Assessing the Impact of Educational Differences in HCI Design Practice

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Abstract

Human-Computer Interaction (HCI) design generally involves collaboration from professionals in different disciplines. Trained in different design education systems, these professionals can develop different conceptual understandings about design. Since the design field is emerging as remarkably different from sciences, engineering, architecture, and arts, understanding and overcoming such differences become key issues for design education. While teaching HCI design techniques to engineering and arts students, we gathered anecdotal evidence of diverse practices, but we also realised that such an account requires systematic and comprehensive criteria, which we find lacking in the literature. This research contributes to develop a systematic account of different design practices.

We developed a technique to assess and compare design artefacts using a set of 22 criteria belonging to two domains: scheme (addressing form) and realm (focusing on contents). Using that technique, our study examines whether and how two different populations of students have different knowledge structures with respect to HCI design. The study compares one specific type of design artefact—conceptual frameworks—created by groups of students with different educational backgrounds: arts and engineering.

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The obtained results show that students with background in engineering (1) focus more on the product of design; (2) rely less on conceptual frameworks to guide the design process; and (3) produce artefacts that are more constrained in terms of signal-to-noise ratio, definition of a symbolic system, and information organization and shaping.

We suggest that such a systematic assessment contributes to better communicate and understand design practice across different educational backgrounds. We support previous research noting that engineering students seem to be more susceptible to fixation than arts students and suggest that an emphasis of reflection-in-action could help compensating this problem.

Keywords

HCI Design, Design Education, Conceptual Frameworks, Sketching, Evaluation of Design Artefacts.

1. Introduction

Design is a problem-solving activity focused on the development of man-made things (Bayazit, 2004). The main challenge of design is to come up with a practical and creative solution to a problem that tends to be ill-defined (Jonassen, 2000). Design is at the heart of Human-Computer Interaction (HCI). HCI strives for the advancement of innovative interaction with technology through design-oriented research and research-oriented design (Fallman, 2003).

Prior research shows that design practice is influenced by the field where it is exerted (Cross, 2004). In the HCI field, design activities generally involve professionals from different disciplines such as computer science, arts, engineering, psychology, sociology, etc. Establishing design guidance and a common ground among these professionals is an overarching goal in HCI (Zitter, Kinkhorst, Simons, & Cate, 2009). Nonetheless, design education in these disciplines varies, which can fundamentally affect how professionals understand what design is about, what it entails, and how they conduct design activities. Haynes et al. (2009) empirical work supports this argument showing that researchers in different disciplines have different conceptual understandings on these issues.

Understanding differences in design practice is important to HCI education by providing meaningful insights on the conceptual obstacles for learning the design practice and collaborating with designers with different backgrounds. Besides, design may only emerge as a scientific field when the distinctions from other fields are fully acknowledged. As clearly stated by Fallman (2003), "if the role of design becomes neglected, HCI research may forgetfully become modelled upon the natural or social sciences" and "[...] these do not typically embrace a proper or elaborate understanding of *what design is.*"

Our research seeks to contribute to this understanding in two ways. One is examining whether and how arts and engineering students have different knowledge structures with respect to HCI design activities. More specifically:

> *We analysed a particular type of design artefact, named conceptual framework, which externalizes semi-structured information, expressed as a combination of text and drawings, elucidating how the designers view a given*

problem and aim to develop a solution. A conceptual framework may identify design issues, concepts, variables, key factors, opportunities, strategies, tasks, options, choices, etc.

Our second contribution concerns the development of a technique for comparing the design artefacts mentioned above. More specifically:

We developed a set of 22 criteria to compare design artefacts in two domains: scheme, addressing matters of form, and realm, which focuses on the contents of design artefacts.

For the last three years, we have been collecting conceptual frameworks developed by groups of students enrolled in undergraduate courses in computer engineering (faculty of sciences/engineering) and design (faculty of arts). These conceptual frameworks were analysed according to the technique mentioned above to highlight major differences and communalities. This research may be significant to HCI researchers, practitioners and educators because it highlights differences in design practice derived from a systematic assessment of design artefacts and using a comprehensive set of criteria.

The paper is organized as follows. We start overviewing several studies comparing the design practice of various communities. We then describe the samples and corpus used by this research. We continue with a discussion of the assessment technique. We then present the obtained results. Finally, we discuss the results and present some conclusions from this research.

2. Related Work

Cross (1982) provides a concise overview of the theoretical bases for considering design as a discipline, which are fundamentally supported by a set of defining characteristics: tackling ill-defined problems, being solution-focussed and constructive, and using languages that translate abstract requirements into concrete objects. Bayazit (2004) complements this perspective with an historical account of design research, emphasising that design research is a systematic search and acquisition of knowledge related to design and design activities. Furthermore, Fallman (2003) relates design research with the HCI field, stating that HCI developers are frequently involved in design activities, as design often is the only way to evaluate novel ideas.

2.1 Background differences in design practice

Focussing on the specific objectives of this study, in Table 1 we summarise the main research findings on background differences in design practice which are reviewed below. Cross (2004) presents an extensive review of research studies investigating differences between senior and novice designers, pointing out that seniors tend to adopt more top-down and breadth-first strategies, and also tend to use more problem decomposition strategies.

Senior versus novice designers (Cross, 2004)	Seniors tend to adopt more top-down, breadth-first and problem decomposition strategies than novices.

Students versus practitioners (Adams, Turns, & Atman, 2003; Atman, et al., 2007)	Practitioners switch more between activities, spend more time considering the problem context and are more attentive to surprises than novices. Practitioners also spend more time in problem scoping and problem definition than novices.
Creative domain versus other domains (Cross, 2004; Dorst & Cross, 2001; Jonassen, 2003)	Practitioners in creative domains treat problems as ill defined, make problems more challenging, and develop richer problem representations.
Engineering versus design students (Cross, 2004; A. Purcell & Gero, 1996)	Engineering students have more predispositions for fixation.
Designers versus non-designers (Chamorro-Koc & Popovic, 2008)	Non-designers tend to focus on broad concepts and social context of use, while designers tend to narrow concepts and focus on product features.
Differences between novices and experts when sketching (Cardella, Atman, & Adams, 2006)	Senior students adopt sketching in more design activities than novice students.

Table 1 - Research findings on background differences in design practice

Atman et al. (2007) investigated differences between students and practitioners in the engineering field for more than 10 years, trying to find pedagogical implications. Their results indicate that practitioners are more likely to move to different design activities throughout the task, to evaluate their designs in multiple contexts, and to be more attentive to surprises and opportunities. A study from Adams et al. (2003) also found out that practitioners spend more time in problem scoping and problem definition than novices.

Cross (2004) reports that design in creative domains is different from design done in more restrictive fields such as software design, as the former seem to deliberately treat problems as ill-defined, even when they are well-defined. Investigating the same concern, Jonassen (2003) notes that designers in creative domains construct richer problem representations. Dorst and Cross (2001) even report that some designers tend to arrange their assignments to be new and more challenging, in order to provoke a creative response.

In the same line of research, Purcell and Gero (1996) investigated differences between engineering and design students. They found out that engineering students show more tendency for fixation, i.e. adopting a prior solution presented as an example. This problem is also reported by Cross (2004), noting that designers in creative domains tend to move more rapidly to early design conjectures and use those conjectures to actively explore further solutions.

Chamorro-Koc and Popovic (2008) investigated the different uses of sketches by designers and non-designers when trying to reflect about a product. Their research reports differences related with two areas. One is that non-designers tend to focus on broad concepts through familiarity with similar products, while designers tend to narrow the concepts to the product being designed. The other difference is that non-designers tend to focus on the social context of use, while designers tend to focus on product features.

Finally, Cardella et al. (2006) compared sketches produced by senior and novice engineering students and noted some trends. One was that senior students seemed to adopt sketching in more design activities than novice students. Another was a relationship between greater use of sketches and more sophisticated design processes.

As an addition to this literature body, this paper reports a study that examines the differences between two populations of students engaged in early design activities. The study is focused on novices and seeks to contrast differences caused by engineering and arts backgrounds on the development of conceptual frameworks.

2.2 Relevance of conceptual frameworks to design

Since our research is centred on one particular design artefact, namely conceptual framework, the relevance of such artefact to design should be established. First, we observe that “both in research and in design, we use conceptual frameworks to structure the world we are investigating or designing […] consisting of concepts such as goals, objects, stakeholders, frames, etc.” (Wieringa, Maiden, & Mead, 2006).

This structuring of the world is inherently associated to problem framing and naming, which are the underpinnings of design. According to Cross (2001), “processes of structuring and formulating the problem are frequently identified as key features of design activity.” The concepts of naming and framing are viewed as the ones that best capture the nature of these processes. Schon (1983) defines naming as identifying the things that will be attended by the designer and framing as the context in which they will be attended. Designers select (name) features of the problem space to which they choose to attend and identify (frame) areas of the solution space in which they choose to explore (Cross, 2004).

Conceptual frameworks also accomplish the purpose of documenting design rationale. As stated by Regli et al. (2000), “keeping track of the design rationale will provide a great aid to designers: it helps to structure design problems, and provides a basis for designers to explore more design options.”

Finally, intertwined with the challenges of framing and naming, is the challenge of coming to a shared understanding about what it is to be developed (Yu & Agogino, 2008). This includes “sharing beliefs, attitudes, assumptions, values, understanding, frames of reference, concepts, relationships, metaphors, commitment, interpretation, perception, content and framing” (Yu & Agogino, 2008).

This combination between representation, framing, naming, design rationale, and shared understanding is what makes conceptual frameworks into paramount artefacts for knowledge externalization (Goldschmidt, 1997) in design. They “reflect the expectations and experience of their creators” (Bodker, 1998). They are “artefacts of knowing” (Ewenstein & Whyte, 2007). As such, we regard conceptual frameworks as very important to document design.

3. Samples and corpus

This study was based on two cohorts, one considering sciences/engineering students and the other consisting of arts students. For convenience, we will designate the former as “Engineering”. Engineering students were enrolled in a 5-year degree in informatics engineering offered by a faculty of sciences. The second cohort, who for convenience we will designate as “Arts”, was enrolled in a 5-year degree in design (with a major in product design) offered by a faculty of fine arts. Table 2 provides age and gender information regarding the two cohorts. The gender differences are typical for these two cohorts. The wide age range is explained by very few cases of relatively old students.

Age

	# students	AVG	STDEV	Lowest	Highest

Faculty of Arts	349	20.0	4.8	17	68
Faculty of Sciences	907	19.5	3.8	17	54
University	4480	20.6	5.8	16	68

Gender (%)

	Female	**Male**
Faculty of Arts	67.0	33.0
Faculty of Sciences	44.3	55.7
University	62.8	37.2

Table 2 - Age and gender information

	Arts	**Engineering**
Background	Physics (statics, materials)	Physics (mechanics)
	Geometry	Algebra
Milieu	History of arts, design styles	Matter-of-fact
Goals	Innovation	Innovation
Methods	Project-orientation	Project-orientation
	Few methods (implicit)	Multiple methods (explicit)
	Trial and error	Stepwise
	Centered on self	Centered on others (standards and best practices)

Table 3 - Main differences between samples, as described by the subjects

We conducted a discussion session with students from both cohorts to help us understand the main differences between them. The results are summarized in Table 3. This table highlights some interesting communalities and distinctions. Regarding education, we note that both cohorts have education in physics and mathematics, although with different focus: Engineering is more focused on mechanics and algebra, while Arts is more focused on materials and geometry. However, the professional milieu is quite different, since the Arts students are educated in arts and design history, while Engineering students are under greater pressure to apprehend and adopt the most recent technology, thus focussing on the present day.

Both cohorts undertake the objective to innovate and develop new technology. Both cohorts are also highly involved in practical projects. In the case of Arts, the project-orientation is clearly reminiscent of the Bauhaus tradition (Bayazit, 2004) and results in a study plan that has five courses named "project."

Some differences between the cohorts should be noted regarding adopted methods. The Engineering students are educated to follow more explicit methods and stepwise approaches to project planning and development. This cohort is also more constrained by external requirements (clients, users, documentation, best practices). On the other hand, the Arts students adopt fewer and less explicit methods, are more engaged in trial and error, and are also more centred on the self when developing projects.

During our study, the sampled students were taking the Systems Analysis and Design (Engineering Group) and the Product and Process Innovation (Arts Group) courses. Both courses are in the fourth year of the respective curricula and had the same lecturer giving the same instructions to the students. Both courses follow the Contextual Design (Beyer & Holtzblatt, 1998) approach to develop skills in problem framing, workplace studies, work modelling and paper prototyping.

All students were instructed to setup groups with the purpose to collaboratively design a technological product up to the point that a "fully functional" paper-prototype can be delivered to a client. The type of product was left open for each group to decide. They were also unequivocally instructed to develop a conceptual framework articulating the design rationale.

We emphasize that all groups were instructed the same way on the main objectives guiding conceptual frameworks: how they are structured with concepts and relationships, the importance of graphical representations, their progression from exploratory to descriptive, and the close relationships with project development. During classes, both samples had the opportunity to see the same set of examples developed by different cohorts. We also emphasize that the development of conceptual frameworks was a long process, with multiple iterations during the whole semester.

For a period of 3 years, we collected conceptual frameworks developed by the two different cohorts. We gathered artefacts from 80 Engineering and 25 Arts groups. The different number of students enrolled in the two faculties caused differences in the data sets. Given this disparity of the data sets, we randomly selected 50 artefacts from Engineering. One conceptual framework had to be later excluded for being a version of another artefact. Thus 25 artefacts from Arts and 49 artefacts from Engineering were used in our study. The remaining artefacts were used to pretest the assessment technique (discussed later).

All artefacts were developed by groups of two to four students. Groups were setup by the students, usually based on prior experience working together. All artefacts were collected in the final development stage, having been consolidated after several iterations done throughout one semester. Finally, we note that most artefacts were hand made. This was presented to students as fundamental to focus their attention on design rationale and not on trying to find and use representation or visualization tools.

4. Assessment Technique

4.1 Approach

The study of design is characterized by several systematic and reliable approaches, where protocol studies have received significant attention, especially because they allow understanding decision-making based on think-aloud and associated actions (Cross, 2001). In this research, we instead adopted an expert evaluation approach, based on a predefined set of criteria applied to design artefacts. This approach affords covering a more extensive corpus, although we should also recognize that in the process we lose insights about how subjects act and make decisions during their design activities. Since this research has an exploratory nature, the initial set of criteria was relatively broad. Our assumption was that: 1) correlated criteria could be consolidated after statistical analysis; and 2) a pretest evaluation using the assessment technique would help removing criteria found difficult to measure objectively or not sufficiently discriminating.

4.2 Selection

For selecting the assessment criteria, we first identified two main areas of concern, the scheme domain and the realm domain (Goel, 1995). The scheme domain is focused on the visual properties of artefacts, regarded as sketches of thought (Goel, 1995), while the realm domain requires knowledge about the design problem and analysis of the proposed/delineated solution. The identification of these domains helped us delimiting the search for criteria.

The initial list of criteria was based on measures used in the evaluation of object-oriented design and user-interface design. Research on object-oriented design quality has been suggesting a set of objective and measurable criteria to assess high-level quality attributes. Bansiya (2002), Meenakshi and Sikka (2012) and Whitmire (1997) provide good overviews of this approach. We posit that object-oriented design artefacts commonly used in the software engineering field, like use-case diagrams and object diagrams, have many common features with conceptual frameworks, especially in the way information is structured and related. Criteria such as coupling, cohesion, complexity, fan-in, and fan-out seem to be relatively consensual in the object-oriented research community and adequate to our goals. Evaluation criteria developed in the user-interface design field, such as signal/to-noise ratio (Lidwell, Holden, & Butler, 2003), were also added to the initial set.

4.3 Tuning

The initial selection of criteria was subject to several pretests. This involved having multiple assessment rounds applied to a small sample of conceptual frameworks (as previously mentioned, this sample was not used in the final assessment). After each round, we evaluated the rating reliability and defined strategies for improving it. The inter-rate reliability was evaluated using the averages/standard deviations of observer agreement. By the end of the tuning process we had elaborated a set of evaluation guidelines describing how the criteria should be rated.

Furthermore, during the tuning process we also discussed if each criteria could be used in an objective way. Some criteria like depth and sufficiency, which were considered difficult to evaluate objectively, were eliminated this way.

4.4 Criteria

For the scheme domain we settled on the following criteria:

- Population – Counting the number of conceptual elements (nodes), considering each individual text element surrounded by a graphical element (e.g. box) and each collection of text showing some cohesion.
- Organization – Perceived structural arrangement of the conceptual elements, classified as: 1) radial, i.e. from a set of central elements towards the periphery; 2) in several levels; and 3) according with several categories.

- Fan-in – The largest number of incoming arcs to a conceptual element. Undirected arcs are considered incoming.
- Fan-out – The largest number of outgoing arcs to a conceptual element. Undirected arcs are considered outgoing.
- Structural complexity – Number of hierarchical elements, counting nodes that have: 1) other nodes inside; or 2) a list of text items inside.
- Representational complexity – Measuring 1) total number of nodes and 2) total number of nodes and arcs. We do not consider directions in arcs.
- Coupling – Measuring the perceived coupling between the conceptual elements, from loose to tight.
- Signal-to-noise ratio – Ratio of relevant to irrelevant visual information: 100 - No irrelevant visuals; 90 - few unnecessary jots (e.g. artistic circles, special arrows); 80 - different types of arrows, jots, colours, etc.
- Primary-to-support ratio – Number of primary elements divided by the total number of elements. Primary elements stand out either graphically or structurally.
- Multiplicity of symbolic system – Counting each type of arrow, box (including the ones that serve to contain other boxes) and bullet (in bulleted lists), and also distinct symbols that serve to raise attention or separate information (e.g. "*" and "/").
- Level of detail – From rough to detailed.
- Shape – Characterizing the primary shape used for nodes: 1) none; 2) rounded; and 3) rectangular.

Of the criteria above, "coupling" and "level of detail" use a 5-point qualitative scale.

For the realm domain we selected the following criteria:

- Process-orientation – Extent to which the artefact is about the design process.
- Component-orientation – Extent to which the artefact is about the design components.
- Design artefacts – Number of design artefacts mentioned in the conceptual framework.
- Comprehensiveness – Perceived understanding of the design problem.
- Relevance – Extent to which the artefact is relevant to frame the design problem.
- Primitiveness – Extent to which the artefact's concepts cannot be constructed from other concepts.
- Redundancy – Extent to which the artefact's concepts may be constructed from other concepts.
- Readability – Extent the evaluator can process the design artefact.
- Cohesion – Characterizing the strength of logical relationships, from coincidental to functional.
- Level of abstraction – From vaguely outlined to descriptive.

All criteria above, with the exception of “design artefacts” use a 5-point qualitative scale.

4.5 Measurement

The selected criteria involve four types of measurement: quantitative, qualitative, ratios and categorical. The quantitative measurements consider the number of units present in a design artefact, such as number of nodes and arcs. The qualitative measurements consider specific qualities of a design artefact, such as complexity and relevance.

During the pretests we used 10-point scales for qualitative measurements, but we realized that such large scale would not allow for a good inter-rate reliability. Thus for the final qualitative criteria we adopted a 5-point scale.

Two criteria use ratios. Primary-to-support ratio is measured by counting elements perceived as primary and secondary in a design artefact. Signal-to-noise is a ratio based on qualitative assessment of the number of unnecessary elements present in design versus the number of essential elements. Finally, we used two categorical criteria to classify design artefacts according to shared qualities.

4.6 Application

The application of the technique involves two persons individually analysing the same design artefact and providing measurements for the 12 criteria defined for the scheme domain and the 10 criteria defined for the realm domain. To achieve good reliability, the evaluators must follow the guidelines and must have been trained on using the technique. One issue that we had to carefully consider was the language skills necessary to assess the conceptual frameworks, since the evaluators had different language backgrounds. The assessment of the scheme domain does not require understanding the textual elements of a conceptual framework, as the criteria only focus on graphical contents. Therefore this type of assessment does not require familiarity with the language used by the conceptual frameworks. On the contrary, the assessment of the realm domain requires familiarity with the language used by the conceptual frameworks.

5. Results

The obtained results are presented in Tables 4 and 5. We show averages and standard deviations for quantitative and qualitative criteria. For the categorical criteria, we present the percentage of incidence for each category that obtained an agreement from the two raters.

Tables 6 and 7 present an analysis of the raters’ agreement. For the quantitative and qualitative criteria, we calculated agreement using averages/standard deviations of the differences between raters. For the categorical criteria, Cohen’s Kappa coefficient was used to measure inter-annotator agreement.

	Arts		Engineering	
	AVG	**STDEV**	**AVG**	**STDEV**
Population	20.56	18.76	14.66	7.22
Fan-out	4.9	2.77	4.12	1.95
Fan-in	3.56	2.22	4	1.87

Structural complexity	2.04	2.43	2.96	2.06
Representational complexity (arcs)	21.68	22.07	12.79	6.86
Representational complexity (nodes and arcs)	42.58	41.91	27.45	13.49
Coupling	2.98	0.85	3.47	0.65
Signal-to-noise ratio	0.93	0.05	0.97	0.03
Primary-to-support ratio	0.26	0.13	0.28	0.11
Multiplicity of symbolic system	5.14	1.23	4.37	1.01
Level of detail	2.58	0.93	2.52	0.80
Organization				
Radial	12		9	
Levels	7		13	
Categories	6		27	
Shape				
None	5		0	
Rounded	8		3	
Rectangular	12		46	

Table 4 - Results from analysis of scheme domain

	Arts		Engineering	
	AVG	**STDEV**	**AVG**	**STDEV**
Process-orientation	2.52	1.31	1.63	0.90
Component-orientation	2.06	0.97	2.64	1.13
Design artefacts	0.88	1.12	1.09	1.10
Comprehensiveness	2.56	1.29	2.05	0.93
Relevance	2.74	1.07	2.20	0.95
Primitiveness	3.54	1.04	3.83	1.05
Redundancy	1.92	0.83	1.50	0.68
Readability	3.20	1.34	3.41	1.03
Cohesion	2.90	1.15	2.83	1.22
Level of abstraction	2.82	1.26	2.41	1.05

Table 5 - Results from analysis of realm domain

	Average of differences	**STDEV**
Population	-0.07	1.72
Fan-out	-0.07	1.29
Fan-in	0.33	1.96
Structural complexity	1.12	1.90
Representational complexity (arcs)	0.28	2.77
Representational complexity (nodes and arcs)	0.44	4.19
Coupling	-2.52	1.21
Signal-to-noise ratio	-0.02	0.09
Primary-to-support ratio	-0.30	0.22
Multiplicity of symbolic system	0.17	1.34
Level of detail	-1.73	1.17
	Inter-annotator agreement	
Organization	0.77 (Cohen's Kappa)	
Shape	All agreed	

Table 6 - Analysis of the raters' agreement for the scheme domain

	Average of differences	STDEV
Process-orientation	-0.21	0.79
Component-orientation	-0.05	0.82
Design artefacts	-0.07	1.07
Comprehensiveness	0.01	0.63
Relevance	-0.20	0.68
Primitiveness	0.13	0.66
Redundancy	-0.07	0.83
Readability	-0.05	0.77
Cohesion	0.05	0.77
Level of abstraction	-0.07	0.68

Table 7 - Analysis of the raters' agreement for the realm domain

With the exception of *Coupling* and *Level of detail*, we found good inter-coder reliability in most of the analysed criteria. The discrepancies found in the assessment of *Coupling* and *Level of detail* may be attributed to their subjectivity, the reason why we decided to exclude them from further analysis.

We found that *Population* obtained very high standard deviations in both samples. The high variation in Population indicates that groups had quite different perspectives on what a conceptual element was in the project. The fact that Arts had more conceptual elements than Engineering (20.56 vs. 14.66) and higher variation (18.76 vs. 7.22) suggest that Arts students perceived more conceptual entities in the design and more diverse understandings on grouping these entities.

We also found that *Representational complexity* had high standard deviations in both samples. Again, compared to Engineering, Arts groups had higher value on this criterion (21.68 vs. 12.79) and standard deviation (22.07 vs. 6.86). These results suggest that Arts students had more complex ways of articulating the artefacts through nodes and arcs, and the degree of complexity varies a lot more depending on Arts groups.

These results seem to hint that Arts students are more complex in conceiving design concepts and more creative in articulating the conceptual framework. However the lack of additional data (e.g., interviews that reveal the rationales of the students' choices on nodes) made it impossible to make this claim. Further investigation is needed to validate this explanation.

The remaining criteria were further analysed for significant differences using two-sample t-tests with MiniTab 16. We found some interesting results as follows:

5.1 Signal-to-noise ratio

The t-test result about the signal-to-noise ratios between the two samples is presented as follows:

	N	Mean	StDev	SE Mean
Arts	25	0.9272	0.0541	0.011
Engineering	49	0.9718	0.0291	0.0042
Estimate for difference:	-0.0446			
95% CI for difference:	(-0.0683, -0.0210)			

T-Test of difference = 0 (vs not =): T-Value = -3.85 P-Value = 0.001 DF = 31

The result shows that the means for *Signal-to-noise ratios* of these artefacts are statistically different between the two samples (i.e., 0.93 vs. 0.97 with standard deviation of 0.05 vs. 0.03). The lower mean of the ratio by Arts suggests that students with background in Arts tend to produce conceptual frameworks with more noise, i.e., they include more irrelevant elements in the artefact regarding the design problem. One example is given in Figure 1:

Figure 1 – A conceptual framework from a group with background in Arts, exhibiting high signal-to-noise ratio (elements in original language; no translation is necessary since this criteria is based on shape only). Observe the different types of nodes and arcs, with various shapes, colours and line thickness.

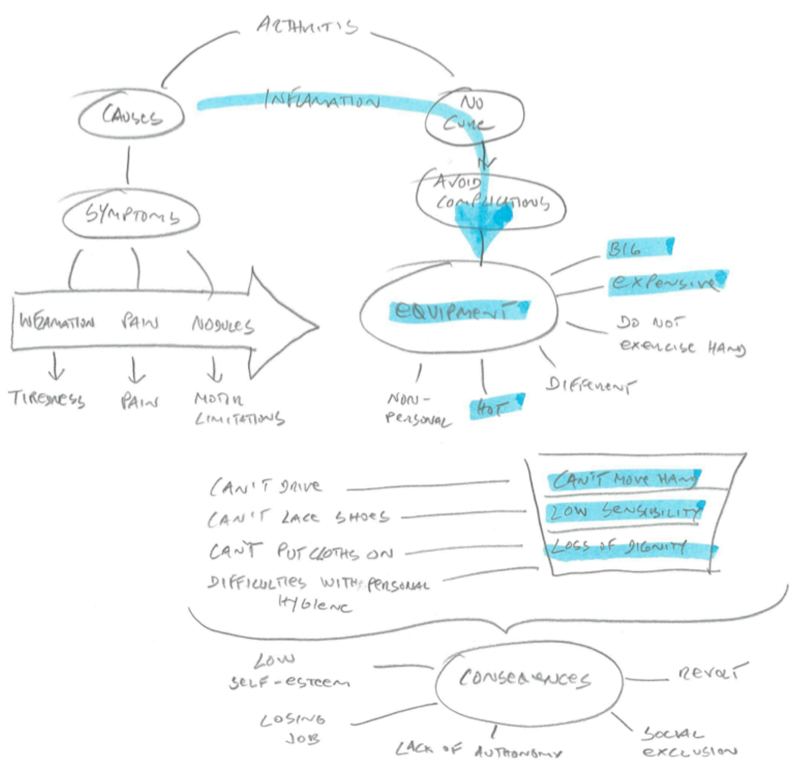
5.2 Multiplicity of symbolic system

The t-test results about the *Multiplicity of symbolic system* between the two samples is presented below:

	N	Mean	StDev	SE Mean
Arts	25	5.14	1.23	0.25
Engineering	49	4.37	1.01	0.14
Estimate for difference:	0.773			
95% CI for difference:	(0.196, 1.349)			

T-Test of difference = 0 (vs not =): T-Value = 2.71 P-Value = 0.010 DF = 41

Again, the t-test result shows that the means for this criterion are statistically different between samples (i.e., 5.1 vs. 4.4 with standard deviation of 1.23 vs. 1.01). The higher mean obtained by Arts suggests that students with background in Arts tend to use a more complex symbolic system than students with background in Engineering. Figure 2 illustrates these differences.



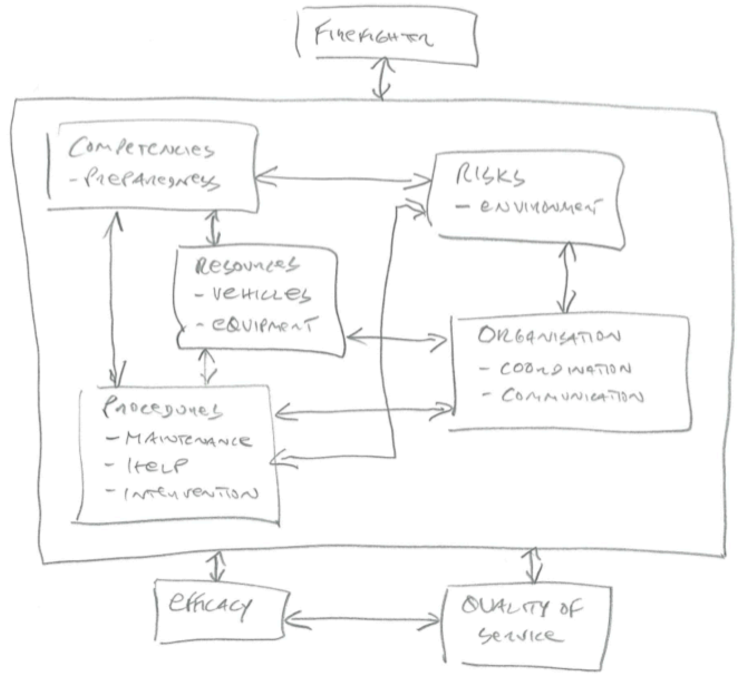


Figure 2 – Conceptual frameworks exhibiting symbolic systems with different complexity. Above: artefact from a group with background in Arts. Below: artefact from a group with background in Engineering (elements in original language; no translation is necessary since this criteria is based on shape only). Observe, for instance, that the artefact shown below uses one single type of link, while the artefact shown above uses various, at least four different types.

5.3 Relevance

The t-test result about the scores for the *Relevance* criterion is presented below:

	N	Mean	StDev	SE Mean
Arts	25	2.74	1.07	0.21
Engineering	49	2.204	0.946	0.14
Estimate for difference:	0.536			
95% CI for difference:	(0.025, 1.047)			

T-Test of difference = 0 (vs not =): T-Value = 2.12 P-Value = 0.040 DF = 43

This criterion is about the extent to which the artefacts are relevant to frame the design problem. The two-sample t-test result shows that there is a statistically significant difference between the two samples in constructing the artefacts with respect to how they are related to design. Interestingly, Arts had higher mean on this criterion implying that their artefacts were perceived more relevant to frame the design problem than Engineering.

5.4 Process-orientation versus component-orientation

The t-test results about the criteria of *Component-orientation* and *Process-orientation* shows that there is a statistically significant difference between the two means for both criteria:

For the *Component-orientation* criterion:

	N	Mean	StDev	SE Mean
Arts	25	2.060	0.972	0.19
Engineering	49	2.64	1.13	0.16

Estimate for difference: -0.583

95% CI for difference: (-1.090, -0.076)

T-Test of difference = 0 (vs not =): T-Value = -2.31 P-Value = 0.025 DF = 55

For *Process-orientation* criterion:

	N	Mean	StDev	SE Mean
Arts	25	2.52	1.31	0.26
Engineering	49	1.633	0.900	0.13

Estimate for difference: 0.887

95% CI for difference: (0.295, 1.480)

T-Test of difference = 0 (vs not =): T-Value = 3.04 P-Value = 0.004 DF = 35

These results suggest that students with background in Arts tend to focus more on the design process, while students with background in Engineering focus more on the actual product of design.

5.5 Organization

We conducted a Chi-square test on the results of the *Organization* category to examine whether the groups used different shapes in constructing the artefacts. As shown below, there is statistically significant difference between the samples. The results suggest that students with background in Engineering tend to construct the design according to several important elements (i.e., the *Category*), whereas students with background in Arts seem to prefer constructing the design from one central element[1].

	Engineering	Arts	All
Level	13	7	20
Category	27	6	33
Radial	9	12	21
All	49	25	74

Pearson Chi-Square = 8.726, DF = 2, P-Value = 0.013

Likelihood Ratio Chi-Square = 8.786, DF = 2, P-Value = 0.012

5.7 Shape

We conducted a Chi-square test on the results of the *Shape* category to examine whether the groups used different shapes in constructing the artefacts. As shown below, there is statistically significant difference between the samples. The results show that groups used shapes very differently. Students with background in Engineering used *Rectangular* shapes dominantly, while students with background in Arts seem to have more diverse choices such as using a *Round* shape.

	Engineering	Arts	All
Rectangular	48	12	60
None	0	5	5
Round	1	8	9
All	49	25	74

Pearson Chi-Square = 21.703, DF = 2, P-Value = 0.000

Likelihood Ratio Chi-Square = 22.630, DF = 2, P-Value = 0.000

There were no significant differences found for the remaining criteria.

6. Discussion and Conclusions

[1] This might indicate that the spatial relations are being used more for problem decomposition than problem solving (A. Purcell & Gero, 1998).

To briefly summarize the obtained results, we highlight that:

Scheme domain: Arts adopted a more open and diverse visual language than Engineering. Thus, Arts had more signal-to-noise ratio, more complex symbolic systems and more diverse shapes. By contrast, Engineering produced more categories and levels, and they primarily represent concepts as rectangles.

These differences may be either attributed to the influence of the discipline's culture on the way the design is presented (e.g., self versus others, style versus matter-of-fact; refer to Table 3) or to gender differences. Prior research has found that gender differences may impact design tasks (Charyton & Merrill, 2009; Ding, Bosker, & Harskamp, 2011).

Realm domain: Arts was perceived to frame the design problem differently from Engineering, as their artefacts were considered more relevant to design. Arts gave more importance to the underlying process of design (more process-orientation, less component-orientation). Symmetrically, Engineering gave greater importance to the end product of design (more component-orientation, less process-orientation).

These results indicate that students with background in arts seem to have more developed abilities to frame design problems and reflect on the developed solutions. These findings were in line with Purcell and Gero's (1996) study that suggests engineering students could be more susceptible to fixation. Furthermore, our assessment technique detected this effect in three different ways: (1) slightly more stereotyped artefacts; (2) slightly less relevant artefacts; and (3) slightly less consideration for the design process.

The goal of our two-dimension (i.e., scheme and realm) assessment technique is to illustrate different dimensions in design practices reflected through the design artifacts. A comparison between our technique and Fallman's accounts of design (2003) showed interesting result. Fallman (2003) identified three different accounts of design: romantic, pragmatic and conservative. With a romantic account, design is like a black box full of magic. There is not a set of design approaches or tools ready for designers to use during the design process. The emphasis is therefore on the end product of design and the way it accomplishes the designers' goals. The conservative account refers to the cases where designers use a systematic and rationalistic approach to design; and methodology and terminology from the natural sciences and engineering provide the basis for transforming a design problem into a solution. Designers with pragmatic perspectives acknowledge design as a situated, experiential and iterative process in which they engage to question, adapt, and/or justify their design solutions. The design process then becomes a quest for reflection-in-action.

In Table 8 we present our results according to our assessment technique and also Fallman's (2003) design accounts. We observe that regarding the scheme domain the differences between Arts and Engineering highlight the emblematic romantic-conservative dichotomy. However, when we consider the realm domain, the differences between Arts and Engineering emphasize the pragmatic-conservative dichotomy.

	Scheme	Realm

Romantic	Arts (more open, more diverse)	
Conservative	Engineering (more structure, less diversity)	Engineering (less relevance, less focus on process)
Pragmatic		Arts (more relevance, more focus on the process)

Table 8 - Classification of Arts and Engineering samples according to Fallman's dimensions.

Overall, the comparison of our study and the existing studies (in particular the research from Purcell and Gero (1996)) suggests that using our assessment technique obtained results consistent to the literature, which validates the technique itself. Moreover, our technique was able to detect more dimensions of the differences between the disciplines' design practices with the design artefacts making it a richer and more nuanced scaffold in comparing the design practices.

The implications of this research are twofold. On the one hand, our research suggests that the conceptual framework is a nice tool to understand and communicate design rationale. As such, it may complement other tools used in the HCI field, e.g., design scenarios, which are often used to communicate product design possibilities (Rosson and Carroll, 2009).

On the other hand, our research suggests that engineering students could be advised to attribute more importance to reflective thinking in their design process. As shown in the results section, engineering students' conceptual frameworks had slightly less relevant artefacts and consideration for the design process. By practicing reflection-in-action in design activities, the students have opportunities to critic how they frame and approach the design problems, thus noticing the drawbacks or irrelevant artefacts in their current design. These reflective thinking processes in the design are also expected to help them be better aware of the design process thus being more flexible on the design focuses and solutions.

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