Intuition in Design:
Reflections on the Iterative Aesthetics of Form

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ABSTRACT

Curious to reflect on the factors contributing to the internal decision-making processes of intuitive design, a reflective study was established to systematically examine and document the practice of intuition while performing an iterative aesthetic task. Autoethnographic techniques were used to document the reflective practices that occurred over numerous iterations spanning several weeks of activity. Our analysis concludes with a summary of reflections on how intuition informs judgment in design cognition. We examine four dimensions of intuition in design—efficiency, inspiration, curiosity, and insight—and the reflective and sensory inputs that drive intuitive speculation and impulse.

Author Keywords

Design; Intuition; Iteration; Self-Reflection; Decision-Making

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Design activity requires constant decision-making and seldom follows a predetermined plan. As the use of Human-Computer Interaction (HCI) technologies becomes increasingly widespread, systemic, and highly contextualized, the designers of interactive systems must increasingly be able to fluently and flexibly react to the shifting terrain of complex, ambiguous, and even unknown demands on their work. This requires that they have a keenly developed sense of their internal, intuitive skills [10, 22]. Indeed, perhaps one of the most important characteristics of expert designers is their ability to approach challenging and ambiguous projects with optimism and confidence, adapting to changing constraints with the ability to make real-time aesthetic (i.e. feeling-based) judgments.

Numerous authors have emphasized the importance of intuition in the processes of design, including perspectives drawn from industrial design [45], engineering [12], mathematics [4], etc. In a systematic analysis of interviews with Nobel laureates in physics, chemistry, and medicine, for example, Marton et al. describe scientific intuition as "characterized as having a certitude based on a feeling or a perception of almost aesthetic or quasi-sensory nature… [it] seems to develop through extended and varied experiences of the object of research and is apparently based on an initially vague, global, not fully conscious, anticipatory perception of the solution searched for" [24]. In generative design activities where envisioning possible alternative futures is the goal of the research process, intuition plays an essential role as it allows "a simultaneous grasp of the whole, well in advances of knowing its parts in detail" [ibid], and elucidates possible future states in the mind of the envisioning designer to guide the "right" action. Suri observes that the ultimate intent of all design research is "to expose patterns underlying the rich reality of people's behaviors and experiences, to explore reactions to probes and prototypes, and to shed light on the unknown through iterative hypothesis and experiment." [42] Indeed, the intuitive nature of design activity involves constant reflection on the process of making throughout the design research activity [18, 46]. In this regard intuitive design is a process of intentional self-leadership that both inspires imagination and informs how individuals interact in the world [40].

This paper describes the results of an investigation specifically performed to reflect on the intuitive nature of decision-making when developing design concepts. We were curious to investigate what happens in the designer's mind as he or she internally reflects on the actions performed while designing, especially when unconstrained by external requirements. Not only does a designer's sense of intuition have a tremendous influence on project outcomes, one of the explicit goals of most interaction design projects is also to design intuitive experiences for those who use them. A deeper understanding of intuition is therefore central to the improvement of HCI design practice in two ways: it is among the primary mechanisms designers use to evaluate their decisions, and it informs their ability to relate with their eventual users. For the purposes of this study we begin with an examination of the literature on intuition in HCI and design, followed by a description and insights from a qualitative investigation of intuitive aesthetic judgment in an iterative design project.

INTUITION IN DESIGN PRACTICE

Intuition is a reflexive and innate kind of knowing, a form of inner guidance responsive to insights arising from the synthesis of inward and outward focus [13]. Intuitive thought emerges through a subconscious "scanning" of the

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senses: externally through our embodied perceptions, and internally as a kind of pre-cognitive experience beyond rational or verbal awareness. Yet while intuition may be defined in this way as subconscious and "unaware" experience, it can also be understood as a conscious and reflective act of assessing the results of an action performed. In this second sense, intuition is understood as a rational and highly cognitive activity. For the purposes of this paper our concept of intuition shall be kept somewhat flexible to include both the constructive and evaluative processes of subconscious intuition as well as its reflective nuances as a conscious act.

Philosophers have dealt directly with intuition for centuries (e.g. Spinoza's *Ethics* [42], Kant's *The Critique of Pure Reason* [21]), but the pre-cognitive aspect of intuition has made it difficult to empirically study. This is in part because cognitive scientists have struggled with a lack of vocabulary to describe intuitive experiences [34], combined with a marked decline in contemplative approaches considering introspection as a valid method of investigation [41]. As a result, the majority of empirical research on intuitive knowing has been relegated to qualitative techniques including in-depth interviews [23], journal content analysis [27], and reflections on intuitive processes through self-exploration [13]. While some researchers have pursued hybrid approaches combining all of the above [34], others have proposed integrated models of analytical and intuitive decision-making where both approaches are used in a complementary and iterative fashion [41, 43]. In the spirit of advancing these discussions in the context of contemporary interaction design practice, our investigation centers explicitly on the role of intuition over time as an iterative practice combining spontaneous judgment and the more deliberate evolution of goals.

While little work has been done tying intuitive practices to the design of interactive systems in particular, the traits of intuition in creative practice are well studied. Most researchers agree that intuitive events originate beyond consciousness, process information holistically, and involve perceptions that are frequently accompanied by emotion (e.g. feeling uplifted, or anxious). People who score high on intuition in psychological tests also tend to score high on creativity and divergent thinking [44], critical attributes for design practice and creativity training [36, 39]. Dane and Pratt identify three kinds of intuition that may explain its importance to human evolution: problem solving intuition, moral intuition, and creative intuition [9]. We feel that a finely tuned sense of intuition underlies the best design practices in each case, in part because designers both learn and innately experience what others have not yet experienced through the act of creating and sensing the results of a given design. In doing so they hone the conscious ability to engage in intuitive insight, affective cognition, and the openness to extra-rational modes of thinking and bodily awareness that are necessary for aesthetic judgment and the perception of quality [12, 34]. Intuition is also central to creative motivation, since, as Thomson writes, the creative individual's "psychoneurobiological capacity to flexibly and dynamically shift states enables heightened intuitive processing that directly informs the inspiration process." [44] In this regard intuition provides a certain kind of dynamic charge to all creative activity—what Maritain refers to as "intuitive pulsion"—that is both intellectual and emotional, evokes nearly unconscious and imperceptible images driving pre-conscious associations, and channels impulses from the sensed environment into speculative, creative action [24].

The power of intuition is magnified in practice through constant cycles of expression and testing that validate or contradict our intuitive knowing and facilitate learning [26]. Schön has identified two primary ways in which designers reflect on these intentional processes of making: reflection *in action* (insight gained through the action of performing design activity), and reflection *on action* (insight gained by stepping away and assessing the results of that activity) [34]. By combining these two approaches, designers draw on their internal, intuitive, best guess judgments about how and what course of action to pursue. In this regard sketching is both a mechanism for *seeing* and *imagining* previously unrealized solutions [26]. Learning to become aware of and trust in these inner motivations is central to the reflective mindset necessary in the performance of a task that best accomplishes the designer's goals [28]. In other words, a designer's aptitudes are shaped by their reflective and iterative application of intuitive methods.

To know that they are making the right decisions, designers must be confident trusting their intuitive knowledge and have fluency when performing the necessary subjective judgments enabling creative discovery and evaluation [29]. Among the primary ways that designers accomplish this is by creating tentative "sketches" of possible designs to evaluate their potential as useful and usable eventual outcomes. Buxton [6] identifies two primary aims of sketching behavior in design: generating as many different ideas as possible to make sure that the designer is "making the right thing," and iterative cycles of prototyping development to increase the fidelity of a design such that the designer can be sure that they are "making it right." Both types of behavior can be considered cognitive mechanisms used by the designers to insure that a landscape of possibilities has been explored and the "best" option(s) pursued. Through iterative processes of expressing and developing numerous such designs, possible solutions can be experienced first-hand by the designer and key stakeholders, and the most important perceived features (and failures) of the design can be identified and addressed.

The intuitive act relies on more than simply generating numerous alternatives, it necessarily requires choosing between them. Internal judgments are made by the designer performing the task as to which of the alternatives is preferable based on a variety of criteria, both internal and sensed. Honed over time, the ability to make these sorts of qualitative decisions can be considered the designer's systemic ("intuitive") method, through which insight and technical mastery are developed [29, 8]. In support of these aims, common design approaches often entail strategies for participant-involvement in the evaluation of artifacts—through "talk aloud" sessions or more carefully structured user-experience prototype testing, and so on [20, 1]. In time, such practices lead to a highly trained sense of generative intuition regarding the aesthetics of form, as well as a heightened and critical attunement to empathy—the synthetic intuition of others' feelings [18, 32].

To summarize, intuition is a critical aspect of design expertise. While intuition in design is generally described as an innate and automatic skill, we believe it is more appropriately framed as an ability that may be learned through experiential practice. This is true in both generative and evaluative aspects of the design process. The framework presented in Figure 1 highlights the role intuition plays as an internal aid in both divergent and convergent design activities.

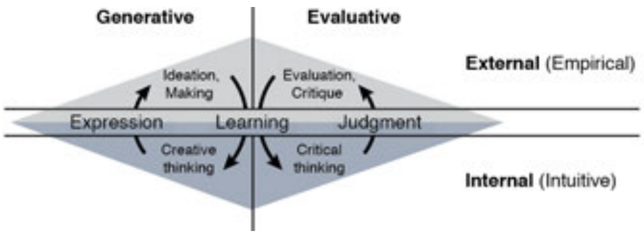

Figure 1. Experienced designers leverage intuition to guide both expressive and judgmental acts. Over time, intuition is learned.

Finally, it should also be noted that a highly attuned sense of intuition in design does not necessarily lead to intuitive design outcomes. Intuitive judgment is tightly bound to the designer's intent, and intentionality is highly subjective and dependent on context [40]. When employing speculative design methods [13, 9], for example, the designers' intent often derives from an unconventional kind of personal and cultural intuition: the heightened perception of anticipated aesthetic discomfort necessary to anticipate the provocation of reactions from people in situations of interest. In such cases the design may be intentionally (or unintentionally) counter-intuitive, and reactions may vary regardless of the designer's intent. Stated differently, not only are the internal motivations guiding a designer's work an essential element of the psychology of design [7], the intentional nature of intuition makes it difficult if not impossible to empirically measure. We therefore resort to reflective methods for the purposes of our study, the details of which are described in the following section.

METHODOLOGY AND OBSERVATIONS

Although the direct study of intuition presents unique challenges, HCI researchers routinely employ a host of social science methodologies that are appropriate for the task. As mentioned previously, popular methods include observational ethnographic approaches such as experience sampling, participant interviews and think aloud protocols. Rode [36] has observed that ethnography is essentially a *reflexive* science in that it satisfies four criteria defined by Burawoy [4]: it intervenes in the world to gather data; it seeks to understand and contextualize what the data means by reflecting on how it was gathered; it finds structural patterns in what was observed; and, in doing so, it extends theory. The HCI community has embraced ethnographic methods because it allows researchers to understand the behaviors and feelings of users in an objective an empirical way, and develop them into insights that enable the evaluation and construction of knowledge. Yet the community has also tended to prefer "realist ethnography"—a strain of ethnography which prioritizes just some of these aspects as a means of defamiliarisation by allowing researchers to obtain critical distance from their own culture—over confessional and impressionistic ethnographic approaches that allow readers to more fully understand the process of data gathering and the ethnographer's place within it [36]. Patton describes these more introspective approaches broadly as *autoethnography*: the qualitative means for "studying one's own culture and oneself as part of that culture" [33].

We employed an autoethnographic approach for this study for three main reasons. First, while it limits our observations to individual and subjective experience, we feel that such methods are necessary for the study of intuition in particular given its internal, reflective nature. As a research method autoethnography provides great value because it allows for deeply personal and internally consistent narratives to be captured and learned from. While this can also be true of other qualitative methods, none of them so directly address the *performative* aspects of intuitive design. Binder et al. note that design action is performative in that involves expressive and experiential processes of awareness; they write "Ways of gaining knowledge that some might refer to as techniques need to be invented anew every time: they do not exist as entities independent from the individuals and groups of people who perform them." [2]. Kuutti et al. have emphasized that there is a difference between what can be known by an external observer and one involved in an activity, for example, and that acting in concrete situations is a valid form of producing new knowledge [22].

Second, building on the previous point, we believe that quality design practice is essential for quality design outcomes, and intuition is a well-established mechanism for successful design practice and scientific discovery. Dourish emphasizes that tacit design knowledge applies generally to situations in which we understand "what to do" without being able to express "how to do it." [10] Zimmerman et al. observe that design research is essentially practice-based action as it is realized through the practice of doing design [47]. Given this, it seems reasonable that research on intuition can and should directly incorporate intuitive methods. Our aim was to structure the performance of an iterative design task in such a way as to capture and document the internal and intuitive decision-making processes confronted by the designer in practice. We believe it is essential for designers to practice and learn directly from in their work, and HCI researchers are no exception.

Third, not only are there intrinsic benefits to demonstrating new reflexive/autoethnographic practices within the HCI community, it is also important to extend relevant knowledge *through* practice. We believe the quality of the methods we use has the potential to influence the results we achieve (i.e., "the medium is the message). Intuitive design methods are likely to be increasingly important in HCI with the rise of ubiquitous AI systems capable of making their own intuitive decisions.

Study Overview

Our study took place in the Human-Computer Interaction Institute in the School of Computer Science at Carnegie Mellon University, where the author was a member of the design research faculty. The author has a PhD in virtual experience design, and over 15 years of experience as a professional design consultant in industry. The ultimate goal of the study was to identify and define a cultural "vocabulary of design intuitions" that can be used to enhance a practitioner's awareness of their reflective process [13].

For our purposes we limited our study to the iterative design of a physical form. Our intent was to examine intuition in the context of a focused and personal act of design, as opposed to a broader set of users, systems, or application domains. With this goal, the author performed a series of iterative three-dimensional prototype construction projects and carefully documented their creation. Personal journal entries were used to catalogue the various internal hypotheses, desires, blocks, new ideas, and so forth that occurred during the process of creating the prototypes. The project concluded by writing up these notes clearly in narrative form and then coding and synthesizing the results into an insights framework using an iterative grounded theory approach [7]. The self-report writeup was printed and analyzed in numerous passes involving different colored highlighter pens. On the first pass an open coding scheme was assigned to each different color of highlighter. This identified high-level codes based on the phrasing of the narrative and nature of the intuitive act described. Photographs were also taken of the evolving design at each stage. Given the highly personal nature of this project I will use the first person tense when describing these activities in detail for the remainder of the paper. Likewise, given the intuitive nature of the methods involved I will describe the study's methodology entirely in the context of the intuitive process of applying the method.

Given that my primary focus of research interest was the intuitive process, the investigation was explicitly designed to be simple and spontaneous with few external constraints beyond basic tools (a laser cutter), materials (cardboard), and my own prior knowledge and experiences as a designer. While the focus of the design activity was not on an interactive (i.e. digital) product, my feeling was that whether conscious or not—introspective discourse is central to design intuition and this intuitive process is inherently interactive. Significant design research has studied human-human interaction and human-computer interaction. Less work has focused explicitly on human-self interaction.

Framing the Prototype Exercise and Getting Started

I began the project with the knowledge that designers actively build things as a way of thinking (i.e., think to build and build to think [2]), and so chose a research domain that involved the physical prototyping of a three-dimensional object. My department had a prototyping laboratory equipped with a laser-cutter that I was eager to use, since I had never experimented with one at length. The decision was made to use the laser-cutter exclusively as my prototyping tool. Regarding the nature of the project to be built, my plan was specifically to not have a plan. Rather, the intention was for the nature of the project to emerge in an intuitive way through the act of designing. Consequently, the observations reported here not only focus on the intuitive functional and aesthetic decisions made in the iterative prototype construction process, but also involve the learning and exploration introduced by the constraint of being required to use an unfamiliar tool as my primary means of expression. The project continued until I felt it had satisfied the intuitive aesthetic goals of being elegant, rigorous, and "feeling done." This took eight iterations.

Iteration 1: The Tower

My first prototype had no clearly defined vision in mind other than to use the laser cutter to construct some kind of three-dimensional model. Near the laser cutter were lots of boxes, so I decided to use cardboard as a material given its high availability, low cost, and structural qualities. The available boxes were white on the exterior and brown on the interior, and needed to be cut down with an X-Acto knife to fit in the bed of the laser cutter. This required unexpected measuring and material preparation. Also, the power settings on the laser required adjustment, in a software print dialogue box, so that the material would be cut all of the way through without catching fire. Having never used the machine before, this involved some experimentation on scrap material.

The decision was made to cut numerous triangles from a single sheet of cardboard, with a notch removed from each of the corners. My intuition was that these notches, cut to precisely the same thickness as the cardboard material, would allow two triangles to slide together forming a simple joint at 90-degrees that would be both structurally interesting and lead to unexpected geometric possibilities when assembled. This also allowed me to cut a full sheet of identical triangles from a sheet of cardboard, efficiently preventing material waste.

Despite my prior planning and testing, two unexpected errors occurred on my first attempt to cut a full sheet of material. First, despite my prior testing the laser didn't quite cut all the way through the cardboard on the majority of the sheet. I took note of the power setting so that I could increase it on the next pass. Second, the laser began cutting two inches lower than I had anticipated, running off the bottom of the cutting bed and over the same lower edge of cardboard several times with the laser and starting a small fire. Regardless, a substantial number of the triangles I desired were produced and could be used for assembly.

Figure 2. The first laser-cut cardboard construction.

The form I ended up constructing is shown in figure 2. To arrive at this form, I simply began connecting triangles together and soon realized that eventually the geometry of the space could be made to produce spherically-connected "structural units" that could then be assembled to create much larger structures. Careful attention was paid to the "internal" or "external" positioning of the white face of the cardboard, with the intent of creating a "symmetrical" three-dimensional pattern. This in turn influenced my positioning of future pieces during the assembly process. At one point I also ran out of triangles and had to cut more, which I used to create "feet" for the tower to stand on. Given my unhappiness with the seemingly "unfinished" corner-notches that stuck out at the periphery, I also designed and cut some small circular pieces (with notches) to "plug" these gaps, as shown in the picture.

Iteration 2: Rigid Internal Support for Exterior Sphere

I was pleased with my first iteration, and immediately knew what I wanted to do next. During the process of assembling the first model, I had become particularly intrigued with how the central structural units of the tower formed a robust spherical geometry. Deconstructing the tower to just one of these single spherical units, it occurred to me, as I held it, that this structure could be used to provide the internal rigidity necessary for the construction of a truly spherical architecture of some kind. My plan was to use the pre-existing triangle pieces as a starting point and extend them spherically outwards with the aim of forming something round.

Figure 3. The second iteration: a spherical structure with rigid internal support. Note the 4-way junctions that join the curves.

For the next iteration I therefore did some measurements of the geometry at play and sketched up the additional parts, in Adobe Illustrator (the software driving the laser cutter), for an additional assembly consisting of 3 great circles intersecting at 90 degrees. Since the internal structure was already assembled, cutting these additional pieces was reasonably quick. The assembled result, shown in Figure 3, proved to be extremely robust, but not nearly as spherical as I had originally imagined. Indeed, as I held it in my hand it felt extremely rectilinear: in the absence of a well-defined "outer shell" structure it felt more like a cube than a sphere.

Iteration 3: A Spherical Shell

The second iteration raised numerous new considerations. My intended desire to create a spherical form, and its subsequent lack of roundness, had made me curious to explore a new strategy of construction. In the first two iterations, my main consideration had been efficiently using pre-existing material (in the first case) and a pre-existing structure (in the second). While aesthetic considerations had been present when making key decisions, the practical desire had been one of speed and convenience.

Now holding the second iteration in my hand I became aware that it would be possible to construct a spherical shell requiring no internal support. This structure could be built out of intersecting great circles using tabs at each node to hold the sphere together. Doing so would require abandoning the majority of my existing geometry, apart from the three primary great circles that intersect at right angles, and the introduction of secondary curved "trusses" to fill in the gaps of the spherical shell.

Figure 4. The first spherical shell, with ring-nodes to fix a mistake.

The challenge now became one of envisioning the eventual three-dimensional form in a program that was cutting out flat two-dimensional pieces. Given the geometry of the primary curves, I decided to cut a notch halfway between the nodes along the arc of each primary truss, and T a secondary truss into the structure at this point. My first attempt cutting new pieces was a geometric failure, however: I over and under shot the connection points given the strangeness of spherical geometry. To address this problem, I ended up cutting special "ring"-shaped pieces for these nodes to fill the gaps in the sphere precisely where the secondary trusses didn't quite meet. The result (Figure 4) is aesthetically quite nice, in large part because there are two sets of differing nodes: 4-way primaries, and 3-way secondaries filled with a ring. Careful attention had to be paid to keep the white and brown sides of the cardboard aligned such that the great arcs continued consistently depending on their rotation around the sphere.

Despite my setbacks I was quite pleased with the spherical shell. It is an interesting shape to ponder, to roll on the floor, and to toss in the air. The sphere was just trusses without a skin, however, so I imagined the "shell" of the sphere being wrapped in elastic or spandex to effectively cover its surface. Alternatively I imagined a mechanical solution: a significant number of more densely packed trusses. This would require a totally fresh re-design of the laser-cut parts.

Iteration 4: Prototype Segment of a Spherical Shell

My next starting point was to look up geodesic domes on Wikipedia, where I discovered a link to the Platonic solids. While interesting, polygons are not spheres and none of their topologies aligned with my cardboard geometry—these were not what I wanted. Further searching led me to the Johnson solids, which intuitively felt much better for some reason. I was particularly drawn to the "deltoidal icositetrahedron," which has kite-shaped sides measuring a ratio of 1:1.292893. "These I can use," I imagined, "to generate a new set of great circles… they will intersect each other at sixteen 8-pointed vertices and eight 6-pointed vertices… (I think)!"

Careful trigonometry was involved to reduce the perceived problem to a clear mathematical model. Not only was I suddenly inspired to learn about spherical geometry—not something that I would ever have imagined at the project's outset—numerous details of the design, such as how the thickness of the cut material affects the design of each two-dimensional object where junctions occur, needed to be considered. Not having done much math since high-school, this version took much longer to mock up in Illustrator.

Compositionally I decided to emphasize the next iteration's shell-like nature by decreasing the relative size of the node junctures to make them less prominent. A clear assembly pattern was also emerging, including the addition of tertiary bars that slid into the spaces between the trapezoids formed by the intersecting primary and secondary struts. Figure 5 shows a screenshot of one of the numerous virtual "jigs" I constructed to envision the intersection of trusses at each of the differing nodes, since a much more rigorous underlying model needed to be constructed off of which to design each of the truss elements needed to cut the design.

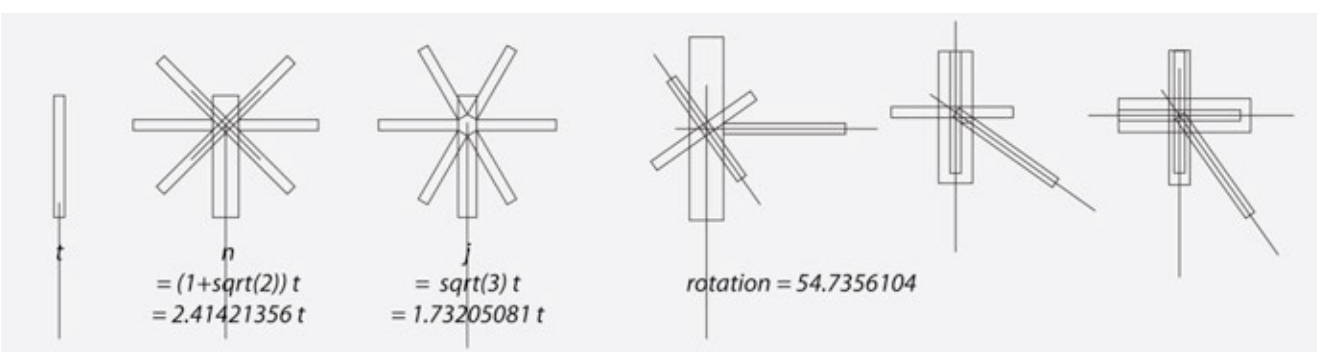

Figure 5. A screenshot from Illustrator showing the virtual "jigs" I constructed to model the notched joints of the various nodes.

A single sheet of cardboard was cut with the laser to test the geometry of a section of a larger sphere. Everything fit together nicely, although the reduction in node size did indicate a potential future problem: the thinner the shell, and the shallower the notches, the less structural strength in each joint. Since only a piece of the shell was being constructed it was difficult to imagine the strength of a completely assembled sphere.

Iteration 5: A Complete Sphere

A significant amount of material is required to go from a 2 dimensional pattern to a 3 dimensional shape. With no more cardboard left at the original thickness, more cardboard was located and the next iteration was cut at 80% size to compensate for a reduction in material thickness at joints. This had two effects. First, less material was required, so additional parts could be added to each printed page. It also reduced the size (and robustness) of the final sphere—which even at 80% size was significantly larger than the previous iteration.

With this version numerous structural factors became clear. The forces acting on a spherical shell are quite powerful, and the long and thin design of the new cardboard trusses could not consistently handle the torque of assembly without crushing. Tensions were also powerful enough to overcome the friction holding together each node, so the completed sphere had a tendency to pull itself apart. At first it was not clear if the mathematical model was slightly off or if the node junctions were too weak, but for the time being, I reasoned, glue and pins might suffice to hold the spherical shell together.

After trying to glue the model together by force (figure 6), I ultimately determined the sphere's mathematical model was off, since the secondary segments still seemed too short. This was frustrating, as I already thought I had fixed this once before. I returned to the computer file to check the template, and yes, indeed, something was wrong because (secondary + tertiary + secondary + tertiary + secondary + tertiary) trusses did not equal 360°. In short, my spherical geometry was off and needed to be re-calculated.

Figure 6. The first complete spherical shell, requiring glue to compensate for weak joints and mathematical error.

The mathematical problem consumed my attention for much of an afternoon. Several web pages were visited describing the basics of spherical geometry: great circles, lunes, the spherical triangle rule (angles always add up to more than 180°), conversion of degrees to radians (i.e.: *What is a radian*? This is very important!), and finally, the Pythagorean theorem for spheres (not easily located in the first several pages I found, and critical to what I was attempting to solve). Curiosity at this point was driving my continued motivation, with the end goal vision of designing a sphere that was "perfect." Aesthetic concerns with this iteration also came to mind: while the thin shell was nice, it also had a lot less personality than the previous version, and the surface was still not smoothly "filled." Adding quaternary segments on the next revision seemed like it would help resolve this issue.

Figure 7. On the sixth iteration, everything fit together as planned.

Iteration 6: Complete Sphere to "Three Degrees"

With the mathematical modeling of the sphere complete in my illustrator files, I laser cut a complete new sphere using six sheets of cardboard. The result was a complete sphere that, when assembled, fit perfectly together (figure 7). The resulting sphere was quite satisfactory, and I was amazed with the beauty and elegance of thoughtful mathematics. Aesthetically this new sphere was graceful, with the diversity of truss thicknesses (quaternary segments were thinner) adding a nice, almost baroque element to the shell. Returning to my office after a few hours away, I had a near-transcendent moment as the sun shone through the window and onto the sphere, casting a shadow on the wall. I could feel the Earth turning as the shadow slowly slid down the wall, and meditated on it quietly for a few minutes before returning to work. Perhaps 20 minutes later I looked up: the shadow had completely changed, and a red hue burned through the window. It was a far more dynamic, different light, with dramatically different shadows. At this moment I also noticed numerous different ways in which the fundamental shape of a sphere can be subdivided, based on this particular topological map, to create numerous alternate designs that would be interesting to explore.

Iteration 7: Matte Board Sphere – Colors and Combinations

I went to the art store to get some matte board, knowing that its thin stiffness would allow the ability to cut far more parts from one sheet of material and result in a smaller product with a denser construction. It also occurred to me that I would like to experiment with combining different colors of material board together in one sphere to evidence different shapes. I ended up selecting a black board and a white board that were both the same thickness.

Relative to the previous iterations, laying out the lasercut parts was a dream! One and a half full spheres fit perfectly on a page. To ensure that no glue would be required, I printed some demo parts on scrap board at various dimensions to scale the notches to the anticipated thickness range (40%, 35%, and 30%) and tested how snuggly they fit together. 30% was best, but it was a little too tight. I therefore created a page layout at 31%, not wanting to risk the assembly being too loose, and laser cut one black sheet and one white sheet of parts. This resulted in enough pieces to assemble a total of three spheres with different combinations of colors.

Assembly took far longer than expected, but relative to the cardboard the matte board was wonderful (figure 8). As a material it's much stiffer and more dense than cardboard, so

Figure 8. Assembly and parts for the final (matte board) iteration.

the resulting spheres felt much more solid. I began by assembling some black pieces, since they were cut first. I made one semi-complete sphere, and one partial sphere using only the primary struts. This latter construction was beautiful in itself, and I was struck by the simple elegance of the sphere's great circles. While assembling the parts, sometimes I had to use force to jam the pieces together, and the joints got slightly crushed or the pieces deformed. I often had to use the X-Acto knife to poke everything into place, as a dentist would, pushing the tip of each truss into its corresponding gap. Nuances of these small assembly tasks could have been improved with iteration on the architecture of each joint, but the tertiary segments fit perfectly and the sphere held together with no glue at all. Although the quaternary segments were extremely fragile, especially the endpoints that were designed to fit tightly into targeted grooves, once the sphere was assembled I was able to perform a "quality check" to insure that all of the node junctions were re-centered and tight.

Aesthetically this sphere met with my stamp of approval. It was satisfying to look at and I placed it on my desk to photograph and admire. When I tossed it in the air and caught it the structure withstood pressure from all directions. It had a very firm shape and felt complete.

Iteration 8: Assemblies and Reflection on Future Action

Pride in the success of the seventh iteration inspired me to create a series of additional spheres that fully demonstrated the robustness of the design and provided an opportunity for further reflection. I began by cleaning-up minor details in the sphere's Illustrator file and printing two additional sheets of black and white parts. It occurred to me that, using just these two colors, there were numerous possible modes of assembly given all of the permutations and combinations of colors across 5 sets of pieces (two different node types and three different kinds of great circle). I could create white spheres or black spheres with white or black nodes, or I could swap some sets of great circles with the alternate color to highlight different topological structures. This made me curious about the mathematics of topology and further possibilities of assembly. It also struck me that, although this study had begun with little specific direction, each iteration had progressively refined the course of future action towards the perfection of an emerging idea. I had become more inclined to pay attention to nuanced details of the design, and attained a heightened awareness of their consequences with each subsequent action. And now, through this act of refinement, a complexity of seemingly infinite patterns was attaining clarity as each permutation lead to countless additional possibilities.

Put another way, with each successive spherical construction a more advanced system of thought had emerged. The project had begun as an intuitive exploration and ended in a systematic process for the assembly and refinement of spherical objects. I had constructed routines to support my evolving intuition of their structure, and in doing so had enhanced my perceptions and ability to shape their design. Not only had the nature of the sphere as a "designable" form become increasingly evident, each subsequent move had become systemized, practiced and refined. Furthermore, motivation and inspiration had emerged through intuitive learning—the weighing of possible outcomes against what felt most aesthetically and insightfully "right." Best of all, the open-ended freedom and motivation associated with the initial intuitive action remained: I could choose at this point whether to dig deeper on the technical aspects of studying the sphere or the formative aesthetics of refining its shape. Having arrived at the intersection of speculative possibility and sensory reflection, I had created a personal system of knowledge capable of motivating continued iterations in a highly complex design space.

DISCUSSION

Self-reflection is an essential aspect of creative design. Yet while it is routinely acknowledged and studied in HCI design research (e.g. [15, 17]), intuition itself is seldom addressed in HCI literature independent from the influence of external reflection and feedback. Indeed, most discussions of reflectivity in design center on user testing or other forms of social engagement, such as participatory design or cultural probes [16]. Design students and educators are quite familiar with the role of "critique" as an educational practice that is used to enhance reflection on design practice and teach critical thinking, for example. Clearly such reflective practices are critical to enhancing the *use* of successful designs, allowing technology to shape and to scale "external" or distributed cognition, as with crowdsourcing systems for instance. The challenge addressed by this paper is to take a different focus by emphasizing the internal act of intuition as performed by the designer during the act of design. By focusing on the self-perceptions and reflections on intuition through an intuitive design activity, my hope is to shine additional light on the role of intuition in the act of designing.

It is important to acknowledge that the self-reflective methodology employed in this paper is not without limitations, nor is it an easy or conventional approach to HCI research. The fundamental limitation arises from the need to translate inner felt experience (specifically the feeling of having "intuited" something) into an externalized and generalizable form. In this case we feel that the auto-ethnographic approach we have employed is appropriate because it allows for the immediate experience of an intuition to be captured first hand—as well as the subsequent reflection on what was intuited. In the self-report narrative on the previous pages, for example, I regularly included statements that were intuited as part of the firsthand experience but which appear (when presented as narrative transcriptions) to be an after-reflection on the design process instead of a firsthand intuition. Discussing the first prototyping iteration, for example, I wrote "My intuition was that these notches, cut to precisely the same thickness as the cardboard material, would allow two triangles to slide together forming a simple joint at 90-degrees that would be both structurally interesting and lead to unexpected geometric possibilities when assembled." This is problematic, as it can give rise to the perception that our understanding of intuition lacks clarity. On one hand intuition has been defined as "reflexive knowing" (a kind of pre-cognitive experience beyond rational and verbal awareness), and on the other it involves what could be understood in a Schönean sense as the combining of "reflection in action" and "reflection on action," a reflexive stepping away and assessing the results of design activity. In practice we believe it is very difficult to separate these two intuitive modes, since what we do is informed by our guiding "inner voice," which itself is an intuitive response to the perceptual/cognitive situation presented. As the diagram presented in Figure 1 represented, what we learn from the world affects our intuitive actions or "inner" response. Moreover, we have used the notion of intuition interchangeably to refer to both generative activities and evaluative activities, which could be perceived as two rather different acts of consciousness. Or are they? We believe suggesting that they are different acts of consciousness is an after-reflection on the nature of intuition, but that in actuality firsthand intuitive experience is both generative *and* evaluative: it is the generation of an intent based on an (internal) evaluation about what to intend. We acknowledge our framing of these issues has involved substantial methodological prescriptions, but in practical terms, for the designer making an intuitive impulse, reflective action and perception are tightly coupled in performance.

A grounded-theory synthesis of the observations from the previous section revealed how numerous dimensions of intuitive knowing affect the choices designers make when pursuing their craft. For example many of the self-reflections captured in the narrative included pragmatic motivations towards a clear course of subsequent action (e.g. the desire to create something using the available triangular parts following the first attempt to use the laser cutter). Another code captured moments of "insight" during the creative process, such as learnings that prepared me to avoid future mistakes. After the first pass through the data, identified "codes" were synthesized to identify four main "clusters" reflective of the more granular details. I then attempted to make sense of these clusters by placing them into a 2x2 framework to understand the basic dimensions that made them unique from one another. Through this exercise it became clear that each area represented an underlying "motivation" for the intuitive action. Specifically, four key motivators that characterized the experienced intuitions were identified: curiosity, efficiency, inspiration, and insight, described in greater detail below.

Figure 9 presents the identified framework for the analysis of design intuition that will guide the remainder of our discussion. The model defines a 2x2 matrix along two axes drawn from the experiential data gathered on intuitive cognition in design: impulsive vs. reflective action and speculative vs. sensory stimuli/intent. This framework is not intended to encapsulate the complex field of theory surrounding intuition research, nor is it advanced as a model summarizing the behavior of intuition in design. Rather, it is referred to simply as a visual guide to our discussion. As described above, the model itself was derived from a grounded theory analysis of the autoethnographic narrative in the previous section that resulted in the open coding scheme that was used in the analysis of the data.

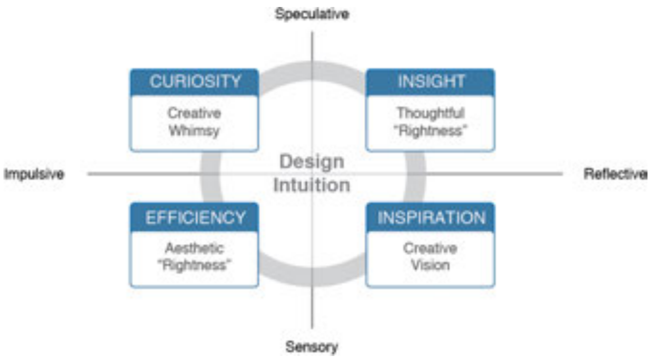

Figure 9. A summary of insights on intuition in design, drawn from grounded-theory synthesis of autoethnographic data.

First, the findings revealed numerous intuitions that were driven by *curiosity*, or creative whimsy. Curiosity is essential to design intuition as a prompt for speculative and impulsive creative action. This is essential for advancing the design action in the absence of concrete insights or external guidance. Indeed, not only did curiosity drive me to perform this study, it led me to experiment with and re-arrange cardboard pieces, see if it was possible to construct spherical shells, and explore their mathematical complexities. In this regard, the designer's curious impulse to ask "what if?" is a critical motivating factor in the quest for knowledge. Creative whimsy also allows the navigation of functional constraints, such as a lack of materials or technical setback. When undeterred by a commitment to unknown outcomes, designers are empowered to learn by doing and gain new insights and confidence through design intuition.

Second, intuition is critical for the *efficiency* of design because it allows for "feeling based" aesthetic judgments to be made that allow for immediate action. Such decisions tend to value elegant, holistic solutions that resolve ambiguity and refresh the cognitive stage. In my first and third iterations, for example, the simple introduction of a "finishing detail" cleared the canvas for the next phase of action. The desire for aesthetic "rightness" also streamlines the process of design: cutting a full sheet of identical triangles maximizes the pieces while eliminating waste; holding a finished model that "feels right" in the hand is an indication that the mathematical model is good. Although it sometimes leads to failure on deeper reflection, designers must learn to trust their intuitive aesthetic judgments to maintain creative momentum—the synthesis of alternative courses of action. These insights are supported by recent design theory; in an examination of the role and development of expertise in design, Cross notes that often design process follows a pattern of 'opportunistic solution development' which has been hypothesized to reduce the cognitive cost of efficient design behavior [8].

Third, beautifully crafted objects also attract attention and playful interaction, leading to the *inspiration* necessary to drive creative vision. The intuitive reflection upon sensory stimuli is what motivates the desire to achieve aesthetic rightness. When we are pleased with our accomplishments we are driven to achieve more. At many steps in my process of self-reflection, pleasure was derived from a reflective sensation of what else might be be possible. For example: how the sun's drifting shadow, projecting across the cosmos, illuminates the geometry of spherical cardboard and inspires countless possibilities that were previously unsensed; how the shell of the structure could be wrapped in elastic or spandex; how it ought to be possible to create something equivalent to a Hoberman sphere [30] that transforms each face of a cube into a sphere; how scaling this up to an architectural structure would allow the Pompidou to turn into into Epcot center, etc.

Finally, it is only by drawing on the intuitive knowledge of what has worked in the past that *insight* can be realized and actualized. Insight requires an intuitive struggle to achieve an understanding capable of grasping the "rightness" of the knowing involved. Such intuition provides designers with a means to frame their practice more intelligently through speculative hypothetical questioning and the learning that results. At many points in the sphere project I advanced blindly into areas with little prior knowledge (e.g. a deep immersion into spherical geometry) and came away with new insights on ways to achieve my goals—whether through the pursuit of new learning or the development of new tools, like improved software features for cutting cardboard that dynamically adjust for material thickness in response to an envisioned 3D form. These intuitions not only enabled the anticipation of future errors, they guided the deeper courses of action necessary for complex design.

Intuition is the ability to acquire knowledge without the explicit use of reason or inference, and it is "in this immediate, pre-representational and pre-discursive experience of the world that all our cognitive activity seems to be rooted." [34] In this framing, the design of HCI systems extends beyond computers or systems of people to all intuitive interactions we have with the world—not just with digital tools or with cardboard spheres, but to the differentials of self that we pass to the world we inhabit. Applied to design activity, intuition provides a means for intelligently framing and acting upon immediate options to guide the possibility of their eventual outcome. My hope is that this discussion has provided a useful framework for understanding the complex nature of intuition in design.

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