Learning design sketching from animations and storyboards

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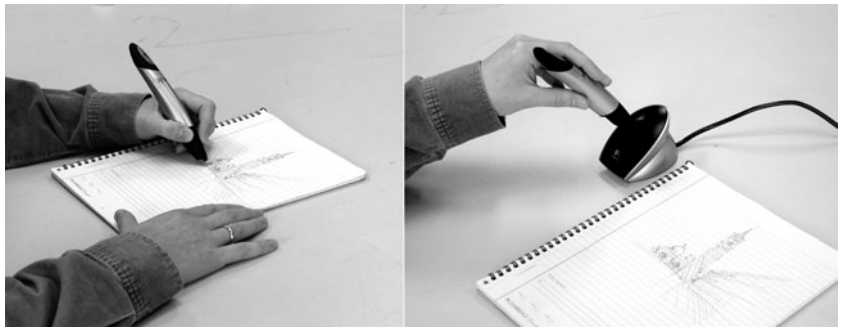
A digital pen-and-paper system that generates stroke-by-stroke animations was used to compare the perception of interactive animations versus printed storyboards. Design students studied a space-planning example as either an animation or a storyboard and then emulated the example in doing a similar problem. Students viewing the animations rather than the storyboards performed marginally better in terms of matching the example steps and meeting design quality criteria. Students may understand the process of design sketching, but may lack the skills to copy the steps. Emulating the solution requires both cognitive skills and graphic facility. While beginners could logically organize spatial adjacencies, they often radically resized required program areas to streamline geometry. After organizing building spaces, they lacked the graphic conventions to articulate architectural features, so they could not copy refinement steps. Subjects at all levels used approximately the same number of strokes, with more productive sketching from advanced subjects.

Keywords: teaching with technology, sketching, design teaching, Pen-based computing

1. Introduction

Design sketching remains a mysterious process. Expert designers see their work in large meta-steps, oblivious to implicit skills they employ. When they teach, they naturally gloss over subtasks that they find intuitive. Beginners need to see projects articulated into explicit substeps, as each represents a challenge and a potential misstep. By recording drawings with a digital pen-on-paper system, we can instantly generate animated sketches that reveal each step in the design process. This paper will discuss the effectiveness of these animated sketches for teaching design.

While stylus-based tablets are a common form of graphic input, mobile digital pens present another level of portability and accessibility. In testing their implications for design teaching, we were inspired by studies that show animations are more effective than static images for teaching physics [1, 2], that movement helps recall [3,4] and that picture recall is superior to word recall [5,6]. We wanted to see if these results held true for our digital pen animations. Underlying questions have been "What can we learn from the digital pen animations about design drawings?" and "How can we make the animations more effective for teaching?"



► Figure 1. Logitech Io Pen, a version of the Anoto pen-and-paper system.

TECHNOLOGY: the project uses the commercially available Logitech digital pen-and-paper to record how expert and student designers draw. The pen's camera captures the location of each mark in relationship to Anoto Technology's proprietary printed pattern, and then the pen's memory stores the sequence of vectors. After downloading the information from the pen through a USB port, one may view the drawings as an interactive animation on a Windows computer. In the Logitech IoReader 1.01 software, the image appears stroke by stroke in bright blue on ghosted light-grey lines of the completed drawing. While this project specifically uses a Logitech pen, its findings can be applied to animations generated by other stroke recording tools. Papers on the Anoto system explain technical details, describe applications, including handheld displays [7,8].

PRECEDENTS: In traditional architectural design teaching, the teacher reveals the design process by talking to the student while sketching. The teacher shows how to develop an idea through sketching, using the graphics

and words to respond to the student's questions [9]. To understand how designers use sketching, we looked at work examining how marks relate to design thinking [10,11], how marks are used for specific design operations [12] and how to parse drawing marks according to function [13] and connect them to cognitive processes [14]. The literature is split on how much of drawing facility comes from the environment vs. how much is innate ability. A person brings ability and responds to a specific training situation. 15]

Papers from both design and developmental psychology show specific methods for analysing the sequence of operations in a group of drawings and for evaluating sequence recall tasks [5]. In drawing, we are strongly influenced by our frame of reference – our background and recent memory shape the world we portray. For example, children shown a complex object pulled apart only draw the newly observed details if they have not already formulated a way to draw it whole [14]. In contrast, successful designers use sketching to transform ideas, reframe the problem, and allow creative solutions to break the original problem definition [16,11]. Digital pens let us easily collect graphic operations for teaching [17, 19] & examine the sequential operations in detail. The animation format fosters process comparisons and trend identification [18].

Our students have found the digital pen animations helpful for revealing expert approaches to sketching and for analysing their own efforts. The animations widen the range of what can be taught and facilitates digital sharing [19,20]. In collecting design drawings for teaching, we had to narrow the task scope to increase comparability between solutions. We devised a design problem composed of 3 short tasks: interior space-planning, lobby redesign and façade design. In winter and spring 2004, we collected 31 examples of the space-planning design task from diverse authors and ran pilot studies of how they were perceived. Subjects shown the same animation would parse it into a different number of steps and label them according to their training. [18]. Throughout 2005, standard tasks were given to students, faculty and professionals in a wide variety of workshop settings. This paper updates initial findings [21] with additional data and analysis.

1.1. Hypothesis

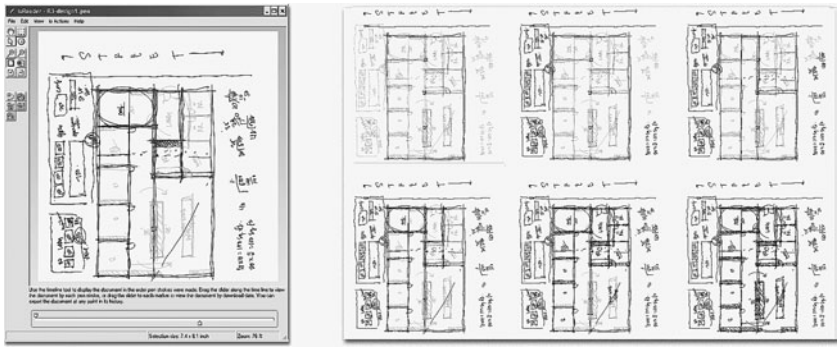
From these examples, we sought to determine whether interactively viewing the animated process would be more effective than viewing static examples. We guessed that people who interactively viewed an animated design solution would learn the steps in a design process better than people who look only at a static completed image.

2. Research method

To compare understanding of animation & storyboards, we looked at abilities to:

INTERPRET the design sequence by numbering given drawing operations in order
COPY the order of drawing operations
DESIGN to fulfill the problem requirements

Subjects were asked to first study a well-ordered planning example as a still image and then interpret it by putting a list of six given design operations in chronological order (a pre-test). Second, they were given the same drawn example as either an interactive animation or a printed six step tabloid size (~A3) storyboard. Third, they were asked to copy the steps in doing a similar space-planning problem. Finally, we asked the students to answer the initial step sequencing again (a post-test) to measure if there was any change in their design approach. We evaluated the quality of these solutions with a jury and evaluation criteria.



► Figure 2. An interactive Animation and a printed six-panel Storyboard of the design process example.

The narrowly constrained space-planning problem allows us to evaluate solutions according to rational criteria. Furthermore, the chosen example uses rational organization in a particularly deliberate step-by-step procedure that allows us to track students' emulation more easily. Most designers work in a more spontaneous fashion, commonly intermingling steps. For example, designers often label a space and articulate its elements in the midst of creating major zones.

For this trial, our subjects were thirty-two students with an average 2.5 years of architectural training who had been drawing about 10.5 years. For convenience we will use the names "Animation group" and the "Paper group." We tested them in groups of one to four viewing the same medium, with the same introduction to the pen technology and the project. All subjects were given a text description of an existing building with a specified list of rock-climbing gym spaces that had to fit in. We gave subjects 10 minutes to peruse the example and an additional 20 minutes to do the space-planning problem. This procedure yielded subject surveys and digital examples to analyse.

3. Data

To analyse the drawings, we looked at the subjects' sequence of design steps and developed a colour bar rating system. From the compiled data we were able to compare student's drawings from both the Paper and Animation groups.

3.1 Step sequencing survey

With twenty subjects, the Animation group performed slightly better than the Paper group at the task of chronologically ordering design steps. Table 1 summarizes how subjects chronologically ordered the design operations in both the pre-test and post-test. We measured how closely the subjects matched the original example by first subtracting the example's score from the average of each group, then summing the absolute value of these differences. A lower number shows a closer match to the original.

The pre-test shows that most students were able to guess the actual steps just from looking at the still image. However, the post-test does show that the average answer given by the Animation group was more accurate than the Paper group (post test variance from the actual steps of 0.9 vs. 1.8).

▼ Table 1. Step-Sequencing by subjects viewing an animation or paper storyboard

		All		Animation		Paper		
	Given Example	Average	Variance from given	Average	Variance from given	Average	Variance from given	Variance: Paper vs. Animation
PRE-TEST: Order of design operations after seeing still image								
Draw program clusters	2	2.4	0.4	2.2	0.2	2.8	0.8	greater
Define individual rooms	4	3.8	-0.2	4.1	0.1	3.5	-0.5	greater
Strengthen graphics	6	5.7	-0.3	5.7	-0.3	5.6	-0.4	greater
Label rooms	5	5.2	0.2	5.0	0.0	5.4	0.4	greater
Document existing site	1	1.4	0.4	1.5	0.5	1.3	0.3	less
Define major organizing lines	3	2.5	-0.5	2.5	-0.5	2.5	-0.5	same
Sum of absolute values of variances			1.9		1.5		2.8	greater
POST-TEST: Order of design operations after seeing animation or storyboard								
Draw program clusters	2			2.3	0.3	2.4	0.4	greater
Define individual rooms	4			3.8	-0.2	3.9	-0.1	less
Strengthen graphics	6			5.9	-0.1	5.9	-0.1	same
Label rooms	5			5.0	0.0	5.0	0.0	same
Document existing site	1			1.2	0.2	1.5	0.5	greater
Define major organizing lines	3			2.8	-0.3	2.4	-0.6	greater
Sum of absolute values of variances					0.9		1.8	greater

3.2. Design sequence colour-bars

To compare subjects' design processes we parsed each drawing into a sequence of colour-coded design operations. We used content categories because they are the most useful for conveying the actual work of design.

Suwa and Tversky support the idea that content information makes a richer protocol analysis [22]. By strictly defining the design steps, we created a reproducible coding scheme that produced consistent labeling by three members of the research team.

SITE INFORMATION lines indicate the given building and the area outside of the building, including columns, site boundaries, dimensions of site and north arrows.

PROGRAM lines show relative sizes of program areas and program adjacency relationships, i.e., abstract box or circle diagrams. They do not place the rooms inside the building envelope.

PARTI lines create simple diagrams defining the overall abstract building order.

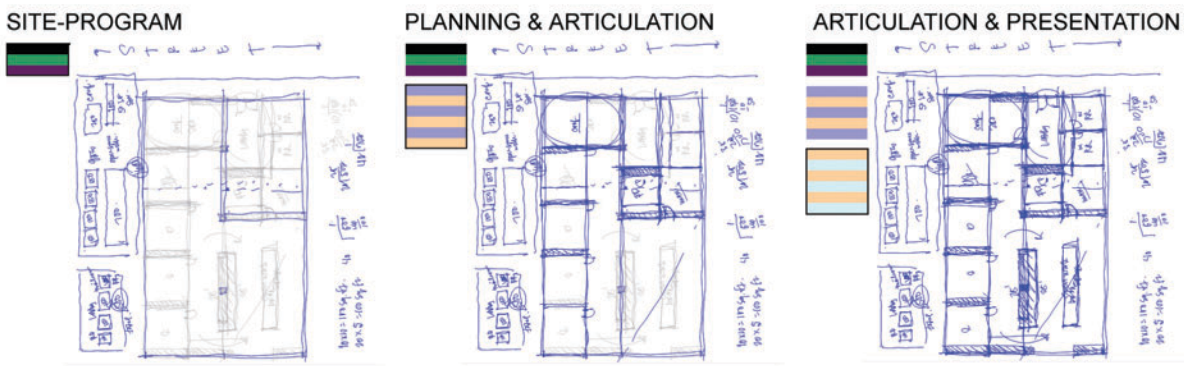
GRIDLINES help draw other lines and do not demark physical walls or site boundaries.

PLANNING lines organize the building into physical spaces such as initial wall boundary lines and stairs.

ARTICULATION lines define physical elements beyond walls and stairs, i.e., doors, windows and furnishings.

PRESENTATION lines are non-physical annotations such as text and symbols. Room labels alternated with planning lines are not called out as a separate step.

We recorded the chronological steps in Photoshop as labeled layers to create a verifiable visual record. To reveal the sequential pattern of operations, the steps were then recorded in Excel using conditional formatting to give each operation a distinct colour bar: SITE INFORMATION (black), PROGRAM (green), GRIDLINES (purple), PARTI (grey), PLANNING (light violet), ARTICULATION (light peach), PRESENTATION (light blue).



▲ Figure 3. Macro-steps in the original example.

After coding each drawing into a sequence of steps and generating the corresponding colour bars, we identified macro-steps, or larger organizational patterns of the basic steps that could be seen in the original:

1. SITE-PROGRAM: Initially the designer documents the problem's constraints of site and program. The designer visualizes the program by drawing areas to scale in two adjacency groups.

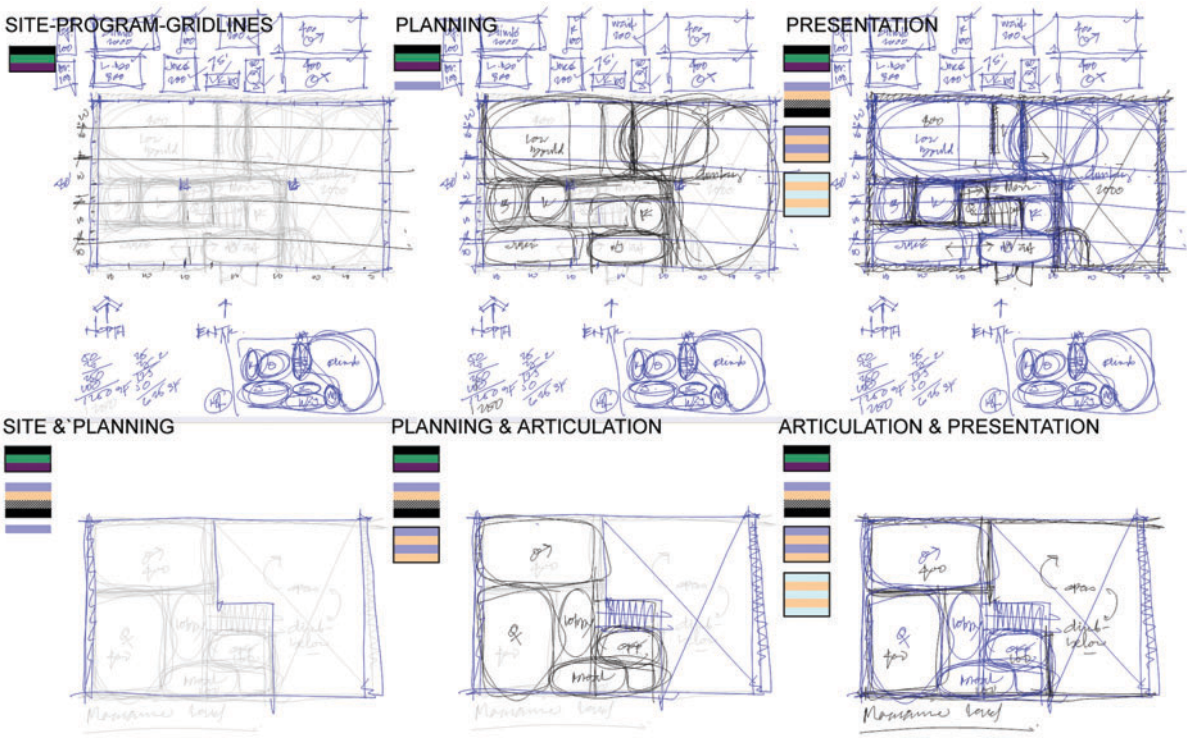
2. PLANNING-ARTICULATION: Calculating the total area for each group allows the designer to divide the overall space into two major zones. He experiments with how to split the space and decides to follow the column grid lines. He places the closed offices in a linear zone separate from the open office area. By enlarging the conference room to extend beyond the zone's width, he both meets the area requirement and increases the privacy of the work area.

3. ARTICULATION-PRESENTATION: The designer makes single-lines architectural by inserting doors and windows and then by doubling the wall lines and hatching them. To explain the drawing, he adds room labels and circulation arrows.

A time accurate version of the animation (translated to Scalable Vector Drawing .SVG format) reveals that the designer is able to quickly draw spaces in a series, encircle pre-conceived groups and label rooms. He takes time before placing the rooms in each zone. After pausing for consideration, he quickly draws a series of partitions, making only minor corrections.

To evalulate how well the students emulated the example, we looked for these patterns in the student copies.

▼ Figure 4. Macro-steps in a student copy.



1. SITE-PROGRAM lines alternately describe the site and program. They may contain traces of planning and gridlines.

2. PLANNING-ARTICULATION lines alternately describe building planning element articulation. They may contain traces of planning and presentation.

3. ARTICULATION-PRESENTATION lines alternately describe element articulation and presentation annotation. They may contain traces of planning.

We developed a six-point system to rate drawings according to how similar they were to the parent drawing. Each drawing could earn 3 points for presence of the macro steps and 3 points for order. Each subject drawing was given a point for the presence of each macro-step pattern, no matter where or how many times it occurs in the drawing. Also, each drawing was given points for order if a step occurred in the right sequence in the drawing process. For example, the expert drawing shows all three macro-steps in order so it gets 3 points for the presence of each step and 3 points for having all the steps in the correct order, yielding a perfect score of 6.

Figure 5 shows matching macro-steps with a thick black outline.

3.3. Quality evaluation

We used two measures to assess whether there was a difference in quality between the groups: jury ratings and quality criteria. A jury of four architectural design professors examined the printed sketch designs (mixed Paper and Animation samples) and rated them on a Likert scale from 1-6. In addition, the research team inspected each solution for quality criteria specific to the space-planning problem. While the jury blind-rated found the Paper and Animation groups as comparable in quality, each averaging 3.0. several quality criteria favored the Animation group.

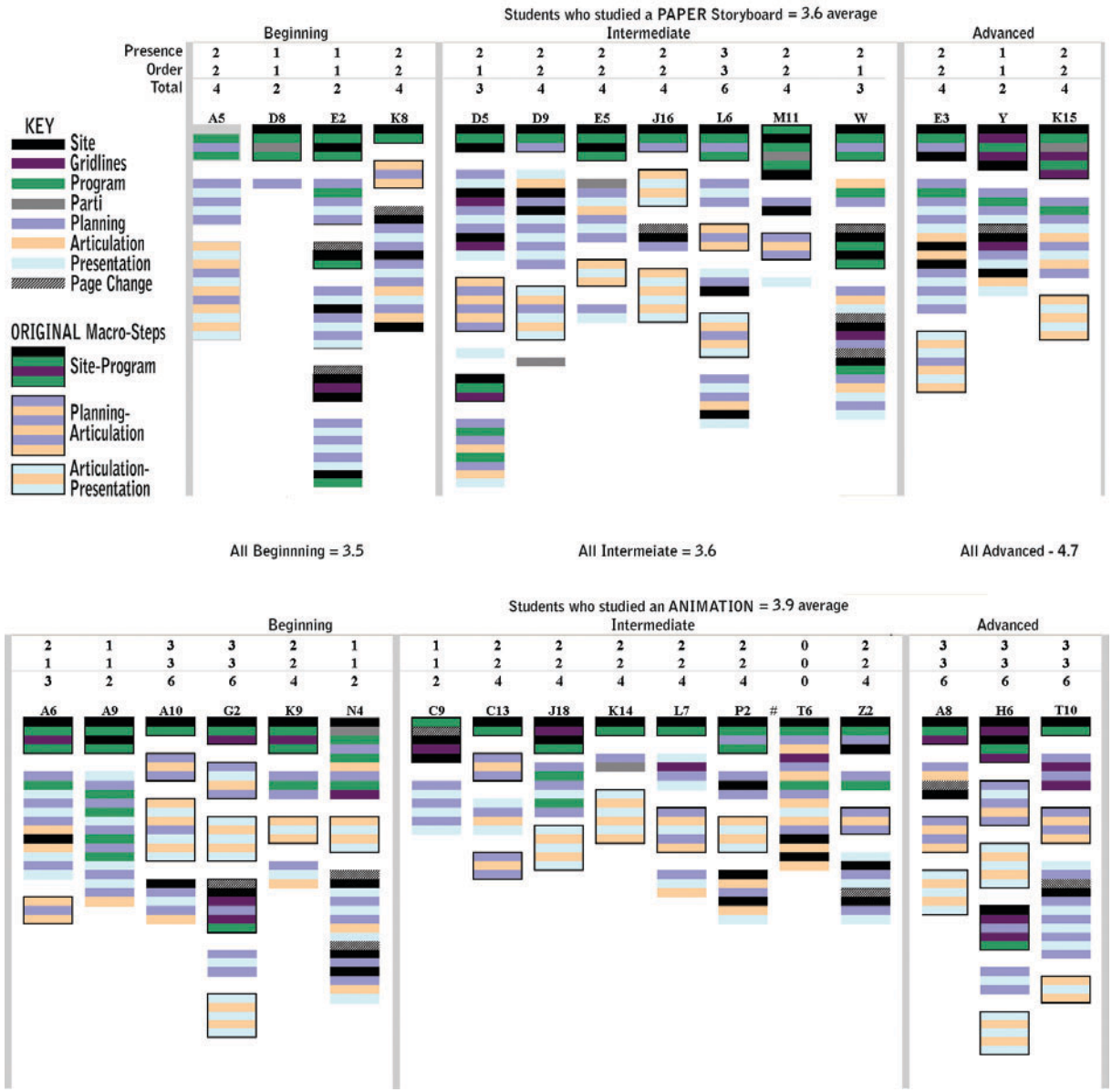
▼ Table 2. Quality criteria by Paper and Animation groups.

Quality Criteria	Average Animation Quality	Animation Standard Deviation	Average Paper Quality	Paper Standard Deviation	Difference (Animation – Paper)
Site drawn correctly	0.92	0.15	0.98	0.08	-6%
Program blocks drawn in clusters	0.62	0.47	0.56	0.47	6%
Program areas calculated	0.82	0.39	0.67	0.44	16%
Geometric zones	0.82	0.30	0.74	0.39	8%
Circulation compact and functional	0.70	0.25	0.63	0.41	7%
Draws more than one solution	0.31	0.46	0.64	0.47	-33%
Included mezzanine	0.89	0.30	0.60	0.51	29%
Program clustered logically	0.88	0.18	0.83	0.27	5%
All program spaces included	0.88	0.26	0.82	0.36	6%
Program areas sized correctly	0.77	0.25	0.47	0.31	30%
Graphic conventions used	0.60	0.32	0.39	0.39	21%
Total Criteria Score (max 11)	8.22	1.62	7.01	2.58	11%
Jury Rating (max 6)	2.94	1.18	2.97	1.44	0.00
TOTAL QUALITY SCORE (2x Jury + Criteria)*20/23	12.27	3.12	11.67	3.80	0.60

4. Analysis

The three quantitative analyses found small differences between the Animation and Paper groups. From our step sequencing survey, it remains unclear whether an animated or storyboard example increased students' ability to identify and recall a sequence of drawing steps. Our colour bar similarity analysis shows marginally better copying from an animation rather than from a storyboard. While the jury rated the quality of the groups' design sketches identical, the Animation group performed better on specific aspects of the space-planning task.

▼ Figure 5. Macro-step scoring of Paper and Animation groups.



4.1. Step survey

While the post-test shows better performance by the Animation group than the Paper group, the difference is not conclusive. The pre-test shows the Animation group had a pre-disposition to seeing the right answers, so it is unclear whether the representation type (animation vs. paper storyboard) made a difference. In considering pre-test versus post-test answers, the Animation group improved 0.6 (from 1.5 to .9), while the Paper group improved more: 1.0 (from 2.8 to 1.8).

Even though the students were able to order the steps properly, the time they took (7 to 10 minutes) shows that translating graphics into words is not trivial. For teaching, asking students to connect graphic steps to text labels could help generate a common understanding about the design process.

4.2. Sequence colour-bar matching: paper vs. animation

Our colour bar analysis shows a distinction between Animation and Paper groups; the Animation group imitated the step sequence of the expert drawing more accurately than the Paper group. Scoring each drawing according to presence and order of the Macro-steps, we found the average score for the 17 Animation samples was 2.0 out of a possible 3 points for presence of macro steps, 1.9 out of a possible three points for order of macro-steps, and 3.9 points total. The average score for the 15 Paper samples was 1.9 for presence, 1.7 for order, and 3.6 points total.

Given that scores ranged from 0 to 6.0 for a six point maximum range, the 0.3 difference in average score indicates a marginal separation between the results of the animated and storyboard drawings. A more significant correlation was found between levels of training.

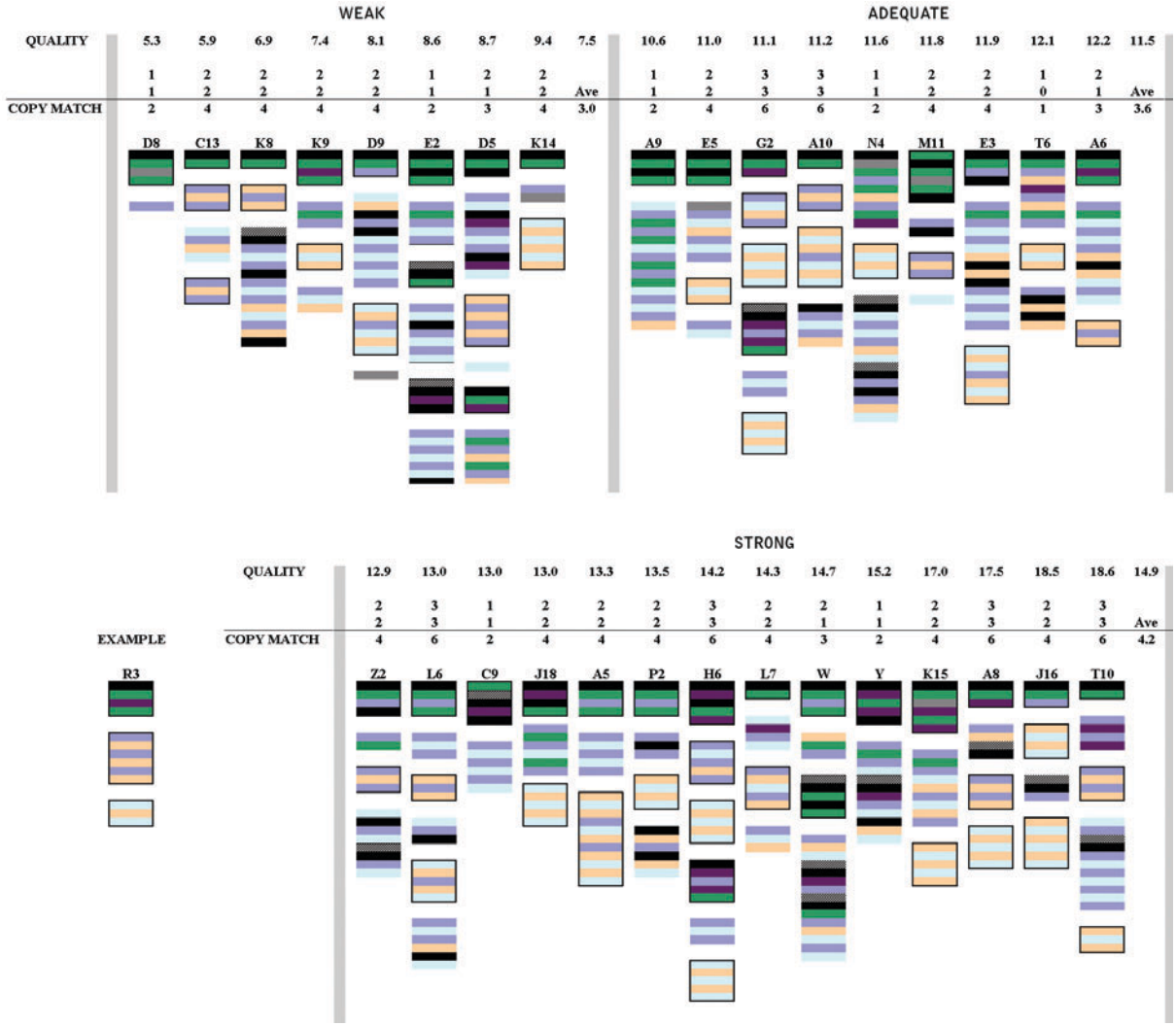
4.3. Sequence colour-bar matching and experience level

The colour-bar sequences reveal that greater experience allows advanced designers to copy the steps in the example more closely than beginners. When sorted by either the authors' experience level (number of years with architectural training) or the rated design drawing quality, the most advanced drawings came up with higher scores for matching the example sequence. Advanced designers having 5 years or more of education scored 4.7 while intermediate students scored 3.6 and beginners scored 3.5. We surmise that beginners could not replicate the example steps because they were less familiar with how to use symbols, line types or lineweight to describe architectural plan elements.

4.4. Sequence colour-bar matching and quality rating

The fact that skilled designers can mimic steps better is confirmed by examining the matching scores according to the rated quality of the

drawings (faculty jury scores and quality criteria). Those with low ratings (8 samples under 10) scored 3.0, those with medium ratings (9 samples rated 10 to 12.5) scored 3.6 and those with high ratings (17 samples rated 12.9-18.6) scored 4.2



▲ Figure 6. Sequence colour-bar matching and quality rating.

The narrow range of colour-bar sequence matching scores shows the limitation of using only design operation sequence to evaluate learning. While our colour-bar categories label the basic purpose of drawing operations, the sequence of colour bars cannot say how well the marks fulfill the larger design objectives. A better measure of how well the students copied the design example would include not only the order of mark intentions but also the progression of idea development and the quality of the resulting graphics. [10, 21]

4.5. Quality criteria

While the jury saw parity between the two groups, specific quality criteria reveal that the Animation group followed the example more closely than the Paper group (see Table 2).

MULTIPLE SOLUTIONS: The original expert example did not show alternative thumbnail layouts. The office layout problem's simplicity allowed drawing alternate arrangements on top of the existing plan footprint. 31% of the Animation group versus 64% of the Paper group varied from the expert example by creating alternative layout solutions. In this respect, those in the Animation group followed the example more closely. As the subjects seeing the paper storyboard took more freedom to do things independently, they may have been less engaged by the example.

NEED FOR MEZZANINE: Both the original office planning problem and the rock-gym planning problem required fitting program spaces into a given existing building. But whereas the given office design example fit all the spaces onto one floor, program spaces for the rock-gym program would not fit on the footprint and required an additional building level or mezzanine. 89% of Animation group versus 60% of the Paper group correctly created mezzanines for the extra program area. We surmise that those looking at the paper example had to spend more time interpreting the information in the example and had less time to reason about their own design solution. Recording how long each subject examined the expert example could reveal the amount of engagement.

PROGRAM AREA ACCURACY: While subjects generally included all of the program areas and got the program adjacencies correct, they commonly distorted program area sizes to follow the expert example's strong orthogonal zoning. Beginners often drew spaces too small, trying to squeeze them into a rigid order, rather than modifying the diagram or adjusting dimensions. More of the Animation group (77%) was able to roughly match the required program areas than the Paper group (47%). We again surmise that the clarity of the animation allowed the subjects to be more task-focused.

In short, the Animation group solutions followed specific aspects of the design example closer than the Paper group's but did not perceptible superiority.

5. Teaching through design process examples

Comparing space-planning designs made by beginners who did NOT see the example with those who did shows what can be taught by graphic example.

In either animated or storyboard format, the example was successful in showing the students how to visually document the problem constraints (site and program). It guided the students in creating geometrically organized rather than piecemeal plans, even if they squeezed or stretched requested room dimensions and adjacencies.

The quality criteria revealed more specifically what was easy and challenging for the subjects who looked at the example. Beginning to advanced students could draw site constraints, include all the program areas and cluster the program areas correctly. There was greatest variability in using graphic conventions, correctly sizing program areas, making compact circulation and including a mezzanine.

Quality Criteria	Average Beginner	Average Intermediate	Average Advanced
Site drawn correctly	0.89	0.96	1.00
Program blocks drawn in clusters	0.51	0.71	0.55
Program areas calculated	0.86	0.56	1.00
Geometric zones	0.81	0.71	1.00
Circulation compact and functional	0.56	0.69	0.83
Draws more than one solution	0.43	0.32	0.80
Included mezzanine	0.52	0.87	1.00
Program clustered logically	0.86	0.81	1.00
All program spaces included	0.88	0.82	0.95
Program areas sized correctly	0.60	0.60	0.83
Graphic conventions used	0.31	0.51	0.87
Total Criteria Score (max 11)	7.2	7.5	9.8
Jury Rating (max 6)	2.0	3.1	4.0
TOTAL QUALITY SCORE 20/23 (2x Jury + Criteria)*	9.8	12.0	15.5
Number of Strokes	562.8	566.5	584.7

◀ Table 3. Quality Criteria by Training Level with top gradients highlighted.

In many cases, the beginners were able to mimic the appearance of the graphics without grasping the essential process. Most vividly, students would draw the program area blocks to scale but would unrealistically squeeze down the size to create a clean geometric plan. Despite mimicking the calculation of the program areas, some did not create a mezzanine to accommodate what would not fit on one floor level.



◀ Figure 7. Competent example (left), undersized spaces with mislabeled areas (middle), naive graphics (right)

Many of the beginner's plans remained diagrammatic. Beginners cannot quickly apply architectural graphic conventions, their drawings lack architectural description. With greater facility in using these graphic shortcuts, experienced designers can more precisely describe and develop architectural features. Abilities to visualize and quickly test alternatives help them create efficient circulation patterns. Experienced designers are much more likely to employ alternative views to study the proposed design in another context or at another scale. They can then add information rather than reiterating what has already been established.

The digital sketches allow us to document the greater efficiency of advanced designers by comparing the number of strokes made by each subject. Automatic indexing shows a similar number of strokes used by beginning (563), intermediate (566) and advanced designers (585). Beginning designers spin their wheels by redrawing without adding information or by drawing alternatives that they cannot evaluate or refine. Advanced designers create more useful strokes; quickly evaluating and correcting what they draw. This correlates with the finding that experienced architects read more about non-visual functional relationships in their drawings (i.e. views, lighting, circulation) than beginners. [15]

So, while learning graphic notations could help students follow a sketch example, students also need to read more deeply into their emerging sketches to make them more purposeful. Studying annotated animated examples can complement design sketching practice in the way that reading supports writing.

6. Conclusions

So far, we have used the digital pen to 1) develop a substantial archive of design and drawing processes, 2) develop a methodology to investigate the perception of animated versus still drawings and 3) observe subtle aspects of beginning and expert design drawing skills.

It was a surprise to see that subjects studying animations perform only slightly better in copying a model design process. We conclude that an interactive animation is engaging, but it masks pauses, requiring the viewer to define cognitive chunks. By contrast, a storyboard provides an interpreted guide, encapsulating key moments of the process in a way that can help beginners. The animations could be both interactive and explanatory if crucial steps were highlighted and annotated with text or audio to explain the rationale behind the steps.

Comparing the perception of still images, interactive vs. autoplay animations and annotated animations would tell us more about making useful lessons. We need to discover what makes specific representations compelling and instructive.

Our collected sketch solutions show us that domain-specific graphic techniques are a challenge for beginners. Experts draw more efficiently

because they know how to use drawing views and conventions to provide information that stimulates further decisions. Expert sketches go fluidly through sub-problems from one vignette to another complementary one, so they add up to development.

The digital pen allows us to review and compare these fine-grained operations in the design process. With it, we can efficiently gather many design examples for comparison. We can use the pens to study domain-specific graphic processes and collaborative design. Careful study of different stylus-based tools could yield a broader understanding of research and interpretation possibilities.

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