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# A Study of Usability of Sketching Tools Aimed at Supporting Prescriptive Sketches

P. Company[1], M. Contero[2], F. Naya[2], and N. Aleixos[1]

[1]Department of Mechanical Engineering and Construction, Universitat Jaume I, Spain
[2]DEGI-ETSII, Polytechnic University of Valencia, Spain

**Abstract**

*Prescriptive sketches are usually drawn, after conceptual design is over, to prepare the creation of digital 3D models. Designers and draftsmen use them as "screenplays" that guide the creation of the final 3D model. Prescriptive sketches are still paper-and-pencil, in spite of the existence of some academic or even commercial, computer tools.*

*In this paper, we defend the hypothesis that this is because current computer tools are less usable than paper-and-pencil sketches and do not posses significantly improved functionality. A pilot study was conducted to validate this hypothesis. Both the study and its main conclusions are described in detail.*

Categories and Subject Descriptors (according to ACM CCS): J.6.1 [Computer-Aided Engineering]: Computer-Aided Design. H.5.2 [User Interface]: *Interaction styles, Input devices and strategies,* Evaluation/methodology.

## 1. Introduction

According to the classification by Ferguson [Fer92], we distinguish among *thinking sketches* used to focus and guide non-verbal thinking, *talking sketches* employed to support discussion on the design with colleagues and *prescriptive sketches* applied to give instructions to the draftsman who is in charge of making the final drawing. From the point of view of machine interpretation of sketches, prescriptive sketches clearly differ from both thinking and talking sketches, as prescriptive sketches contain many standardized conventions (like symmetry lines, dimensions, hatched cut views, etc.) that greatly affect to both the input and the reconstruction process of a final model.

The machine interpretation and reconstruction of thinking sketches has attracted a lot of attention. A number of different authors and groups using different techniques have contributed to this field (see the recent survey in [CPC*05]). Besides, the judgment of designers about computer support for thinking sketches in the conceptual design of industrial products has been a field of interest for some time and is still very active at present (see, for instance, [BD03] and [LQP*04]). Talking sketches, which are aimed at enhancing communication among design teams, have not received so much attention. Some recent developments from the computer support collaborative work (CSCW) scientific community are aimed at both collaborative creation and the sharing of 2D sketches. However, relating to the objectives of this paper, few differences separate them from thinking sketches in terms of its automatic interpretation and conversion into 3D digital models. Finally, although it obviously benefits from the general advances in pen-based interfaces and the like (e.g. Computers & Graphics 29(4), special issue on pen-based computing), few works were found in the literature aimed at studying the singularities of the input and the transfer from prescriptive sketches into 3D computer models. Although concerned with architecture rather than product design, the work by the Lucid group (e.g. [JLA05]) is a pioneering effort in this field. Prescriptive sketches were ignored at the time when a lot of effort was concentrated in automatic digitalization of engineering drawings, since, at that time, they were considered to be more "noisy" than line-drawings, and just temporary documents (instead of valid documents containing long-term information). In our opinion, this point of view obviates the fact that prescriptive sketches are typically done by head designers, and are later converted into final line-drawings by draftsmen. Certainly, some draftsmen are very expert in solving geometrical incoherencies and not well defined details of the sketches. But many of them simply tidy up (or, in the worst cases corrupt!) the original prescriptive sketch, which already contains all the relevant information. Hence, creating prescriptive sketches, then converting them into line-drawings and finally creating a 3D model is a clearly inefficient flow. Yet, the need of prescriptive sketches is clear, as they are still drawn (after conceptual design is over), in

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order to prepare the creation of digital 3D models: designers and draftsmen use them as “screenplays” that guide the creation of the final 3D model. Hence, the first question is whether or not creating a paper-and-pencil prescriptive sketch is more or less efficient than creating a “digital” prescriptive sketch. This question is relevant since digital sketches are the output of computer-aided sketching (CAS) tools, which should become the new design paradigm.

In this paper, we defend the hypothesis that paper-and-pencil is still preferred because current CAS tools are less *usable* and do not posses significantly improved *functionality*. A pilot study was conducted to validate this hypothesis. Both the study and its main conclusions are described in detail.

Apparently, creating a prescriptive sketch and then creating its 3D model from scratch is also inefficient: prescriptive sketches should be the input for the automatic creation of 3D models. This should constitute the functionality improvement that greatly compensates the reduced usability of digital prescriptive sketches. Hence, this shift would convert digital prescriptive sketches into a valid alternative. Sometimes, it is assumed that current “pseudo-sketchers” embedded into CAD applications solve this problem, i.e. they can substitute hand made prescriptive sketches without loss of usability and they can also increase functionality by semi-automatically aiding the user in creating the final model from the different views of the sketch. In our pilot study we have tried to measure the validity of this belief.

## 2. Discussion

The absence of digital prescriptive sketching tools in the design process is not due to prescriptive sketching not being necessary any more. It is just that appropriate hardware was not available until the recent advent of tablet PCs, and currently available SBIM tools are still too academic, and no commercial tools have yet arrived to the end users.

However, it is to be noticed the difference with the origin of other CAD tools. Indeed, even the most primitive and simple advances in “digital” curves, from the field of CAGD, were anxiously adopted by designers’ community as soon as they became available. Furthermore, they were considered to be such a technological advantage that they were kept under trade secret for as long as their owners could do so [Far02].

In our opinion, this was because “digital” curves solved a critical problem in aeronautical and automotive industries that traditional tools could not solve. Designers and manufactures needed a mathematical description of curves (ready to CAM), which had to be, at the same time, meaningful and simple for design purposes. Traditional approaches to curves from descriptive geometry were limited to conics. Analytical curves depended on abstract parameters and its behaviour was not intuitive for designers.

On the other hand, sketching is certainly a powerful way to communicate design ideas and to enhance the designer creativity! Many studies ([Tve02], [PA02], [BD03]…) guarantee sketching to be an important conceptual design tool. A recent survey conducted by the Engineering Design Graphics Division of the American Society for Engineering Education (ASEE) includes the ability to sketch engineering objects in the freehand mode as the second main engineering students’ outcome [Bar04], [BKA04]. The same happens in the American Society of Mechanical Engineers ASME [Ros05].

However, apart from the advantages of paperless office, “plain” digital prescriptive sketches do not solve any *real* problem, since paper-and-pencil sketching is simpler, polyvalent and well suited for giving instructions to the draftsman in charge of making the final drawing or 3D model. We have not found direct evidence of the previous asseveration, but Lim et al [LQP*04] conducted a study aimed at identifying the requirements for developing a computer-based sketching system. They focused on thinking sketches, as they tried to validate sketches as input interface for 3D free-form surface modelling. Nevertheless, they designed a questionnaire whose results aroused our interest. The first one was that the main reason to use paper-and-pencil is because it allows fast expression and it is easy to capture impulsive ideas. The second was that there are no appropriate tools that fully support free-hand sketching and recognition. And the third was the list of weaknesses of existing CAD tools: too time consuming with slow feedback, different feeling to paper and pencil, difficult interface, too expensive and poor results. In sum, the respondents wanted a simple sketching environment with qualities as good as real paper. In addition, the drawing tool in a system should be able to be used as a multiple purpose (in terms of the stroke thickness and possibly colour support) just like a real pencil does. All these conclusions appeared to be plausible for prescriptive sketches too, as far as commercially available CAD tools with some “pseudo-sketching” capabilities have been considered to be clearly oriented towards detailed design [Ott98]. Hence, they may represent the nucleus of the future paradigm in prescriptive CAS tools.

As a consequence, it can be concluded that achieving or even enhancing the usability of paper-and-pencil appears to be a key issue for the success of digital prescriptive sketching. Following this assumption, we did not investigate existing research tools for sketch input because our pursuit was digital sketches obtained in a simple virtual paper and pencil scenario, i.e., sketch space should be deliberately minimalist [PA02]. On the contrary, adding some extra functionality, without suffering any reduction in usability, should increase the acceptance of those tools.

Some additional considerations must be taken into account, as we can agree with Plimmer and Apperley [PA02] that giving the user feedback of whether a glyph, and edge or an entire model has been recognized distracts him or her from the creative activity. Hence, future CAS tools should simulate a *minimalist* virtual paper-and-pencil scenario. To emulate this minimalism, the three modes suggested by Plimmer and Apperley (draw, handwrite and edit) can even

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be simplified to two, as text processing belongs to a relatively separate research field. An *edit* mode can be maintained apart from *draw* mode, since we assume that cut, copy, paste, resize, and similar transformations are explicit actions that the designer uses in a higher conscious plane, and, hence the explicit invocation of such action from a menu does not broke the thinking process.

Other evidence exists. Some relevant works compare traditional versus digital media, although they are mainly oriented towards ideation sketches. Some of them are not directly related to this study, because they are particularly oriented to conceptual sketching and, besides, they do compare 2D sketching versus 3D gesture based modelling [OSD05]. However, other studies are related in some way. For instance, in their interesting work, Bilda and Demirkan [BD03] decompose the entire problem into segments, where prescriptive sketches may be classified in the particular segment: "F reproduction of design", i.e. copy the design/tracing on a new sheet/redraw the layout. They consider four action categories, and again, prescriptive sketches also fit into the three sub-categories of "physical" action category (draw, modify and copy). Hence, their conclusions can be considered valid for prescriptive sketches. It is particularly relevant that their main conclusion about physical actions was that the mean frequency of "draw" actions was lower in CAD than in HAND, while "modify" actions are more frequently used in CAD when compared to HAND. They concluded that this is because current commercial CAD software usually works on "draw and then modify" principle.

In sum, maintaining usability while increasing functionality of future digital prescriptive sketches seems to be the goal. Current levels of sketching usability can be derived from a comparison among a) paper-and-pencil, b) "pseudo-sketching" capabilities commercially available CAD tools, and c) a minimalist virtual paper-and-pencil scenario.

## 3. Hypothesis

Our current goal is making easier the input of geometrical information into CAD applications. Our hypothesis is that the less intrusive the interface, the better for the designer. We understand "intrusive" as equivalent to attracting the attention of the designer. In other words, an intrusive interface is permanently requiring the user to do things, and tends to gain more and more control on the process of fixing geometry of a new shape or design.

Besides, our hypothesis is clearly geared to interactive sketching tools, as opposite to the avenue of lettting people sketch on paper and then capture and process the pencil-paper sketch, using a video camera, a scanner, or an instrumented marking drawing device, plus the appropriate software (e.g. [SFL*04]).

It has been extensively argued in current literature that hand-drawn sketches, i.e. traditional paper-and-pencil sketches, are almost "transparent" to the designer. Where transparent is used in the sense that the creativity flows free from the mind's eye to the paper, which neither interferes nor alters the creativity flow.

On the contrary, it is usually argued that current CAD "sketchers" are permanently asking the user to completely define all the details of every step, before proceeding to the next. This is considered to cut down the creativity flow. Hence, paper-and-pencil sketching is seen as a more usable alternative that CAD systems when conceptual design is in progress.

Besides, sketches are not only used as "creative" tools. According to Ferguson [Fer92], prescriptive sketches are also used in the design process. In this context, parametric 2D drawing is usually considered a better alternative than paper-and-pencil. The argument comes from the lack of functionality of paper-and-pencil prescriptive sketches.

If a prescriptive sketch must pay attention to geometrical details, it is argued, the expertise of the draftsman becomes crucial; because a poorly drawn sketch will not show the details, while a good sketch will require a large drawing time and a very expert hand. Following the argument, current parametric 2D CAD are seen as "intelligent tools that allow not very expert designers to generate high-quality drawings".

Our hypothesis is that the previous argument is true, although it hides a relevant advantage of hand-made sketches, and the corresponding CAD sketches disadvantage. CAD applications are permanently forcing the designer to choose what type of stroke is to be drawn next. Besides, while in automatic constraints detection mode (the default one in many applications), the applications are interactively detecting constraints (supposed to fit "design intentions") and modifying the current sketch. This means that the usability of the final "sketch" is partially extracted from a set of unconscious user action, and partially extracted from "subliminal" queries that the system is permanently asking the user. In fact, what is obtained in the output is not a true sketch, but a precise line-drawing made of "strokes" (linear entities) accompanied by an extensive set of geometrical constraints that, supposedly, retain the design intention. Hence the result is richer than a paper and pencil sketch and, besides, fully integrated in the computer flow. This means that it is more functional. But the constant access to menus to select the next "action" and the subliminal queries that the user is permanently forced to answer greatly reduces usability.

In sum, in CAD environments, prescriptive sketching functionality is achieved at the expense of usability. On the contrary, prescriptive sketches done through paper and pencil lack functionality, but do not pay any "toll" in the form of reducing their usability.

In order to validate, reject or modify this hypothesis, we elaborated a pilot questionnaire to determine the opinion of the potential users of prescriptive sketches tools. It is a pilot questionnaire because it is still too long for a real field test. However, we believed we could obtain information of capital importance to design an accurate and still precise final questionnaire.

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## 4. Questionnaire

Our intention is to compare paper-and-pencil against parametric 2D CAD. In order to clearly separate the “intrusive” behaviour of 2D CAD from a possible “generic” intrusion of the computer, compared to paper and pencil. But, as far as we intend to determine the hypothetical usability of a future non-intrusive CAS tool, we decided to simulate this environment by asking the interviewed people to draw a sketch on a tablet PC with the least intrusive digital drawing tool we could find. We opted by Microsoft’s PAINT, but reducing its set of tools to just paintbrush and rubber. 2D CAD was simulated by the sketching capabilities of UGS’s SolidEdge, because of its availability and because of the familiarity that many of the interviewed had with it. In sum, the respondents were asked to compare prescriptive sketching done in three different scenarios: a) hand (H), b) Paint+tablet (P/t) and c) SolidEdge (S/E).

It was decided that just answering a set of questions related to sketching activity was not a good strategy. On the contrary, sketching should be the main task for the interviewed people. First, because in this way they would be really concerned on the subject. Second, because this should give us extra information to externally evaluate, compare and score people’s ability to sketch in the different scenarios.

Our population was conceived as a mixture of experts (E’s) and beginners (B’s). In our case, eight teachers of engineering design and CAD, and 22 first year engineering students; who gave us the point of view of beginners. Our aim in chosing this population was to try to separate the "familiarity" issue from the underlying "usability" issue. Some of our experts are mostly used to paper and pencil and dislike current software, while other are real experts in CAD teaching. Finally our students have been taught in a computer-dominant environment, and feel less comfortable with paper and pencil.

We rated the previous experience of respondents as: null (0), poor (1), average (2), good (3) and excellent (4). Experts were asked to rate themselves, while beginners were rated according to their grades. Results are tabulated in the “previous experience” columns of table 3. Almost none of the participants had used tablet PC’s beforehand. All of them received a short training session (ten minutes) about tablet PC’s and Microsoft’s PAINT. Some experts had never used SolidEdge beforehand, and they received a short training session (ten minutes). Those short training sessions were considered enough, because our pilot study was aimed at getting user’s opinions on ease of use, rather than to objective measurements such as time taken to complete the tasks.

### 4.1 Templates

We selected four sketches (fig. 1 to 4), intended to be representative of the most current sketch types, while being simple enough to allow completing the test in one hour.

We asked the respondents to reproduce the four sketches as close as possible as they appear in the figures: distinguishing thin and thick lines, drawing dot-dash lines, and drawing dimensions without paying attention to the numeric value, although maintaining the general proportion of models (as usual in engineering sketching).

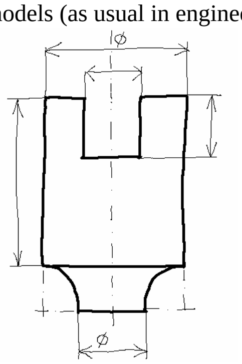

**Figure 1:** *Sketch A. Symmetrical shape with few rectilinear strokes and just two curves.*

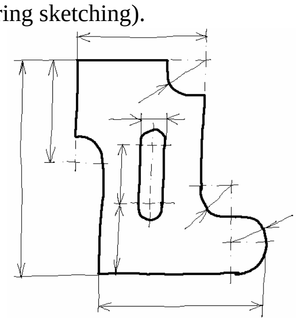

**Figure 2:** *Sketch B. Non symmetrical shape with rectilinear strokes all of them horizontal or vertical, plus some 90° or 180° tangent arcs.*

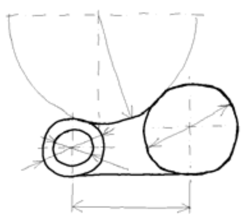

**Figure 3:** *Sketch C. Neither symmetric nor rectilinear shape, with concentric circles and a complex tangent arc.*

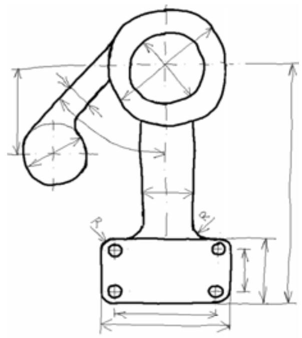

**Figure 4:** *Sketch D. Partially symmetric and orthogonal shape, combined with oblique and tangent arm with circle.*

Every sketch was to be reproduced in the three scenarios: a) hand, b) Paint+tablet and c) SolidEdge. The respondents were free to decide the sequence when realizing the drawings, but they had to inform us about it. We thought this information to be relevant because of the learning “effect” deduced by Bilda and Demirkan in a similar study [BD03] where they observed a significant reduction in the number of “transitions” required to solve the same problem for a second time. Our respondents also had to measure the time spent in doing every drawing. To gain some insight of the specific advantage introduced by tablet PC’s we asked the respondents to draw sketch “A” using paintbrush and rubber of Microsoft`s Paint in a conventional PC computer, via mouse. To prevent excessive fatigue, we demanded just sketch A; as our own experience indicated mouse to be much more tiring and frustrating than pen.

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| Respondent | Sequence | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hand (H) | | | | Paint/tablet (P/t) | | | | SolidEdge (S/E) | | | | P/m |
| | A | B | C | D | A | B | C | D | A | B | C | D | A |
| B01 | 1 | 2 | 3 | 4 | 7 | 8 | 9 | 10 | 5 | 6 | 11 | 12 | 13 |
| B02 | 3 | 5 | 7 | 9 | 10 | 11 | 12 | 13 | 2 | 4 | 6 | 8 | 1 |
| B03 | 5 | 6 | 7 | 8 | 1 | 2 | 3 | 4 | 9 | 10 | 11 | 12 | 13 |
| B04 | 1 | 11 | 12 | 13 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | 10 | 6 |
| B05 | 5 | 6 | 7 | 8 | 1 | 2 | 3 | 4 | 10 | 11 | 12 | 13 | 9 |
| B06 | 5 | 7 | 8 | 9 | 13 | 12 | 10 | 11 | 1 | 2 | 3 | 4 | 6 |
| B07 | 10 | 11 | 12 | 13 | 6 | 7 | 8 | 9 | 1 | 2 | 3 | 4 | 5 |
| B08 | 1 | 2 | 3 | 4 | 8 | 9 | 10 | 11 | 5 | 6 | 7 | 13 | 12 |
| B09 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 1 |
| B10 | 10 | 11 | 12 | 13 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| B11 | 10 | 11 | 12 | 13 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| B12 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 13 |
| B13 | 1 | 2 | 3 | 4 | 9 | 10 | 11 | 12 | 5 | 6 | 7 | 8 | 13 |
| B14 | 10 | 11 | 12 | 13 | 5 | 6 | 7 | 8 | 2 | 3 | 4 | 9 | 1 |
| B15 | 1 | 2 | 3 | 4 | 10 | 11 | 12 | 13 | 6 | 7 | 8 | 9 | 5 |
| B16 | 1 | 2 | 3 | 4 | 10 | 11 | 12 | 13 | 6 | 7 | 8 | 9 | 5 |
| B17 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 13 |
| B18 | 10 | 13 | 12 | 11 | 6 | 9 | 7 | 8 | 2 | 3 | 4 | 5 | 1 |
| B19 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| B20 | 1 | 2 | 3 | 4 | 10 | 11 | 12 | 13 | 5 | 6 | 7 | 8 | 9 |
| B21 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 2 | 3 | 4 | 5 | 1 |
| B22 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| E01 | 9 | 10 | 11 | 12 | 5 | 6 | 7 | 8 | 1 | 2 | 3 | 4 | 13 |
| E02 | 4 | 7 | 10 | 13 | 2 | 6 | 9 | 12 | 1 | 5 | 8 | 11 | 3 |
| E03 | 1 | 2 | 4 | 5 | 3 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 6 |
| E04 | 6 | 7 | 8 | 9 | 1 | 2 | 3 | 4 | 10 | 11 | 12 | 13 | 5 |
| E05 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| E06 | 1 | 2 | 3 | 4 | 9 | 10 | 11 | 12 | 5 | 6 | 7 | 8 | 13 |
| E07 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| E08 | 3 | 4 | 6 | 7 | 10 | 11 | 12 | 13 | 1 | 2 | 5 | 8 | 9 |
| E09 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 11 | 12 | 13 | 9 |
| Ave-rage | 4,2 | 5,7 | 6,8 | 7,8 | 5,6 | 6,8 | 7,6 | 8,7 | 5,5 | 6,7 | 8,0 | 9,4 | 8,2 |
| | 1 | 4 | 7 | 9 | 3 | 6 | 8 | 12 | 2 | 5 | 10 | 13 | 11 |

**Table 1:** *Drawing sequence of every respondent (where 1 stands for first drawing and 13 for last).*

In order to evaluate the results for each participant, drawing quality was rated by one of the authors of this paper, who has many years of experience in teaching engineering graphics. Finally, the respondents had to answer the following questions:

1. Arrange the four sketches (A, B, C and D) scoring them from easiest (1) to most difficult (4).
2. Arrange, from most important (1) to less important (4), the following criteria to determine which is the most difficult sketch: a) the one that contains more lines; b) the one that contains more curves; c) the one that is less symmetrical, and d) the one that contains more angles.
3. Signal the tool (H if hand, P if Paint/tablet or S if SolidEdge) with which you have obtained the best version of every sketch.
4. Arrange the tools (Hand, Paint/mouse, Paint/tablet and SolidEdge) scoring them from the easiest (1) to the most difficult (4).
5. Enumerate the main advantages of hand-made drawings.
6. Enumerate the main advantages of Paint with tablet.
7. Enumerate the main differences between Paint with tablet and Paint with mouse.
8. Enumerate the main advantages of SolidEdge.
9. Add any observation you consider to be relevant.

## 5. Results and analysis

First of all, some checks were made to validate the process of data collection. The ratings of students were compared to their grades and showed no significant differences. The drawing sequences were found to have so many differences (table 1) that no learning effect was considered in the aggregate data. Still, for a detailed study of the behaviour of each respondent, the particular sequences, or, at least the "average" sequence (last row in table 1) should be considered.

The numerical results linked to questions 1 to 4 have been summarized in table 3, while the main comments about questions 5 to 9 are compiled in table 2.

| Query | Answers | |
|---|---|---|
| 5 | a | Fast and easy |
| | b | Consents improvisations and imperfections |
| | c | Low cost |
| | d | Ergonomic |
| | e | You can move the paper |
| | f | It does not do what you want not. |
| | g | Fully accessible everywhere |
| 6 | a | Similar to hand |
| | b | Clean and precise erasing |
| | c | Fast |
| | d | The output is already digitized in the computer |
| | e | A little bit uncomfortable |
| | f | Easy to understand |
| | g | Does not consume real paper or pencil |
| | h | Limitless drawing space and includes zooming facilities |
| | i | Worse than hand for fast sketches, and worse than CAD for finished drawings |
| 7 | a | It's more complex to draw with a mouse than with pen. |
| | b | Pen is more precise than mouse. |
| | c | Pen is more synchronized with cursor than mouse. |
| | d | Straight lines are easier with mouse than with pen |
| | e | Curved lines are easier with pen than with mouse |
| 8 | a | Lines are perfect |
| | b | Easy to add geometrical constraints |
| | c | Easy to dimension |
| | d | Easy to transform sketches into 3D models |
| | e | The drawing can be edited a posteriori. |
| | f | Allows dimensioning / Requires dimensioning |
| | g | Requires training |
| 9 | a | Tablet is a little bit uncomfortable |
| | b | Tablet requires more training |
| | c | Tablet is embarrassing for left-handed. |

**Table 2:** *Answers to questions 5 to 9 listed from more to less frequent.*

Our initial distinction between beginners and experts seems wrong if we simply compare their average previous experiences: 3.2 vs. 2.9 in hand; 0 vs. 0.4 in Paint/tablet and 2.9 vs. 2.4 in SolidEdge environment. The explanation to this apparent contradiction can be found by comparing execution times: experts were correctly considered so, at least in sketching; because they required much less time than beginners to achieve a good solution both when drawing by hand and when drawing in a Paint/tablet environment.

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| Respondent | Previous experience H | Previous experience P/t | Previous experience S/E | Execution score Hand (H) A | Hand (H) B | Hand (H) C | Hand (H) D | Hand (H) Average | Paint/tablet (P/t) A | Paint/tablet (P/t) B | Paint/tablet (P/t) C | Paint/tablet (P/t) D | Paint/tablet (P/t) Average | ABS(H-P/t) | SolidEdge (S/E) A | SolidEdge (S/E) B | SolidEdge (S/E) C | SolidEdge (S/E) D | SolidEdge (S/E) Average | P/m A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B01 | 3,56 | 0 | 3,4 | 3 | 3 | 3 | 3 | 3,0 | 2 | 3 | 3 | 3 | 2,8 | 0,3 | 3 | 3,5 | 3,5 | 3,5 | 3,4 | 2,0 |
| B02 | 2 | 0 | 2,9 | 3 | 2,5 | 2 | 2,5 | 2,5 | 1 | 1,5 | 1 | 1 | 1,1 | 1,4 | 3,5 | 3,5 | 3 | 3 | 3,3 | 3,0 |
| B03 | 3,32 | 0 | 2,9 | 2 | 2 | 2 | 2,5 | 2,1 | 3,5 | 2,5 | 2,5 | 2,5 | 2,8 | 0,6 | 3,5 | 3,5 | 4 | 4 | 3,8 | 3,0 |
| B04 | 2,76 | 0 | 2,0 | 3 | 3 | 2,5 | 2,5 | 2,8 | 3,5 | 3,5 | 3 | 3 | 3,3 | 0,5 | 4 | 3,5 | 2,5 | 3,5 | 3,4 | 3,0 |
| B05 | 3,96 | 0 | 3,6 | 3,5 | 3,5 | 3,5 | 4 | 3,6 | 2,5 | 3,5 | 3 | 3,5 | 3,1 | 0,5 | 3,5 | 4 | 3,5 | 4 | 3,8 | 3,5 |
| B06 | 3,64 | 0 | 3,1 | 2 | 2,5 | 1,5 | 2 | 2,0 | 2,5 | 3 | 2,5 | 3 | 2,8 | 0,8 | 3 | 2,5 | 2,5 | 3 | 2,8 | 3,0 |
| B07 | 2,16 | 0 | 2,5 | 3 | 3 | 3 | 2,5 | 2,9 | 2 | 3 | 1,5 | 2 | 2,1 | 0,8 | 3,5 | 3,5 | 4 | 3,5 | 3,6 | 3,0 |
| B08 | 3,96 | 0 | 3,5 | 4 | 4 | 4 | 4 | 4,0 | 3,5 | 3,5 | 3,5 | 4 | 3,6 | 0,4 | 2,5 | 3,5 | 4 | 4 | 3,5 | 4,0 |
| B09 | 3,44 | 0 | 3,1 | 3 | 3 | 3 | 3,5 | 3,1 | 3 | 3 | 3,5 | 3 | 3,1 | 0,0 | 3,5 | 3 | 3 | 4 | 3,4 | 2,0 |
| B10 | 3,28 | 0 | 2,7 | 1,5 | 2 | 1 | 2,5 | 1,8 | 3 | 2 | 2 | 2 | 2,3 | 0,5 | 3 | 3 | 3,5 | 3,5 | 3,3 | 3,0 |
| B11 | 3,12 | 0 | 1,6 | 2,5 | 2,5 | 2,5 | 3 | 2,6 | 1,5 | 2 | 2 | 3 | 2,1 | 0,5 | 3,5 | 2,5 | 4 | 4 | 3,5 | 2,5 |
| B12 | 3,92 | 0 | 3,2 | 3 | 3 | 3 | 3 | 3,0 | 3,5 | 4 | 3,5 | 3,5 | 3,6 | 0,6 | 4 | 3,5 | 3,5 | 2,5 | 3,4 | 4,0 |
| B13 | 3,72 | 0 | 3,3 | 3 | 3 | 2,5 | 3 | 2,9 | | 3,5 | 3 | 3 | 3,2 | 0,3 | 3,5 | 2 | 3,5 | 3 | 3,0 | 3,0 |
| B14 | 2,56 | 0 | 2,6 | 2,5 | 2 | 1 | 2 | 1,9 | 3 | 3 | 2 | 1,5 | 2,4 | 0,5 | 3,5 | 3,5 | 3 | 4 | 3,5 | 3,5 |
| B15 | 1,96 | 0 | 3,4 | 1,5 | 1 | 2 | 2 | 1,6 | 2,5 | 1 | 1,5 | 2,5 | 1,9 | 0,3 | 3 | 4 | 3 | 3,5 | 3,4 | 3,5 |
| B16 | 3,76 | 0 | 3,6 | 2,52 | 2,5 | 3 | 3 | 2,8 | 4 | 3 | 2,5 | 2,5 | 3,0 | 0,2 | 2,5 | 4 | 4 | 3 | 3,4 | 3,0 |
| B17 | 2,52 | 0 | 2,6 | 3 | 3,5 | 3 | 3 | 3,1 | 1,5 | 3,5 | 3 | 3 | 2,8 | 0,4 | 2,5 | 2,5 | 2,5 | 3 | 2,6 | 3,0 |
| B18 | 2,64 | 0 | 2,1 | 2 | 2,5 | 3 | 2,5 | 2,5 | 2 | 2,5 | 1,5 | 2 | 2,0 | 0,5 | 3 | 2 | 3 | 4 | 3,0 | |
| B19 | 2,32 | 0 | 3,1 | 3 | 3 | 3,5 | 2,5 | 3,0 | 3,5 | 3,5 | 3,5 | 2,5 | 3,3 | 0,3 | 3 | 3 | 4 | 3 | 3,3 | 3,5 |
| B20 | 3,72 | 0 | 3,2 | 2,5 | 2,5 | 2 | 2 | 2,3 | 1,5 | 3 | 1 | 2 | 1,9 | 0,4 | 3 | 2,5 | 1 | 1 | 1,9 | 3,5 |
| B21 | 3,24 | 0 | 3,1 | 2 | 2 | 1,5 | 2 | 1,9 | 2,5 | 3,5 | 3,5 | 3,5 | 3,3 | 1,4 | 2 | 2 | 2,5 | 3,5 | 2,5 | 3,5 |
| B22 | 4 | 0 | 3,7 | 3 | 3 | 3,5 | 3,5 | 3,3 | 3,5 | 4 | 3,5 | 4 | 3,8 | 0,5 | 2,5 | 2,5 | 4 | 3,5 | 3,1 | 4,0 |
| E01 | 2,0 | 0 | 4,0 | 3 | 2,5 | 2 | 2 | 2,4 | 2 | 2 | 1,5 | 1,5 | 1,8 | 0,6 | 3 | 3,5 | 3,5 | 3,5 | 3,4 | 3,0 |
| E02 | 4,0 | 0 | 0,0 | 3,5 | 3,5 | 3,5 | 3,5 | 3,5 | 3,5 | 4 | 3,5 | 3,5 | 3,6 | 0,1 | 3,5 | 3,5 | 2,5 | 3,5 | 3,3 | 2,5 |
| E03 | 1,0 | 2 | 4,0 | 2,5 | 3 | 2 | 1,5 | 2,3 | 2 | 3 | 3,5 | 2 | 2,6 | 0,4 | 3,5 | 3,5 | 3,5 | 3,5 | 3,5 | 3,0 |
| E04 | 4,0 | 0 | 0,0 | 4 | 4 | 3,5 | 3,5 | 3,8 | 4 | 4 | 4 | 4 | 4,0 | 0,3 | 3 | 3 | 3,5 | 4 | 3,4 | 4,0 |
| E05 | 3,0 | 0 | 1,0 | 2,5 | 2,5 | 2 | 2,5 | 2,4 | 3,5 | 3,5 | 3,5 | 4 | 3,6 | 1,3 | 2,5 | 4 | 3,5 | 3,5 | 3,4 | 4,0 |
| E06 | 4,0 | 0 | 2,0 | 2 | 3 | 2 | 3 | 2,5 | 3 | 3 | 3 | 3 | 3,0 | 0,5 | 3,5 | 4 | 2,5 | 3 | 3,3 | 4,0 |
| E07 | 3,0 | 1 | 4,0 | 3 | 3 | 2,5 | 2 | 2,6 | 3 | 3,5 | 2,5 | 2,5 | 2,9 | 0,3 | 3 | 3 | 3 | 4 | 3,3 | 1,0 |
| E08 | 3,0 | 1 | 4,0 | 4 | 4 | 3,5 | 4 | 3,9 | 4 | 3,5 | 4 | 3 | 3,6 | 0,3 | 3 | 4 | 3,5 | 4 | 3,6 | 3,5 |
| E09 | 2,0 | 0 | 3,0 | 3,5 | 3,5 | 3,5 | 3,5 | 3,5 | 3,5 | 3,5 | 4 | 4 | 3,8 | 0,3 | 4 | 4 | 4 | 4 | 4,0 | 3,5 |
| Average | 3,1 | 0,1 | 2,8 | 2,8 | 2,8 | 2,6 | 2,8 | 2,8 | 2,8 | 3,1 | 2,8 | 2,8 | 2,9 | 0,5 | 3,2 | 3,2 | 3,3 | 3,5 | 3,3 | 3,2 |
| B's | 3,2 | 0,0 | 2,9 | 2,7 | 2,7 | 2,5 | 2,8 | 2,7 | 2,6 | 3,0 | 2,5 | 2,7 | 2,7 | 0,5 | 3,1 | 3,1 | 3,3 | 3,4 | 3,2 | 3,2 |
| E's | 2,9 | 0,4 | 2,4 | 3,1 | 3,2 | 2,7 | 2,8 | 3,0 | 3,2 | 3,3 | 3,3 | 3,1 | 3,2 | 0,4 | 3,2 | 3,6 | 3,3 | 3,7 | 3,4 | 3,2 |

| Respondent | Time Hand (H) A | Hand (H) B | Hand (H) C | Hand (H) D | Hand (H) Average | Paint/tablet (P/t) A | Paint/tablet (P/t) B | Paint/tablet (P/t) C | Paint/tablet (P/t) D | Paint/tablet (P/t) Average | SolidEdge (S/E) A | SolidEdge (S/E) B | SolidEdge (S/E) C | SolidEdge (S/E) D | SolidEdge (S/E) Average | P/m A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B01 | 3 | 4,5 | 6 | 9 | 5,6 | 9,5 | 12 | 12 | 14 | 11,9 | 8,5 | 13 | 4 | 10 | 8,9 | 9,0 |
| B02 | 3 | 4 | 3 | 7 | 4,3 | 8 | 7 | 5 | 12 | 8,0 | 4 | 11 | 2 | 9 | 6,5 | 6,0 |
| B03 | 2,5 | 2 | 2 | 3 | 2,4 | 5 | 5 | 4 | 5,5 | 4,9 | 3,5 | 5 | 4,5 | 6 | 4,8 | 4,0 |
| B04 | 5 | 4 | 5 | 8 | 5,5 | 10 | 8 | 10 | 10 | 9,5 | 5 | 12 | 12 | 13 | 10,5 | 8,0 |
| B05 | 4 | 4 | 8 | 9 | 6,3 | 8 | 6 | 5 | 7 | 6,5 | 4 | 9 | 4 | 8 | 6,3 | 7,0 |
| B06 | 2,5 | 4 | 1 | 6,5 | 3,5 | 4 | 5 | 4,5 | 9 | 5,6 | 4 | 5 | 2 | 5 | 4,0 | 5,0 |
| B07 | 5 | 7 | 5 | | 5,7 | 13 | 10 | 7 | 8 | 9,5 | 5 | 10 | 5 | 10 | 7,5 | 16,0 |
| B08 | 6 | 10 | 12 | 16 | 11,0 | 10 | 9 | 6 | 8 | 8,3 | 5 | 20 | 9 | 16 | 12,5 | 6,0 |
| B09 | 3 | 8 | 6 | 12 | 7,3 | 5 | 10 | 8 | 11 | 8,5 | 4 | 7 | 5 | 9 | 6,3 | 5,0 |
| B10 | 5 | 8 | 6 | 9 | 7,0 | 12 | 17 | 10 | 11 | 12,5 | 5 | 7 | 3 | 6 | 5,3 | 12,0 |
| B11 | 3 | 5 | 9 | 9 | 6,5 | 3,5 | 7 | 8 | 8 | 6,6 | 4 | 7 | 4 | 7 | 5,5 | 4,0 |
| B12 | 7 | 6 | 8 | 9 | 7,5 | 7 | 8 | 8 | 10 | 8,3 | 5 | 6 | 4 | 4 | 4,8 | 4,0 |
| B13 | 6 | 8 | 12 | 15 | 10,3 | 4 | 5 | 5 | 5 | 4,8 | 5 | 6 | 4 | 5 | 5,0 | |
| B14 | 2 | 3 | 3 | 5 | 3,3 | 5 | 10 | 12 | 9 | 9,0 | 5 | 10 | 8 | 7 | 7,5 | 8,0 |
| B15 | 3 | 4 | 5 | 7 | 4,8 | 10 | 7 | 4 | 9 | 7,5 | 3 | 4 | 4 | 5 | 4,0 | 9,0 |
| B16 | 6 | 8 | 8 | 10 | 8,0 | 7 | 7 | 3 | 8 | 6,3 | 4 | 5 | 3 | 10 | 5,5 | 12,0 |
| B17 | 5 | 9 | 8 | 11 | 8,3 | 10 | 10 | 10 | 11 | 10,3 | 5 | 7 | 5 | 10 | 6,8 | 8,0 |
| B18 | 3 | 7 | 5 | 7 | 5,5 | 5 | 7 | 9 | 10 | 7,8 | 6 | 10 | 25 | 5 | 11,5 | 5,0 |
| B19 | 4,5 | 7 | 9 | 9 | 7,4 | 6 | 7 | 5 | 6 | 6,0 | 5,5 | 9 | 7 | 8 | 7,4 | 6,0 |
| B20 | 5 | 10 | 15 | 20 | 12,5 | 10 | 16 | 3 | 18 | 11,8 | 5 | 7 | 2,5 | 10 | 6,1 | 10,0 |
| B21 | 8 | 8 | 3 | 8 | 6,8 | 8 | 5 | 6 | 7 | 6,5 | 4 | 8 | 4 | 10 | 6,5 | 7,0 |
| B22 | 5 | 10 | 13 | 10 | 9,5 | 10 | 8 | 8 | 12 | 9,5 | 7 | 11 | 5 | 10 | 8,3 | 15,0 |
| E01 | 1,5 | 3 | 2 | 3,5 | 2,5 | 2,5 | 4,5 | 2,5 | 4 | 3,4 | 4 | 11 | 6,5 | 6,5 | 7,0 | 3,0 |
| E02 | 1 | 2 | 2 | 4 | 2,3 | 3 | 4 | 2 | 5 | 3,5 | 14 | 22 | 14 | 28 | 19,5 | 5,0 |
| E03 | 2 | 4 | 3 | 4 | 3,3 | 2,5 | 3,5 | 3 | 4 | 3,3 | 3,5 | 6 | 2 | 3 | 3,6 | 2,5 |
| E04 | 2 | 3,5 | 2,5 | 3,5 | 2,9 | 5 | 10 | 6 | 7 | 7,0 | 2 | 5,5 | 2,5 | 6 | 4,0 | 6,0 |
| E05 | 3 | 4 | 4 | 6 | 4,3 | 3 | 4 | 3 | 8 | 4,5 | 6 | 4 | 6 | 11 | 6,8 | 4,0 |
| E06 | 1 | 2,5 | 2 | 2 | 1,9 | 1 | 1,5 | 0,5 | 1,5 | 1,1 | 5 | 3 | 6 | 7 | 5,3 | 2,0 |
| E07 | 1,5 | 2 | 2 | 3,5 | 2,3 | 2 | 2 | 1,5 | 3 | 2,1 | 3 | 4 | 2 | 4,5 | 3,4 | 2,0 |
| E08 | 5 | 5 | 4 | 7 | 5,3 | 1,5 | 3,5 | 2 | 5 | 3,0 | 4 | 7 | 6 | 10 | 6,8 | 4,5 |
| E09 | 2 | 4 | 3 | 6 | 3,75 | 2,5 | 5 | 3 | 6 | 4,13 | 2 | 5 | 3,5 | 8,3 | 4,7 | 5 |
| Average | 3,7 | 5,5 | 5,7 | 8,0 | 5,7 | 6,2 | 7,2 | 5,7 | 8,1 | 6,8 | 4,8 | 8,3 | 5,6 | 8,6 | 6,8 | 6,7 |
| B's | 4,4 | 6,4 | 6,9 | 9,5 | 6,8 | 7,7 | 8,5 | 6,9 | 9,5 | 8,1 | 4,8 | 8,6 | 5,7 | 8,3 | 6,9 | 7,9 |
| E's | 2,1 | 3,3 | 2,7 | 4,4 | 3,1 | 2,6 | 4,2 | 2,6 | 4,8 | 3,6 | 4,8 | 7,5 | 5,4 | 9,4 | 6,8 | 3,8 |

| Respondent | Easy (1) to difficult (4) A | B | C | D | Most (1) to less difficult (4) More lines | More curves | Less symmetry | More angles | Best result for every sketch A | B | C | D | Simple (1) to complex (4) H | P/m | P/t | S/E |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B01 | 1 | 2 | 3 | 4 | 4 | 1 | 2 | 3 | s | s | s | s | 1 | 4 | 3 | 2 |
| B02 | 4 | 2 | 3 | 1 | 3 | 1 | 2 | 4 | p | h | h | s | 1 | 4 | 3 | 2 |
| B03 | 1 | 3 | 2 | 4 | 2 | 1 | 3 | 4 | h | h | h | s | 1 | 4 | 3 | 2 |
| B04 | 1 | 2 | 3 | 4 | 4 | 1 | 2 | 3 | s | s | s | s | 2 | 4 | 3 | 1 |
| B05 | 1 | 3 | 2 | 4 | 4 | 1 | 3 | 2 | p | p | h | h | 1 | 4 | 3 | 2 |
| B06 | 1 | 3 | 2 | 4 | 1 | 2 | 4 | 3 | s | s | p | s | 2 | 4 | 3 | 1 |
| B07 | 2 | 1 | 4 | 3 | 2 | 1 | 3 | 4 | s | h | s | p | 2 | 4 | 3 | 1 |
| B08 | 1 | 4 | 2 | 3 | 4 | 1 | 2 | 3 | s | p | p | h | 1 | 3 | 2 | 4 |
| B09 | 1 | 2 | 3 | 4 | 4 | 1 | 2 | 3 | h | p | s | s | 1 | 4 | 3 | 2 |
| B10 | 1 | 2 | 4 | 3 | 2 | 1 | 3 | 4 | p | h | s | s | 2 | 4 | 3 | 1 |
| B11 | 1 | 2 | 4 | 3 | 3 | 1 | 4 | 2 | s | s | s | s | 1 | 4 | 3 | 2 |
| B12 | 1 | 2 | 3 | 4 | 4 | 1 | 2 | 3 | p | s | s | s | 2 | 4 | 3 | 1 |
| B13 | 4 | 3 | 1 | 2 | 4 | 1 | 2 | 3 | s | h | s | s | 2 | 4 | 3 | 1 |
| B14 | 1 | 2 | 3 | 4 | 4 | 1 | 3 | 2 | s | s | s | s | 2 | 3 | 4 | 1 |
| B15 | 1 | 2 | 3 | 4 | 4 | 1 | 3 | 2 | s | s | s | s | 2 | 3 | 4 | 1 |
| B16 | 1 | 2 | 4 | 3 | 2 | 1 | 3 | 4 | s | s | s | s | 3 | 4 | 2 | 1 |
| B17 | 1 | 2 | 3 | 4 | 4 | 1 | 3 | 2 | s | s | s | s | 2 | 3 | 4 | 1 |
| B18 | 3 | 4 | 1 | 2 | 4 | 3 | 1 | 2 | h | s | p | h | 2 | 4 | 3 | 1 |
| B19 | 4 | 3 | 1 | 2 | 2 | 1 | 3 | 4 | s | h | h | s | 2 | 4 | 3 | 1 |
| B20 | 1 | 2 | 3 | 4 | 4 | 1 | 2 | 3 | h | s | s | s | 4 | 2 | 3 | 1 |
| B21 | 1 | 3 | 2 | 4 | 4 | 1 | 2 | 3 | p | s | s | h | 2 | 4 | 3 | 1 |
| B22 | 1 | 2 | 3 | 4 | 4 | 1 | 2 | 3 | | | | | 3 | 1 | 2 | 4 |
| E01 | 1 | 3 | 2 | 4 | 3 | 1 | 2 | 4 | s | s | s | s | 1 | 4 | 2 | 3 |
| E02 | 1 | 2 | 4 | 3 | 1 | 2 | 4 | 3 | p | h | h | h | 1 | 4 | 2 | 3 |
| E03 | 1 | 4 | 3 | 2 | 1 | 3 | 4 | 2 | s | s | s | s | 1 | 3 | 2 | 4 |
| E04 | 1 | 3 | 2 | 4 | 3 | 1 | 4 | 2 | h | h | h | h | 1 | 3 | 4 | 2 |
| E05 | 1 | 2 | 3 | 4 | 4 | 1 | 2 | 3 | s | s | s | s | 1 | 4 | 2 | 3 |
| E06 | 1 | 3 | 2 | 4 | 3 | 1 | 4 | 2 | h | h | h | h | 1 | 3 | 2 | 4 |
| E07 | 1 | 3 | 2 | 4 | 2 | 1 | 3 | 4 | p | p | p | p | 2 | 4 | 1 | 3 |
| E08 | 1 | 3 | 2 | 4 | 4 | 2 | 3 | 1 | s | s | s | s | 1 | 3 | 2 | 4 |
| E09 | 1 | 2 | 4 | 3 | 4 | 1 | 2 | 3 | s | s | s | s | 1 | 3 | 2 | 4 |
| Average | 1,6 | 2,9 | 3,1 | 3,9 | 3,6 | 1,4 | 3,1 | 3,3 | | | | | 1,9 | 4,1 | 3,1 | 2,4 |
| B's | 1,5 | 2,4 | 2,7 | 3,4 | 3,3 | 1,1 | 2,5 | 3,0 | | | | | 1,9 | 3,6 | 3,0 | 1,5 |
| E's | 1,0 | 2,8 | 2,7 | 3,6 | 2,8 | 1,4 | 3,1 | 2,7 | | | | | 1,1 | 3,4 | 2,1 | 3,3 |

**Table 3:** *The numerical results linked to questions 1 to 4 from the questionnaire.*

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Notice that neither beginners nor experts generated excellent solutions, as they both knew excellence being out of place when sketching. But, when drawing by hand, experts required just 3.1 minutes, instead of up to 6.8 minutes required by beginners. Besides, they got better hand drawings (3.0) than beginners (2.7). A similar difference can be observed in Paint/tablet environment. Even in the Paint/mouse environment appeared similar differences. However, no significant differences were measured between beginners and experts when drawing with SolidEdge.

From the analysis of answers to question 1, we can conclude that our attempt to obtain four examples representative of four different levels of difficulty was validated by the arrangement of the respondents: example A was considered the least difficult (average 1.6), example B was the next (2.9), example C was the third (3.1) and example D was rated to be the most difficult (3.9). However, it should be pointed out that experts rated example C to be a little easier than example B (2.7 vs. 2.8). Besides we gained an interesting insight on criteria to determining what makes sketches more difficult: more curves (1.4); less symmetry (3.1), more angles (3.3) and more lines (3.6). Again, experts disagree, as they consider more angles being less problematic than losing symmetry (2.7 vs. 3.1).

The first question addressed in this study was whether or not a paper-and-pencil prescriptive sketching environment is more or less usable than a “digital” prescriptive sketching environment. According to the results, paper-and-pencil is still considered to be easier and “handier” than our simulation of a minimalist digital prescriptive sketching tool achieved through Microsoft’s Paint limited to just using paintbrush and rubber. Hand was rated 1.9; second was SolidEdge (2.4); Paint with tablet was third (3.1) and Paint with mouse was last (4.1). However, the disagreement between beginners and experts is quite significant. Beginners rated (S/E, H, P/t, P/m) while experts rated (H, P/t, S/E, P/m). In spite of beginners feeling more comfortable with SolidEdge (because “lines are perfect”…), the first conclusion is that both groups consider Paint/tablet to be more complex than hand.

However, none of the respondents had had previous experience with tablet PC’s. Hence, one interesting question for a future detailed study is to determine whether or not this feeling disappears after a reasonable training time.

Actually, those feelings from respondents do no match with the objective fact that, although the execution time was a little bit greater (almost 20%, i.e. from 5.7 to 6.8 minutes), hand drawings achieved similar scores (2.8) to Paint/tablet (2.9). In fact, the differences (ABS (H-Pt)) were below the scoring minimum increment (0.5) in all but three cases. Hence, respondents achieved similar results, needing more time, but in an environment completely new to almost all of them. Besides, the time require to finish the drawings in the Paint/tablet environment (without previous experience) was similar to the time required to complete SolidEdge drawings (where most of them had had extensive training).

Certainly, this result is just an approach, mainly because our “simulation” of a digital prescriptive sketch environment may contain some hidden and unexpected significant differences with current or future digital prescriptive sketching environments. However, we can infer that currently available systems are going to still be rejected (in terms of usability) by current designers, as they are clearly less simple than our simulated environment, which was considered by the respondents not as usable as paper-and-pencil.

Some respondents included observations that can give some light about their rejection. They considered that the small uncoupling between tablet PC’s pen and cursor (mainly due to bad screen calibration and the thickness of the screen that produces a physical separation between pen and cursor) distracts the draftsmen and reduces the accuracy of sketches. A future taks is exploring whether uncoupling between tablet PC's pen and cursor could be skipped by using other devices. However, the unfamiliarity of the users with Tablet PCs may have left them disliking them. According to this, the hypothesis to be validated or rejected by future studies should be that in the long run there is little *fundamental* difference between the interface provided by a tablet PC and a piece of paper.

The second question addressed in this study was measuring the validity of the belief that current “pseudo-sketchers” embedded into CAD applications can substitute hand made prescriptive sketches without loss of usability, at the time they increase functionality by semi-automatically aiding the user in creating the final model from the different views of the sketch.

As far as it is obvious that CAD environment gives users more functionality than paper-and-pencil, and because the SolidEdge output is not a sketch but a final line-drawing, we expected the respondents to massively answer question 3 by signalling SolidEdge to be the tool with which they had obtained the best version of every drawing (perhaps with the exception of those experts that rated themselves as excellent in sketching and completely null in SolidEdge). Maybe the question was not clear for the respondents, but the dispersion in the answers still seems to indicate that the belief in the strength of CAD versus hand-made sketches is not so obvious, or, at least, does not compensate its lack of usability. Indeed, comparing execution times in both environments, hand (H) times are very similar to SolidEdge (S/E) times for beginners (6.8 vs. 6.9) but much lower for experts (3.1 vs. 6.8). Besides, experts required much less time in all Paint environments (both with tablet –Pt-, and mouse –Pm-) than they required with SolidEdge. Thus, the time required to complete a drawing in this entirely new environment is a little bit greater for beginners, but clearly less for experts than the time required in the CAD environment. The Bilda and Demirkan principle of “draw and then modify” seems a plausible reason for this. Besides, some respondents observed that sometimes the system captures false design intentions, i.e. sometimes imposes constraints not desired by the user (see answer 5f in table 2). In sum, the respondents seem to put in value the in-

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crease of functionality given by SolidEdge, but still notice the loss in usability. This apparently contradictory feeling should be investigated in more detail.

Some other interesting results arose from the study. The decision to exclude handwriting from our study, assuming that text processing belongs to a relatively separate research field and is mature enough for CAS environments, was partially validated by some comments of respondents that considered easy and precise the tablet PC input panel they used simply to write the files' names.

A surprising result was the translation to the mouse movement of some "trade tricks" typical of hand sketching, like obtaining almost straight lines by moving the mouse while the hand slides on the edge of the table and so on [BWM*03]. Besides, some users confessed they used the inertia of the mouse in order to move it simulating vertical and horizontal "T-square-like" movements. This "tricky" use of mouse explains why Paint with mouse was not massively considered worse than paint with tablet. Some comments support this observation, e.g. "painting with mouse is better for straight lines, while painting with tablet is better for curves". These trade tricks were not spontaneously translated to the tablet PC environment. It remains to be determined whether or not this is due to some significant difference in the attitude of the users, or it is simply due to some ergonomic failure associated to the tablets, the tables or the optional laptop coolers we enabled as bookrests for the test.

## 6. Conclusions

It was argued in the first part of the paper that CAD-based design of industrial products still requires prescriptive sketches. But sketches should be "digital" so as to be linked to the rest of the New Product Development tools (CAD, PLM, etc). Digital sketches are the natural output of computer-aided sketching (CAS) tools, which should become the new paradigm. Hence, in the second part of the paper, the usability and functionality requirements that CAS tools must provide have been compared against traditional paper and pencil sketching. Our pilot study concludes that CAS tools will replace traditional paper-and-pencil design *only after* being perceived by designer as having clearly equal or superior usability, which is not the case of current CAD pseudo-sketchers. In addition to confirming this currently accepted assertion, our study detected some key issues to be addressed by a more general study aimed at separately assessing usability and functionality of different hardware and software approaches.

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