. This explains our attention for the early design phase.

Design activities can also be separated between co-located [OT1] and distal activities, as the CSCW-matrix shows [J1]. According to Olson et al., “*co-located teams are twice as productive as teams that are merely nearby*” [OT1]. This explains our attention for co-located activities.

Wang et al. defend the interest in experiencing a significant paradigm shift, the conceptual design needs to *adopt a more pragmatic and aggressive approach through collaboration, supported by artificial intelligence, and fuelled by information technologies*. [WS1].

This is why we, are interested in computer-based tools and why we developed, among others, a CSCWD tool for conceptual design activities [JK1], [GG1]. CSCWD is the acronym for Computer Supported Cooperative Work in Design. CSCWD systems, such as the one in figure 3, are extremely heterogeneous; no standard configuration has

emerged, even if interactive tabletops and walls are the main component of such systems.



Figure 3: An example of CSCWD media [GG1]

This computer-based technology is disruptive in respect of the actual one, paper-based. Thus, we are in the “transitional phase” from a paper-based product to a computer-based one. Understanding the benefits of such devices is pivotal to promote their use among designers; what are the benefits if these CSCWD systems are used? Are they “better” than paper-based tools? Are they worth to be employed? Should they substitute paper-based tools?

Without a unified evaluation paradigm, no valiant answers can be proposed for these questions. There is a lack of a set of common criteria for comparing CSCWD and paper-based tools. This is why we want to apply UP to identify a basic set of common functions and associated criteria to enable comparison.

4- A proposal for an evaluation procedure for the UP.

The evaluation paradigm requires a procedure to be followed. The procedure contains the practical aspects describing the set-up of the evaluative studies. According to Buisine’s et al. work [BB1], evaluative studies can be grouped in three categories: user needs analyses, interfaces evaluations, and paradigm evaluation. The first two categories aim to improve the quality of the device, erasing system failures and interaction ambiguities. Several studies fall within these two categories (e.g. [SC1], [SC2], [HT1]).

However, their approaches are not based on comparison, and this a key element for our unified paradigm of evaluation. This is why we follow the third category of studies, paradigm evaluation that is a comparative study of the same design activity (the same task), between computer-based condition and a traditional paper-based setting.

A critical analysis of the literature concerning paradigm evaluation (between CSCWD devices and control paper-based settings for co-located collective preliminary engineering design activities) has been conducted. The main studies used in this paper are Buisine’s and al. work [BB1] and Gidel’s and al. [GK1] works.

Furthermore, Buisine et al.’s article states that to get an “increasingly detailed picture of user experience in tabletop interface use (e.g. effectiveness, usability, pleasantness of interaction, etc.)” ethnographic studies should be used [BB1]. The proposed procedure associated to UP can be formally defined with the following attributes:

- **Qualitative:** studying things in their natural settings, attempting to make sense of, or to interpret, phenomena in terms of the meanings people bring to them, according to Denzin and Lincoln’s definition [DL1];
- **Descriptive:** cross-sectional study according to Blessing and Chakrabarti [BC1]’s definition of Descriptive Study I;
- **Ethnographic:** realistic context of observation with a minimalist intervention of the experimenter, concurring Buisine et al.’s [BB1] definition.

Figure 4 provides an example of such qualitative, descriptive, and ethnographic evaluative studies [GG1, GG2]. Two design teams are evaluated performing the same design activity, but on different media.



Figure 4: An example of qualitative, descriptive, ethnographic comparative studies [GG2]

Interestingly, this kind of studies is still not very diffused [HR1][RL1][GK1][GG2]. In our opinion, this poor diffusion is mainly due to a lack of a common set of functions to compare those two conditions, confirming the urgencies to find it. After the proposition of a common procedure, it is essential to agree upon common criteria to decide which product (paper or computer based supporting tools) is “better” than the other.

What is the criterion associated to better? Buisine et al. [BB1] propose that be the **usefulness**, transforming the generic “Which product is better?” into “Which product is more useful?” Although we share Buisine et al. [BB1] approach concerning the evaluation paradigm, we would argue against considering usefulness as the main criterion for comparison. In the next section, we detail our proposal for the main criteria to assess.

5- Applying UP to compare computer and paper-based product for co-located collective preliminary engineering design.

In the following section we are going to present only the isofunctional comparison. As we will argue extensively in section 6, this choice is to avoid any possible criticism about the impossibility to heterofunctionally compare two products. Moreover, an isofunctional comparison is a worst-case scenario. Usually, a new product, on top of improving existing function satisfaction, also introduces new function. Therefore, when making an isofunctional comparison, all the new functions that are absent in the old product are put aside, lowering the perceived effectiveness of the new product.

If even in this worst-case scenario the new product (in this case CSCWD) is more effective than the traditional one (in this case paper-based), the heterofunctional comparison cannot but augment the effectiveness gap.

We define

OLD_PRODUCT = {The set of paper-based product for co-located collective preliminary design activities}

NEW_PRODUCT = {The set of computer-based product for co-located collective preliminary activities}.

The first step of UP is to find a set of common functions *COMMON_F*. We propose to consider *COMMON_F* = {The ability of a product to support co-located collective engineering preliminary design activities}.

This is, in our opinion, the main function to start with. Other functions can be considered, as we will discuss over in section 6.

In order to find a set of common criteria, *COMMON_CRITERIA*, we need to evaluate the impact of a product that mediate a collective human cognitive activity such as design. Literature on cognitive interaction is extremely wide and out of the scope of this article. We simply report three important school of thought: intra-cranial cognition [AA1], extra-cranial cognition ([CC1], [H2]), and enactive cognition [SG1]. We share the latter position, so that a product, with which we are interacting, is a mediator of the perception of the world.

The human perceptive component, subjective to each person, is one of the two aspects to consider for the identification of a set of criteria. This subjective component, for us, is what Buisine et al. call usefulness. We define **usefulness** as the users' perceived quality of having utility and especially practical worth or applicability; it summarizes the set of functions related to **subjective criteria**.

However, we also have to assess an objective point of view that is what we define as efficiency. We define **efficiency** as performing a task with the least waste of resources (time, efforts, money, etc.); it resumes the set of functions related to **objective criteria**.

A product can be useful but not efficient or, on the contrary, efficient but not useful. In both cases there is no benefit in using it. It becomes really interesting for the user only when it is both useful and efficient. Our proposition is to identify **effectiveness** as the main criterion to use. Effectiveness is given by efficiency and usefulness. We define effectiveness as something adequate to accomplish a task. It is adequate to accomplish a task, because it does it with the least waste or

resources, and the quality of the result is clearly perceived by the users.

COMMON_CRITERIA contains two subsets of criteria, objective criteria *OBJECTIVE_CRITERIA* and subjective criteria *SUBJECTIVE_CRITERIA*.

$$COMMON_CRITERIA = OBJECTIVE_CRITERIA \cup SUBJECTIVE_CRITERIA.$$

As a consequence, objective criteria and subjective criteria, need to be both assessed but in a different way.

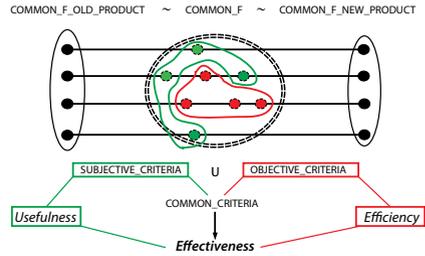


Figure 5: Objective and subjective criteria representation

5.1 - Assessing Efficiency

All the criteria contained into *OBJECTIVE_CRITERIA* compare the efficiency.

As we said in section 3, CSCWD systems for co-located collective engineering preliminary design activities are still research prototypes, quite far away from industrial ones. Measuring the efficiency of such prototypes can be worthless, because as all research prototypes, they are less efficient compared to industrial prototypes. In literature, specific techniques to assess human-performances using CSCWD are proposed, such as [FA1]. Aiming to assess an eventual transition on markets, our proposal is more adapted for industrial prototypes.

To measure efficiency we should consider that in the actual capitalistic market model, we neither approve nor criticize (we assume it as a standard "de facto"), an activity should generate a profit. Starting with an amount X of resources, we should obtain at the end, an amount X + Y, where Y is the created added value.

From an external point of view, the above-described process looks like Figure 6:



Figure 6: The creation of the added value

The added value Y can so measure efficiency. Using a paper-based tool or a computer-supported one, which condition generates the greatest added value Y compared to the resources used X?

If $\frac{Y_{computer}}{X_{computer}} \geq \frac{Y_{paper}}{X_{paper}}$ then it is possible to say that computer-

based supporting tools are more efficacious than paper-based supported tools. This idea is reproduced in Figure 7.

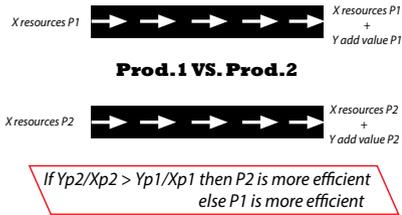


Figure 7: Measuring added value to assess efficiency

Independently from the type of resources considered, they can all be translated into an economic value, such as the cost of the material, the cost of labour, the operating cost, etc. We are aware that an extremely heterogeneous set of costs can be included under the term resources. We propose a list, which should serve as a basis for a discussion. The idea is that it is possible to calculate all the different costs that can pass through our mind, but at least the following costs need to be calculated and compared to assess efficiency.

- Cost of the support tool / hour of work.
- Cost of labour (cost x hours of work).
- Cost of learning (cost x hour of training).

In the actual studies, based on research prototypes, efficiency is very frequently assessed as a matter of time; e.g. which condition is the fastest?

5.2 – Assessing Usefulness

All the criteria contained into *SUBJECTIVE_CRITERIA* compare the usefulness.

Usefulness is measured through subjective factors. The term subjective apparently clashes with the idea of universal criteria, equal for everyone. Nevertheless, by being able to compare numerous studies, through a unified paradigm of evaluation, we will reach a statistically significant number of people, to assess usefulness.

To statistically process their perceptions, questionnaires based on a Likert’s scale of 10 (that guarantee an adequate precision [D1]) should be used.

We propose 7 basic and recurrent subjective factors in the above-cited literature:

- Individual motivation: if users feel engaged or not in their activities.
- Agreement on results: if users agree or not with the results produced by the group.
- Entertainment: if users perceive a recreational aspect or not when using the support.
- Ease of use: if users find supports easy to use or not.

- Communication easiness: if users perceive their communication, when using the supports, easier or more difficult than usual.
- Group cohesion: if users feel or not as a part of greater entity.
- Agreeableness: if users had an agreeable experience or not, concerning the whole activity.

More than for quantitative criteria, there is a plethora of qualitative criteria that can be assessed, and we totally agree about this observation. Nonetheless the proposed set should stay simple for the purpose of being comparable. The authors of each study then can add other criteria, for the sake of their particular research purpose.

6- Reflecting on the limits of the UP

Some authors disagree about the possibility of comparing CSCWD systems and their traditional counterpart [H1] [ND1]. Different technologies may offer different functions, and thus, being not comparable. For them, the existence of *UNCOMMON_F_OLD_PRODUCT* or *UNCOMMON_F_NEW_PRODUCT*, will bias the comparison. For example, computer-based tools can store ubiquitous data, while paper-based tools cannot. We understand this position, and in fact, we present only an application based on an “isofunctional” comparison, but we disagree with it.

The very essence of disruptive technologies is to propose new ways of carrying out a function.

By comparing cardinalities, if: $\frac{|UNCOMMON_F_OLD_PRODUCT|}{|UNCOMMON_F_NEW_PRODUCT|} <$

then the new product can offer more than the previous one in term of functionalities, and the criterion of existence is able to provide a mean of comparison.

Otherwise if: $\frac{|UNCOMMON_F_OLD_PRODUCT|}{|UNCOMMON_F_NEW_PRODUCT|} >$

the new product is offering less functionalities than the previous one.

Heterofunctional comparison follows a binary logic, either the product has the function or it has not. This comparison completes the isofunctional one, giving a holistic evaluation of the two products. To explain this concept, consider as example, the shift from chemical photography to digital one. Isofunctionally, chemical photography was (and in some cases is still) more effective than digital one. However, the new functionalities introduced by the digital (that are missing on chemical photography), such as the ability to instantaneously share a photo, made the digital photography to substitute almost totally the chemical one. Without a model describing the heterogeneous comparison, this phenomenon was inexplicable. We do not deny that a set of common function is needed; otherwise we will derive in comparing products that have no functional affinity. The point is that perception of a missing function can both influence the subjective perception of the user, and so the

usefulness or the objective performance of the product, and so the efficiency. Considering our case study, a function of computer-based technology is to allow the access to ubiquitous data, on the contrary of paper-based one. If the users perceive this disparity, their opinion will be influenced, affecting the criterion of usefulness. Besides, this function may decrease the time needed to complete a preliminary design task, clearly impacting on the criterion of efficiency.

Observing our proposal for a unified paradigm to compare disruptive technologies, an attentive lector may take expectation about the human subjectivity that plays a pivotal role, which cannot be neglected. Our objective to compare several studies (and so a greater number of people than in the actual study in the domain) will statistically ease this problem. Additionally, in order to be able to confront different studies involving different people, individual characteristic can be considered. We share the use of the "Wonderlic Personnel Test", the "NEO Five Factor Inventory" test, and the "Reading the Mind in the Eyes" test to provide an optimal characterization of a person, as in Woolley et al. [WC1]. Moreover, our proposition for comparing CSCWD systems and their traditional paper-based counterpart is itself a subjective proposition. As a consequence, different judgements about the functions and the associated criteria to assess are possible.

Concerning the identification of a set of common functions, we may be accused of being too abstract, only assessing one general function. We can answer by saying that we are afraid that the more we detail, the more we will increase the number of criteria to address, especially for an introductory case study as in this paper. The more the number of criteria grows, the more is going to be difficult to reach a common consensus. On the other hand, we agree that finding the correct level of "functional depth" is crucial. UP is able to describe all the functional levels addressable. It can be used to compare high-level function, such as supporting a preliminary design session, as well as low-level function, such as comparing a virtual keyboard with a physical one. The choice of the functional depth is up to the user; we think that this freedom endorses the interest for our proposal.

Although, we defend our criteria, we strongly point out, that our main goal is to find a common consensus around a basic set of shared criteria to use. We welcome a discussion nourished by other proposals.

7- Conclusion

The current paper proposes an exploratory study toward a Unified Paradigm (UP) of evaluation for the transitional phase between two products (when a disruptive technology tries to substitute another one on the market).

We want to apply it for the study of the transitional phase from paper-based to computer-based products to support co-located collective engineering preliminary design activities.

This simplified vision can be widely applied to other sectors: personal computers substituted the typewriting machines, or postal mail and email.

Our goal is to understand if CSCWD systems are worth to substitute actual paper-based products.

Analyzing the actual studies in the sector, we get the conclusion that they are too heterogeneous in term of functions (and associated criteria) addressed, making a comparison

among them worthless.

To overcome this gap, we propose a common protocol of evaluation based on the use of qualitative, descriptive, ethnographic comparative studies to collect the data.

To avoid criticism about the impossibility to use a heterofunctional comparison, we used only an isofunctional comparison. Isofunctional comparison, in our specific case, is not far from the worst-case scenario, because a lot of the advantages deriving from computer-based-technology new functions are not assessed. Our point is that, if computer-based products are isofunctionally more effective than traditional paper-based ones, when we will compare these two products, also heterofunctionally, the effectiveness gap cannot but increase.

We used a high level function as common function to compare: the ability of a product to support co-located collective engineering preliminary design activities.

Due to our quest for a simple set of criteria, we assess effectiveness, which is the combination of efficiency and usefulness, objective and subjective criteria. Those are high-level criteria that constitute the tip of the iceberg as in figure 8.

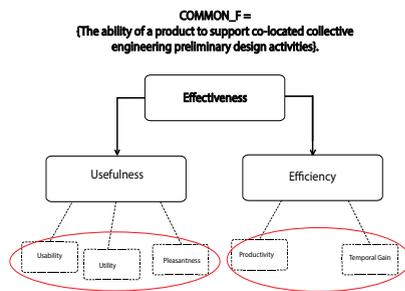


Figure 8: The criteria of effectiveness

The future of the research is to identify other functions to be compared, or to detail the criteria, as done in the red ovals.

We are well aware that the Holy Grail of a common shared standard for comparing computer-based and paper-based computer tools is far from being reached. On the other hand, we defend the necessity to introduce and to discuss over a minimalist set of functions (with their criteria) to assess across the different studies in the domain.

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