— hi-fi smell prototyping: slow (hours), high-tech, & costly ——

Figure 1: An overview of prototyping with *Smell & Paste* (lo-fi) versus current practices (hi-fi). Smell & Paste: Our technique leverages low-fidelity materials to *make low-fidelity prototyping of smell experiences approachable and fast* for novices and experts alike. Here, a designer (a) tests their drafted odor sequence for a virtual reality experience. They decide to tweak the sequence, so they (b) open the cassette with the loaded smell tape. They (c) modify the odor interaction by cutting and pasting off-the-shelf scratch-and-sniff stickers onto the tape. Within minutes, (d) they test the changes by advancing the cassette with its driver, and the cassette's comb scratches the tape to release the stickers' smells. This allows for a quick and easily approachable prototyping workflow. In contrast, current practice: Today, experts jump directly to high-fidelity development. They must often (1) handle fragrance chemicals directly and (2) are required to build and program a delivery system before they can (3) test their experience. Each step in current practice is time-consuming: a single iteration can take hours, days, or – in some extremes – months.

ABSTRACT

Low-fidelity prototyping is so foundational to Human-Computer Interaction, appearing in most early design phases. So, how do experts prototype olfactory experiences? We interviewed eight experts and found that *they do not* because *no process supports this.* Thus, we engineered Smell & Paste, a low-fidelity prototyping toolkit. Designers assemble olfactory proofs-of-concept by pasting

Jas Brooks

University of Chicago

jasbrooks@uchicago.edu

CHI '23, April 23–28, 2023, Hamburg, Germany

© 2023 Copyright held by the owner/author(s). Publication rights licensed to ACM. ACM ISBN 978-1-4503-9421-5/23/04...\$15.00 https://doi.org/10.1145/3544548.3580680 scratch-and-sniff stickers onto a paper tape. Then, they test the interaction by advancing the tape in our 3D-printed (or cardboard) cassette, which releases the smells via scratching. Our toolkit uses commodity materials; keeps iterations quick, approachable, and cheap; and circumvents electronics, programming, and chemical handling. We evaluated Smell & Paste in two studies. We found that the toolkit was approachable to people of any technical background and that novices and experts appropriated and extended the toolkit, making it personalized. Novices produced prototypes quickly, and experts were excited about the kit's technical affordances and integrating it into their practice.

Pedro Lopes

University of Chicago

pedrolopes@uchicago.edu

CCS CONCEPTS

• Hardware \rightarrow Emerging technologies; Emerging interfaces; • Human-centered computing \rightarrow Human computer interaction (HCI).

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.

KEYWORDS

Smell, Olfactory, Olfactory experience, Rapid prototyping, Paper prototyping, Design

ACM Reference Format:

Jas Brooks and Pedro Lopes. 2023. Smell & Paste: Low-Fidelity Prototyping for Olfactory Experiences. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23), April 23–28, 2023, Hamburg, Germany.* ACM, New York, NY, USA, 16 pages. https://doi.org/10.1145/ 3544548.3580680

1 INTRODUCTION

Low-fidelity prototyping approaches, such as paper and video prototyping, are foundational to Human-Computer Interaction. Many practitioners, researchers, and students are taught to use these essential techniques because they allow for quick *iteration cycles* and use *non-technical (low-tech) media* when designing screen-based user interfaces. However, experience designers have recently moved beyond the screen [40], noticing the opportunities afforded by many new modalities, including olfaction [39]. Odors play critical roles in our lives: from the pleasures of food and its influence on our metabolism [45] to detecting potential hazards [55] to an essential role in memories and emotions [21, 48].

Moreover, all societies have their own cultures and practices around smell, charged with cultural values that also shape how they interact with the world [8]. For example, in the past, Northern Māori villages were noted for the pungent notes of fermenting corn (kānga pirau) emanating from steeping pits [9] (a dish that can be smelled several houses away even today [63]), while Roman Catholic masses marked symbolic transitions with the smell of burning balsam [19]. HCI researchers have been leveraging these opportunities in interactive experiences, such as to increase virtual presence [3], provide notifications [30], promote wellbeing [1], enhance safety [33], and support funeral rites [57], just to cite a few.

However, while lo-fi techniques support visual UIs, the same does not hold for experiences leveraging smell. Even with advancements in scent technologies, olfactory experiences remain rare. We posit that designers need *both* hi-fi hardware for final development *and* low-fidelity prototyping techniques to make olfactory experience design *quick*, *low-cost*, and *approachable* to those of diverse backgrounds/regions (including those without technical experience).

Following this, we asked, do olfactory experience designers draft lo-fi prototypes? In short, *they do not*. In our first study, we interviewed experts that previously authored smell experiences for the public (games, interactive exhibits, etc.). We found most *jumped* from concept to hi-fi version, *taking months before they integrated or tested actual smells*. These difficulties stem from lacking structures or toolkits to prototype with low-fidelity odor materials. In turn, experts take an idea and must often compose or buy fragrances, build, and program a dispensing system, and test ergonomics before they can test design choices or ideas. Each step ultimately requires significant time, cost, and expertise.

To tackle this, we designed a low-tech, low-fidelity toolkit that makes prototyping olfactory experiences quick, cheap, and easily approachable. As seen in Figure 1, our toolkit comprises (b) a 3D-printed (or cardboard) cassette with which users draft odor sequences and transitions by adding scratch-and-sniff stickers. These low-cost stickers have a coating of microencapsulated fragrances, which lets one store and later release smells by scratching their surface. The toolkit enables drafting experiences by (c) simply cutting and pasting stickers onto paper tapes, loading them into a cassette, and (d) hand-operating the cassette. This editing workflow draws inspiration from film, tape, and reel editing techniques. The kit exhibits all the fundamental elements of paper prototyping: it (1) leverages commonly available materials (printer paper and scratchand-sniff stickers), (2) does not use hardware or software, (3) is cheap to make, and (4) has low operational costs. Our toolkit frees users from electronics, liquids, or programming during early prototyping phases. Most importantly, the kit is approachable to people of any technical ability to draft expressive olfactory experiences.

We evaluated our device through two additional user studies. In the second study, our toolkit supported novices to experiment with the full breadth of key olfactory design features, drafting sequences that leverage smell's chemical, emotional, spatial, and temporal features [29]. The kit also paired well with established prototyping strategies (paper, video, Wizard of Oz) and let participants even compose custom smells. In the third study, two experts incorporated the toolkit into their professional practices. One expert demonstrated its use in a small storytelling workshop with two young children. Both experts especially highlighted Smell & Paste's technical and tangible affordances, and both were interested in incorporating the toolkit into their future professional work. Ultimately, our toolkit let the participants iterate over and draft lo-fi smell prototypes, allowing them to focus on design. We found that novices and experts alike appropriated and extended the toolkit, making it highly personalized.

We believe our prototyping toolkit will enable new work across HCI, design, and education. To accelerate the lo-fi prototyping of smell experiences, we not only provide our device as open-source but complement it with a dataset of 800 scratch-and-sniff stickers (some as cheap as 0.035 USD per cm²) that can be purchased online.

Smell & Paste is *not* an end product but a *process* to enable designers *to rapidly validate and test design decisions early in prototyping,* and could be combined or help users transition to high-fidelity smell toolkits [24, 26, 31].

2 WALKTHROUGH: PROTOTYPING WITH SMELL & PASTE

We present an example walkthrough in which a designer uses Smell & Paste prototyping to draft smell interactions for an existing virtual reality (VR) experience. As seen in Figure 2, the experience is a simple game in which the player must find food and shelter in a forest. They stumble across fragrant ingredients to cook with, such as a suspicious mushroom. The player then finds their way to a cabin by following a smokey scent that grows stronger as they approach. Once inside, they find a boiling stew to which they can add foraged ingredients, changing its smell. If they add the mushroom, the stew's smell turns foul to warn that it is poisonous.

First, our designer iterates over the moment the player steps from the forest into the cabin—their objective is to immerse the player in the rich smell emanating from the kitchen. They test this



Figure 2: Key moments of this VR experience, for which our designer intends to prototype its olfactory experience.

scene on themselves and, with every run, tweak the smell sequence. Figure 3 shows the key to prototyping with Smell & Paste: (a) the designer tries the VR scene while holding and manually advancing the cassette to release odors; (b) dissatisfied with the current smells, they modify the sequence by adding a sticker to the exposed tape; and now (c) rewind the tape to (d) try the olfactory transition once more. This olfactory prototyping is approachable and takes the designer *a few minutes*.



Figure 3: (a) The designer tests a fade-in of a chili scent while entering the cabin and modifies the sequence. They rewind and (b) cut a square of lavender to (c) add to the start, emphasizing the soup's fragrant herbs. (d) Sequence presented outside of the cassette.

Since our technique uses low-tech materials (paper and stickers) and is approachable, the designer rapidly drafts variations of the interactions, see Figure 4. Each variation tests their ideas for the forest scents, the transition from woods to cabin, and the aromatic notes released when entering the kitchen. These three variations took *3-4 minutes*.



Figure 4: Our designer made three different sequences to test how to transition between the forest and cabin kitchen.

The designer repeats this process for the cooking interaction to experiment with how the foraged ingredients change the stew's scent. The designer wants to warn the player when the stew becomes poisonous, so they try adding a sharp, pungent aroma (Figure 5). Smell & Paste lets them draft and test many combinations to identify which works best.



Figure 5: (a) An odor sequence for the kitchen stew interaction initially uses a transition from savory chili to a meat medley with hints of onion. (b) The designer decides to warn their user of the poisonous mushroom by increasing the onion odor's intensity. (c) The designer then tests the modified sequence while immersed in the scene.

In contrast to Smell & Paste's rapid prototyping, most olfactory experience designers take hours to months to produce one draft of a similar olfactory experience, as informed by our Study 1 and prior work [24,26]. Figure 6 illustrates the standard steps when prototyping an experience using electronics. This process often requires formulating or finding fragrances compatible with the delivery mechanism and then making or programming electronic dispensers, which are less approachable in early phases. These limitations can hinder the designer's creativity too early in the process [14].



Figure 6: Illustration of typical key steps involved in hardware-based olfactory prototyping.

While our walkthrough depicts Smell & Paste used to draft smells for an existing experience, our prototyping toolkit is suited for many stages of the design process. Designers can pair Smell & Paste with established techniques like paper prototyping, video prototyping, and Wizard-of-Oz sessions (as observed from participants in our Study 2), or even combining our lo-fi smell toolkit with hi-fi smell toolkits (e.g., Lai and Cao's kit [24] or O&O [26]).

3 RELATED WORK

Our work builds on low-fidelity and low-technology prototyping, especially paper-prototyping. As our toolkit leverages scratch-andsniff stickers, we cover microencapsulation to familiarize the reader with this little-discussed format in HCI.

3.1 Low-fidelity and high-fidelity prototyping

Low-fidelity prototypes act as *stand-ins* for an interactive application: these are meant to be produced *rapidly* and *early in the design process*. They allow designers to validate and test design decisions as well as test how users might respond to the envisioned final UI design or experience [49]. In HCI literature, lo-fi prototype implementations are often implemented for visual or auditory mediums, such as via a series of static UI layouts that represent scenarios and choices in an application or even acted through the Wizard-of-Oz session [34]. The most popular and rapid lo-fi prototypes are typically paper prototypes, usually hand-drawn sketches of a user interface or experience. As the user then interacts with the prototype, a human facilitator guides the experience by modeling the prototype responses such as changes in the layout [44]. This methodology is widespread in HCI and taught in virtually all introductory HCI or design courses.

Lo-fi prototypes introduce a wide range of advantages [47]. They require little development cost (e.g., pen and paper), which enables designers to evaluate multiple design concepts. The prototypes can help address issues in the layout or experience and are useful artifacts for communicating the concept to others. Unfortunately, they also have disadvantages as they represent rough approximations of the eventual design or experience. For example, they need a facilitator, have limited utility after requirements are established, and have issues with navigation or flow in an interface or experience.

Inspired by traditional paper prototypes, our toolkit can be facilitated but it can alternatively be experienced by a user independently. The latter resembles the *experience prototyping* attitude, which focuses on the experiential aspect of prototyping [6]. In other words, where traditional ways of prototyping often focus on a passive audience witnessing a demo or someone else's experience, the experience prototyping attitude focuses on methods that allow an active audience to "experience it themselves" via low-fidelity prototypes. In contrast to lo-fi prototypes, hi-fi prototypes are more functional and interactive versions of a design that can be experienced by the user alone. These prototypes often have the look and feel of the final version. However, hi-fi prototyping has its disadvantages too, namely: these are more expensive to develop, require a lot of time to create (at times weeks or even months), and are inefficient for proof-of-concept designs.

3.2 Olfactory interfaces

HCI researchers and artists have long explored ways to incorporate our senses into digital experiences, including olfaction [16,18,36,59]. Olfactory interfaces typically deliver smells by diffusing vapors [43, 60], heating solids [11, 22] or liquids [10, 23] to produce vapors, or aerosolizing [2, 5] fragrant liquids. The resulting vapor or aerosol is commonly delivered near the nostrils or guided by fans, air vortices [60], bubbles [51], or ultrasound arrays [17]. HCI researchers have largely explored olfaction for immersion [23, 42] and communication [30, 58]. While researchers are refining delivery technologies, little attention has focused on how designers prototype olfactory experiences.

3.3 High-fidelity toolkits for olfactory experiences

While toolkits with fragrances—such as the *Smell Memory Kit* [27]—exist to evoke and share autobiographical stories using smells as probes, little work has investigated lo-fi or low-tech toolkits for *prototyping olfactory experiences*.

In fact, the existing toolkits explicitly designed for olfactory experiences are on the high-fidelity and high-tech end of the spectrum. For instance, Lai and Cao created an electronic-based toolkit to facilitate high-fidelity prototypes of olfactory interactions as part of their TEI 2019 studio [24]. The kit includes electronically controlled smell diffusers with a control module connected to an Arduino microcontroller and a set of liquid containers. This type of smell hardware can only emit smells from very low viscosity fragrances and needs circuit modifications to allow more than four smells at a time. To prototype with this toolkit, a designer fills the containers with fragrances to be aerosolized via a transducer and a wick. Designers then combine the kit with sensors, props, and

Fable 1: Contrast between	high-fidelity	toolkits and our	low-fidelity toolkit.
---------------------------	---------------	------------------	-----------------------

			low-fidelity attributes					
fidelity	toolk	it	low-cost	no hardware	no software	many odors	fast	remix
High	OWidgets [31]		~	N/A (a)	\checkmark	\times (b)	\checkmark	\times (c)
	Lai &	Cao's kit [24]	~	×	×	\checkmark	×	\checkmark
	0&0	[26]	~	×	×	\checkmark	×	\checkmark
Low	Smell	& Paste	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark
table footnotes: (a) software only, but still requires access to and some knowledge of smell delivery hardware.								
(b) odors extendable but requires database (valence, arousal, associations); initial database has 9 odors; number of								
odors dependent on hardware.								
(c) modification and remixing require an understanding of programming.								
	Blue tildes (~) are used when the kit's cost is unclear, as it depends on the price of electronics, Arduinos, transducers,					nos, transducers,		
		insulation, etc.						

everyday items to produce their experience. Similarly, O&O [26] is a DIY toolkit for high-tech prototyping of olfactory interfaces that provides odor-delivery modules using a combination of electronics (fans, transducers, etc.), cardboard, and plastics or waterproofing materials. While both kits are useful, the components are high-tech (based on transducers and electronics often found in final devices [2, 5]) and, consequently, *require* engineering and programming knowledge as well as fragrance handling. These researchers acknowledged this limitation in the workshops (and workflows) they conducted using their toolkits. (1) In Lai and Cao's TEI studio, participants did not present scent-enabled prototypes, but presented visual or tangible prototypes that considered the toolkit's formfactor. (2) In O&O's first workshop, participants reported relying on team members with engineering/software experience to prototype, and the one team without such expertise received guidance from the organizers [26]. Additionally, some participants reported that the prototyping phase was insufficient to complete a hi-fi prototype; thus, in their follow-up workshop, each individual participant received programming and hardware mentors to complete a single hi-fi prototype over the course of 5 days.

In contrast to hardware solutions, *OWidgets* is a software solution that provides a GUI for olfactory design [31], but is not designed to support lo-fi prototyping. The software coordinates scheduling and delivery across arbitrary olfactory interfaces (hightech), which can also be used for high-fidelity prototyping, but has yet to be tested with designers.

To summarize in Table 1, we contrast existing toolkits and the key attributes expected of a lo-fi toolkit: i.e., low-cost, approachable to users without hardware or software expertise, supporting many odors, fast to use, and easy to appropriate or remix. As shown in Table 1, because prior work focused exclusively on hi-tech prototyping or final products, there is no work that has investigated lo-fi prototyping of olfactory experiences.

3.4 Scratch-and-sniff stickers (microencapsulated fragrances)

"Scratch-and-sniff" media is paper, or plastic, covered in fragrances sealed in microscopic capsules. Pressure from scratching the surface breaks these small capsules and releases the odor. The earliest uses of microencapsulated fragrances included perfume advertisements in magazines [61], and later postage stamps with odors congruent to their illustrations [12, 50]. Moreover, another application lies in the food industry as scratch-and-sniff finishes allow consumers to preview a product's smell before purchase (e.g., jam packaging with scratch-and-sniff [20]).

Many took note of scratch-and-sniff stickers' ability to produce olfactory experiences for printed media and leveraged them to create more engaging and accessible products. For instance, scented books and stickers were proposed as methods to engage blind and visually impaired children (or parents) in readings [4, 15, 56].

While scratch-and-sniff was only paired with static print media in its earliest decades, the 80s explored its use in film, notably through John Waters' iconic *Polyester* [62]. These explorations continue to the present date, with games [28, 35] and contemporary movies at premier festivals leveraging the format (e.g., *The Beach Bum* at SXSW 2019 [64]). The only proposed use of scratch-and-sniff in a device appeared in 2001 as a patent that described the concept of an electrically actuated odor bank, which would move to the target odor and heat it to release the microencapsulated scent [37]. To our knowledge, this proposed device was never produced or studied.

4 CONTRIBUTION, BENEFITS, AND LIMITATIONS

Our key contribution is a toolkit that enables low-fidelity, low-tech prototyping of olfactory experiences informed by expert interviews and user studies.

The Smell & Paste toolkit has the following benefits. (1) The toolkit enables very fast drafting of an odor sequence. In turn, designers can iterate on an interaction or experience to test ideas much faster and earlier than with high-fidelity or high-tech approaches. Like any lo-fi and low-tech prototyping method, Smell & Paste is only a stand-in for an experience meant to validate and test design decisions early on. (2) The toolkit's materials keep iteration costs low when compared to iterating via fragrances and delivery hardware. Like paper prototypes, Smell & Paste prototypes use readily available paper and scratch-and-sniff stickers, which can be acquired and operated for lower cost than delivering fragrances with pumps, atomizers, etc. Due to this, there is also a low cost to creating, remixing, or discarding drafts. Additionally, the cost of our cassettes can be lowered by using cardboard and paper towel tubes. Finally, the cost of our approach depends on the cost and accessibility of scratch-and-sniff stickers themselves, which might vary over time or by region. (3) The cassette form factor overcomes the limitations of the low-fidelity odor product and is intuitive to use. As seen in Study 1, designers are excited about using low-fidelity materials like scratch-and-sniff stickers but do not have the infrastructure to address their limitations (e.g., need for manual scratching, insufficient surface area for long sequences, unclear how to produce fades). Unlike books or cards, our cassette design allows for an arbitrarily long sequence stored in a small space. Studies 2 and 3 demonstrated that the design is also robust for odor delivery. Our cassette also leaves the eyes unobstructed (unlike scented books). (4) Designers can combine our toolkit with existing prototyping techniques. As seen in Study 2, Smell & Paste is flexible enough to allow participants to combine their prototypes with video prototypes of interactive experiences, paper prototypes of UI designs, or even Wizard-of-Oz prototypes. (5) Smell & Paste is simple and expressive. Designers only need to cut & paste stickers and advance or rewind the tape to draft odor sequences rapidly. By building off these simple actions, a designer can fade and crossfade a variety of scents or even compose new fragrances.

Our approach is not without its limitations. (1) Our toolkit inherits navigational, flow, and facilitation limitations typical to lo-fi prototyping techniques. Designers must find ways to map branching experiences onto a linear form factor, which is typical of these techniques [47]. Additionally, designers know the pace to advance their cassette but must provide facilitation for others (e.g., metronome for pacing), which is also common to lo-fi prototyping techniques (see Section 4.1). Finally, (2) while our toolkit enables lo-fi prototyping, more research will need to follow to measure how it impacts translating low to highfidelity prototypes. Unlike other modalities, olfaction can vary based on the delivery method, and, as is for all prototyping methods, *materialities* (the material artefacts used during prototyping) may influence the design process [32]. So, while Smell & Paste may be helpful for low-fidelity prototyping, future work needs to investigate how it translates to high-fidelity and final experiences that do not use low-fidelity materials like scratch-and-sniff. Still, our toolkit provides the groundwork to explore this question.

5 STUDY 1: ARE THERE LOW-FIDELITY OLFACTORY PROTOTYPING METHODS?

Our first study sought to understand the prototyping processes of artists and researchers working with smell, particularly what challenges they faced. We conducted semi-structured interviews (via Zoom) with experts, each lasting approximately one and a half hours. This study was approved by our Institutional Review Board (IRB-20-2071).

5.1 Participants

Eight participants were directly recruited for their olfactory experience expertise covering a range of interactive applications (narrative, games, art, research) for all ages (children to adults), see Table 2. Four identified as women and four as men. All participants reported having produced several olfactory experiences for the public: four participants were game designers, three worked with film or performance, and one was an artist & researcher focused on olfactory experiences. We compensated each expert with a 25 USD gift card for their time.

5.2 Procedure

We started our semi-structured interviews by gathering professional experience around scent, using their prior work as a probe. This structure follows the critical incident technique [13], in that we gave a clear statement to participants of what is being investigated. We discussed what influenced their prototyping, project iterations, and challenges.

Qualitative data analysis steps were then followed to identify major themes from an a-priori list of categories. We used Burnard's stage by stage method [7] as follows: (1) close reading of the transcripts; (2) open coding of the responses; (3-4) developing broader categories based on the open coding; and (5) reducing the interviews to words and phrases.

5.3 Results

We summarize and report the three most relevant major categories.

1. Most experts skip lo-fi prototyping. Six of eight experts (E1, E2, E3, E4, E7, E8) did not introduce smells in their early design process. They typically delayed integrating actual smells until they finished producing the underlying hardware. When reflecting on their hardware choices, experts that developed custom hardware for their experiences (E4, E7, E8) mentioned spending most of their time on this portion of their projects, to the detriment of the experience design (E8). As E8 explained, they were "not [...] able to focus exclusively on the olfactory experience design due to the time spent on developing hardware and learning electrical engineering." Experts often emphasized the overhead associated with acquiring domain expertise and tacit knowledge early in their work. Experts stated difficulties or time spent learning how to (1) program or engineer (E4, E7, E8); (2) produce their own fragrances (E2, E3, E7); (3) use existing delivery technologies (E2, E4, E7, E8); and (4) determine best practices for safety (E7).

2. Reusing low-tech & low-fidelity smell products to make a final experience. Five experts explored less conventional methods of odor delivery (E1, E2, E3, E6, E7). For example, E2 designed an interactive art installation in which visitors could spray post-it notes with ready-made fragrances and attach them to a zoetrope, which combined the ease of assembling a sequence with the zoetrope's ability to animate the sequence by spinning. E1 similarly recounted using spices from a store in unlabeled jars to make a small story with a friend's child, as they prefer thinking about "the sequence of odors

Table 2: Experts on interactive olfactory experiences interviewed for Study 1. These experts covered a range of backgrounds and media for all ages (from children to adults) and audience scales (individual to theater experiences).

Expert	Background	Relevant projects or experience
E1	Filmmaker, olfactory artist	Olfactory experience designer for film screenings with scent, scented workshops and activities with children and people with disabilities, etc.
E2	Artist, exhibit and experience developer, playworker	Olfactory experience designer for film screenings with scent, olfactory experiences for children, smell experiences for neighborhood communities.
E3	Film programmer	Olfactory experience designer for film screenings with scent.
E4	Game designer, researcher	Academic researcher on scent in games, olfactory game designer.
E5	Game designer, programmer	Lead designer for commercially distributed video game with scratch-and-sniff card (over 750,000 copies sold).
E6	Game designer, programmer	Lead designer for commercially distributed text-adventure with scratch-and-sniff card (over 130,000 copies sold).
E7	Game designer, researcher	Interactive art installations and games exhibited internationally, sensory design & teaching.
E8	Artist, HCI researcher	Interactive olfactory installations, research on olfactory HCI.



Figure 7: The kit is made from: (1) tape, (2) cassette, (3) scratch plate with comb, (4) driver, and (5) cassette connector.

than to get caught up in [smell] delivery." Others used low-tech and low-fidelity products like scent-imbued fabrics, commercial food products and items (e.g., soaps), and even scratch-and-sniff stickers. Commercial foods and items left experts with little control over the odors and their intensity. All options required manual cueing. Conversely, when asked about their experience with scratch-and-sniff stickers, the consensus was that it was easy to use and offered a variety of available odors. E3 mentioned scratch-and-sniff saved production (instead of foods and fabrics) and that stickers addressed "issues of cross-contamination" and "offered a variety of new odors" (E3, E5, E6).

3. Early tests. Only E5 and E6 introduced odors early in the development of a major project. They iterated on their interactive games' scents by changing the layout with scratch-and-sniff sample cards. They both remarked that testing their games' smells with scratch-and-sniff was "straightforward" and did not require domain expertise (it is just paper).

5.4 Discussion

Most experts went from concept to directly spending their time building and iterating over complex high-fidelity or high-tech versions of their experiences. While high-tech solutions provided the benefit of control, experts did not draft and test their olfactory design choices early on.

This issue arises because there is no structured toolkit or method to help experts draft lo-fi prototypes. However, the exploration of low-tech, low-fidelity products to quickly create final experiences provided insights. We identified scratch-and-sniff stickers as the ideal candidate for enabling olfactory prototyping. Unlike foods or beverages, they do not spoil, are consistent over time, and can be stably stored. Unlike ready-made fragrances, even children can handle them safely. Unlike imbued fabrics, they do not crosscontaminate easily. Scratch-and-sniff stickers are cheap, widely varied in smell, easy to access, compact, and easy to handle. However, scratch-and-sniff cards require cueing for manual operation (e.g., number flashing in a corner) and - as a form factor - cannot handle long or complex odor sequences. For example, how does one draft a crossfade between two smells on a scratch-and-sniff card? Our toolkit design needed to improve upon the card form factor for scratch-and-sniff stickers.

Second, olfactory experiences can be thought of and deconstructed into component *odor sequences (E1)*. Following this, our toolkit must provide the flexibility to produce many individual odor sequences and allow designers to compare sequences easily. These findings provided design considerations and inspirations for Smell & Paste.

6 SMELL & PASTE TOOLKIT IMPLEMENTATION

With these findings, we implemented the Smell & Paste toolkit around a 3D-printed cassette (no electronics). This design builds upon the scratch-and-sniff card form factor. With Smell & Paste, designers draft odor sequences by adding stickers along the cassette's paper tape and can animate the sequence, allowing complex effects like crossfades. The cassette form factor also supports arbitrarily long odor sequences as it is compact (rolled up), like a *Compact Cassette* for music. As demonstrated in Study 3, our toolkit reliably delivers odors. Figure 7 presents the key components of Smell & Paste. We open-sourced all assembly and design files for replication, modification, and dissemination¹. We also provide a hyper-low-cost version that uses commonly available corrugated cardboard and paper towel tubes (craft tubes).

6.1 Toolkit components

Smell & Paste components were optimized to be printed with small, entry-level FDM printers. We designed the 3D models to require almost no support materials or overhangs. Alternatively, we implemented a hyper-low-cost version of the cassette with corrugated cardboard and craft tubes. We made our designs parametric to support size modifications. For example, users can change the tape width, and the 3D or cardboard cutting files will adjust accordingly.

1. Paper tape. We use inkjet or copy paper for the tape material as it is commonly available and flexible. Most scratch-and-sniff stickers adhere to it well since the paper is uncoated (or they can be glued on easily). To produce a paper tape, a user must tape together paper cut to the intended tape width. We recommend washi tape to connect paper strips (for its flexibility and thinness) and a stickier tape (e.g., gaffe tape) to connect the paper tape to two spools. The user then authors sequences by pasting stickers and can play a sequence by placing the tape (with spools) in a cassette.

2. Cassette. To assemble a cassette, the user prints and assembles the top, bottom, idle rollers, and hinges. The cassette's two slits let the user monitor the tape's progress. The idle rollers align the tape with the comb and decrease tape friction. After inserting a tape, the user closes the cassette and attaches the scratch plate.

¹https://github.com/humancomputerintegration/smell-and-paste (includes all files to produce both versions of the toolkit and a dataset of 800 commercial scent stickers).

3. Comb and scratch plate. The scratch plate is a modular attachment that clips onto the cassette and aligns the comb with the tape at the cassette's opening. The comb slots around a loaded tape and scratches its stickers. We designed the comb to print separately from the plate so future designers could make new designs and integrate them quickly into the kit. We initially made the comb entirely 3D-printed; however, three out of five participants from Study 2 mentioned the 3D-printed teeth would sometimes jam the tape. In turn, we redesigned the comb to use Velcro-like hook and loop fasteners, and Study 3 showed this new version worked reliably. We additionally ran a small pilot that further demonstrated this final comb's reliability. Over the course of scratching a five-smell sequence 105 times, the tape never got jammed and two participants had a detection rate of $100\pm0\%$ and identification rate of $85\pm14\%$ (getting better over time instead of worse) for the smells.

4. Driver. We designed a simple driver to mechanically advance the tape: a gear with a solid cantilever inserted through one cassette hole. The cantilever slides into one of the cassette holes and clicks in place, securing the driver to the spool. The user then rotates the driver to advance the tape.

5. Cassette connector. We designed an optional component that allows users to *stack* multiple cassettes, as in Figure 8. This component attaches to a cassette's bottom and exposes two cantilevers that can couple with another connector. Both the scratch plate and connector have clearance for the driver of another cassette. Connecting two cassettes can help a designer – for example – evaluate the legibility of odor interactions (sequences) happening at the same time.



Figure 8: (a) Two cassettes side-by-side and (b) two cassettes stacked together using the connectors (for multi-track mode).

6.2 Editing techniques

While we purposefully designed our low-fidelity toolkit for *simplicity*, its simplicity does not hinder its expressivity. As we now present, Smell & Paste provides simple modes of operation that, when combined, allow users to test complex odor sequences quickly. For example, users can try switching odors, fading in or out, mixing aromas in parallel, or even transferring entire chunks of a sequence

from one tape to another. These editing techniques build upon existing film, tape, and reel-based editing techniques (e.g., for film or audio) [25, 54], which are widely used and versatile.

1. Cut and paste. Our toolkit's underlying technique is cutting and pasting. Users select scratch-and-sniff stickers and cut these to fit the paper tape. By pasting several odors, they can prototype a sequence in less than a minute (Figure 9) and even control the odor's intensity by changing its surface area on the tape.



Figure 9: Designers cut and paste scratch-and-sniff stickers to form an odor sequence. Here, it would play root beer then smoothie.

2. Fade. Users can produce fade-ins and fade-outs by controlling the sticker's surface area *over time*. Figure 10 depicts two simple methods. In the first method (a), the user cuts the sticker so that it tappers or enlarges as the tape advances. Alternatively, the user can *pulsate an odor* (b) by cutting an odor into pieces and spreading the fragrance over time, which allows for more control over fading duration. Both techniques translate to *crossfades* (e.g., fade between smells).



Figure 10: (a) Fade in of smoothie scent by cutting sticker into a long triangle. (b) Fade out of root beer scent by pulsing stickers. Both techniques can be extended to crossfades.

3. Multi-track. To mix odors, users can cut thin slices of stickers and lay them side-by-side on the same tape or use connectors to smell two tapes simultaneously (Figure 11). The latter is helpful when testing scent combinations non-destructively, iterating over previously authored sequences, etc. However, while smelling two



Figure 11: Playing two smells simultaneously: (a) cutting scratch-and-sniff stickers into thinner tracks and superimposing them, or (b) using the included connector to play two independent cassettes simultaneously.



Figure 12: (a) A user will insert a recent odor sequence into (b) another previously prototyped sequence (c). They cut the base sequence (c) and then use washi tape to insert (also known as splice) the old sequence into the new one (d).

tracks is manageable, anything beyond would require the user to sweep their nose across all tapes.

4. Splice. Finally, a user can cut the paper tape to join two different areas together or introduce a new sequence. Users then use washi tape to reconnect the areas into a single tape. As shown in Figure 12, this technique enables quick reuse of previously drafted sections or could even be used to crossfade entire sequences.

6.3 Dataset of commercial scratch-and-sniff stickers

For our toolkit to be practical, users must acquire scratch-and-sniff stickers. Commercial scratch-and-sniff stickers for children are incredibly accessible and cheap, including good and bad scents. We created a dataset of 800 scratch-and-sniff stickers from 22 brands to facilitate sticker selection. We manually extracted each sticker's scent, dimensions, and price per cm². The dataset includes 538 unique scents, depicting a wide variety at costs as low as 0.00035 USD per cm².

7 STUDY 2: EXPLORING SMELL & PASTE WITH NOVICES

While novices can use paper prototyping to design and explore their first screen-based interfaces in minutes (as used in virtually all Introductory HCI classes worldwide), the same is not possible for novices who want to explore olfactory UIs. We realized that Smell & Paste's low-fidelity materials might be approachable to novices with introductory skills.

In turn, we designed our second study to explore Smell & Paste with a group of novices, recruited from an HCI class. We were interested in whether our kit (1) supported novices to quickly explore olfactory design [29, 39] and (2) what techniques emerged when using the kit. This study was approved by our Institutional Review Board (IRB 20-2071).

7.1 Participants

We deployed our study as an optional assignment in a universitylevel HCI course. Participating in the study was entirely optional for the course. We recruited seven students (three women and four men), aged 20 to 26. While five had no experience in design or engineering, two had engineering degrees. None had any prior experience conceiving olfactory applications or experiences. Participants were compensated 50 USD for their participation.

7.2 Procedure

Participants received a toolkit with two cassettes and 41 different scratch-and-sniff odors. We also provided a short video tutorial. As the study occurred during social distancing measures, participants received their toolkits by mail.

We assigned design prompts to allow a refined analysis of the design and prototyping experience [41, 46, 52, 53]. See Table 3. The prompts reflected a small variety of previous olfactory applications from HCI (notifications [30] and games [38]) and product design [65]. As participants had no experience conceiving olfactory applications, providing prompts let them focus on the olfactory interaction design. In turn, this focus allowed us to observe their techniques with our kit and whether the toolkit supported rapid exploration of olfactory design [29]. We randomly assigned prompts to all participants (P1-5), while, given the engineering backgrounds of P6 & P7, we assigned them a prompt to test the kit's flexibility for add-ons. Upon finishing, participants submitted at least three process photos and a video of their prototype(s) that explained their work. Participants could also provide written feedback on our toolkit.

7.3 Results

We clustered our findings into nine categories based on the video, photo, and open feedback analysis. Smell & Paste enabled participants to rapidly draft lo-fi prototypes of their olfactory experiences (see Figure 13). Participants enjoyed prototyping their experiences with Smell & Paste. P1 stated that it was a "great experience" and "incredibly useful to have a physical form as a starting point for brainstorming and prototyping." P2 and P3 appreciated the variety and realism of the scratch-and-sniff smells and stated that "it was very fun using this smell kit" (P2).

1. Smell & Paste allowed novices to draft lo-fi prototypes exploring all key olfactory design features. Each participant (P1-5) explored chemical, emotional, spatial, and temporal design features in detail. P4 and P5 conveyed information through established scent-associations to provide information about the visual, spatial, and temporal qualities of their makeup products and iterated on these aspects. We now present focused examples from P1 and P2 to further exemplify the design ideas participants were able to quickly draft and evaluate with Smell & Paste.

P1 began prototyping their "Olfactory Pomodoro timer" by testing whether "certain aromas may perceptually and materially improve concentration, task lag time" (P1). They iterated over two key Table 3: Participants, their design prompt, and prototyped experience summary from Study 2. As participants had no experience conceiving olfactory applications, we provided these prompts to inspire participants and encourage using smells.

Participant	Prompt	Description	Resulting prototypes from participant
P1	1	Design an olfactory notification system.	Pomodoro-timer with olfactory notifications conveying timer state and urgency.
P2	2	Design smell interactions for a game.	Interactive odor cues for <i>Mario Kart & Pokémon Go</i> , as well as olfactory versions of popular board games, a smell escape room puzzle, a smell maze.
P3	2	Design smell interactions for a game.	Olfactory Pictionary.
P4	3	Design olfactory experiences for a user interacting with two makeup products.	Face mist that conveys its fragrance and functionality (spray) before use.
Р5	3	Design olfactory experiences for a user interacting with two makeup products.	Eye shadow palette with scents matching shades. Lipstick, whose odor presents its shade and changes if it's fresh or expired.
P6 (engineer)	4	Engineer an add-on for the toolkit's cassette.	Add-on to automatically advance and rewind the cassette.
P7 (engineer)	4	Engineer an add-on for the toolkit's cassette.	Adapter to turn cassettes into an automated olfactory interface for VR headsets.



Figure 13: Participants made lo-fi prototypes by taking their design ideas and repeatedly (1) drafting with stickers, (2) loading tapes into cassettes, and (3) testing their ideas with their nose. Photos by and reproduced with the permission of participants.

aspects: the chemical and emotional features of selected odors and their semantic meanings. They tested if scents felt like (1) "boost one's state" and (2) "motivate to work". For the start-time interaction, they compared and experimented with lemon to reduce stress or peppermint to increase concentration, settling for the latter after trying both options in the prototypes ("my experience with peppermint smell was poignant stimulation"). For their break-time notification, they compared lavender for its "known relaxation properties" and menthol as a simpler stimulator (a component of peppermint), settling for menthol. Then, P1 also experimented with "more pungent" and "strong smells to encourage users to resume timer and work intervals" that conveyed a semantic sense of urgency. They selected and compared star anise, cinnamon, hay, manure, wet dirt, and campfire from the kit. P1 then arranged and composed scent notifications according to pungency and semantic meaning to convey urgency: hay for five idle minutes (slightly unpleasant), a manure and wet dirt combo for ten idle minutes ("funky"), and

burning campfire for fifteen idle minutes (strong, pungent, and semantically urgent).

For P2, who delivered several lo-fi prototypes, we focus on their most advanced one: odor interactions for *Mario Kart*. P2 compared and combined scents for different effects after drafting and iterating on individual sequences. For the squid ink penalty (screen blocked by ink), P2 experimented with translating its visual mechanism to scent by using strange combinations with abrupt transitions to confuse and distract the player. They tried many combinations of smells and eventually settled on three "stranger" composite odors "so that scent changes *are* distracting" (emphasis by P2): smell one with bubblegum, rose, and manure; smell two with tomato, cotton candy, and campfire; and smell three with cake, new car, and corn. In contrast, P2 designed the invincibility power-up to "do gradual scent transitions [with] familiar scents [...] so that the scent changes are not distracting," selecting "pleasant scents" like strawberry, chocolate, and lilac. The cassette allowed P2 to iterate and refine



Figure 14: Participants cut stickers to control their intensity. P2 used two methods: (a, b) long triangles for fades followed by a burst (clear stickers) and (c) transitions by staircases between odors. Photos by and reproduced with P2's permission.

the sequence transitions): "scents for invincibility are tessellated for smoother scent transitions"; "scents for squid ink have gaps (...) for abrupt transitions"; and "speed boost has one segment for a briefer scent experience" whereas "invincibility and squid ink each have three segments, since these are meant to be experienced for a longer time." P2 additionally drafted scent interactions that conveyed spatial information (competitors approaching), semantic information (fish for incoming tortoise shell), and more.

2. Participants rapidly drafted and iterated on many lo-fi prototypes. Not only did all participants complete their prototypes within the assignment timeframe, but they produced iterations. Alongside *Mario Kart interactions*, P2 initially rapidly prototyped olfactory interactions for a battery of other games: *Hide and Seek* (imagining scents for each player that would get stronger when approaching); an interactive maze in which two cassettes encode the solution (left vs. right turns); an envisioned expansion to *Pokémon Go* (including scents for spatial information and monster states); and more. Participants also reported completing many iterations of odor sequences and composed smells (P2, P4, P5).

3. Smell & Paste paired well with established lo-fi prototyping strategies. Participants combined Smell & Paste with other prototyping strategies. **(1) Paper prototype:** P1, P3, and P4 used our toolkit with the more traditional paper prototyping, especially for interactive applications well suited for this method, such as P1's screen-based UI for a Pomodoro timer complemented with olfactory notifications. **(2) Wizard-of-Oz:** P2 used our toolkit in combination with Wizard-of-Oz, in which they "played the scent tapes" while a friend played the actual game of *Mario Kart*. This combination let P2 quickly prototype by querying the user on how the smell interactions contribute to the experience. P3 similarly leveraged this combination to test their olfactory game with a roommate. P5 did this when possible, such as advancing or rewinding the tape while opening their lipstick. (3) Video prototype: P2 also employed our toolkit with prerecorded videos of *Mario Kart* runs, allowing them to iterate quickly over a sequence until it felt right.

4. Participants iterated on sticker size to control and test odor intensity. Participants tested and controlled an odor's intensity over time by cutting the sticker into smaller or larger areas. As shown in Figure 14, P2 prototyped interactions to convey approaching vehicles (fading natural gas) and collisions (burst of wet dirt). By changing a sticker's thickness for intensity and length for the duration, P2 experimented with transitions, such as homing in on noticeable switches between disparate scents for squid ink to fade-ins to convey approaching competitors.

P4 used scent intensity the most in their face mist interaction prototypes. They prototyped how to encode the product's delivery mechanism (spray) before use through scent, settling on a prototype that delivered a sudden strong watermelon scent that quickly fades when the user opens the face mist's cap. They used a second cassette to precisely control the watermelon scent's intensity (more surface area to work with) and add short bursts of vanilla.

5. Stickers can be combined to compose a new scent. Participants prototyped not only sequences but also *new scents* by recombining scratch-and-sniff stickers. For example, P4 tried to



Figure 15: An example of how participants prototyped not only an interactive odor release but also mixed new fragrances (P4).

Jas Brooks and Pedro Lopes

CHI '23, April 23-28, 2023, Hamburg, Germany



Figure 16: P5 used advancing and rewinding to prototype an interaction that branched based on whether an envisioned interactive lipstick was fresh or expired. Photos by and reproduced with P5's permission.



Figure 17: (a, b) P2 separated scent-triggering events across two stacked cassettes. (c) P2 also embedded notes directly on the tape to keep track of prototyped interactions, such as "close" and "hit". Photos by and reproduced with P2's permission.

compose a powdery smell. They first investigated what fragrance notes produced powdery perfumes, identifying rose, vanilla, cake, and lavender. They then tested and combined those odors at various intensities to create a new identifiable scent. P2 also used a similar technique for their more complex odor-releasing *Mario Kart* game events. P4 took this a step further and prototyped conveying the makeup's state (closed, opened, in-use) by subtly changing the component odors' intensities, see Figure 15. P3's entire prototype relied on scent composition, as players craft new scents and sequences to convey a prompt to others.

6. Participants developed strategies to map branching experiences onto the tape. We observed different approaches to mapping branching experiences onto the cassette's linear structure. P5 used advancing and rewinding the cassette to encode and proto-type branching states, with the area at the opening representing the branching point.

For instance, P5 translated the eye shadow palette's physical layout by splitting it at the central eye shadow and letting the user move the tape either left for the shades to the left or right for the matching shades. This participant reapplied the technique to prototype their lipstick interaction in which its odor changes to convey whether it is fresh or expired, as shown in Figure 16. If the lipstick is fresh, the user rewinds to receive a lemon odor (refreshing) followed by cherry (smell-color association). If the lipstick is expired, the user advances the tape and gets a corn odor.

For their Pomodoro-timer, P1 prototyped odor sequences for each machine state in separate areas. P1 used advancing and rewinding to different regions to then test certain decisions. In contrast, P2 leveraged two *connected cassettes* to prototype an olfactory experience accompanying *Mario Kart*), see Figure 17. P2 used two tapes for two types of scent interactions: one for spatial interactions (i.e., a kart approaching and colliding) and another for power-ups (player state). Using two cassettes allowed them to quickly test how the experience would smell when interactions of two types occurred concurrently and then adjust the odors to make them mutually intelligible.

7. Participants took notes directly on the tape. For example, P2 prototyped their interactions in separate areas of the tapes with no specific order, so they wrote each sequence's name on the tape, as seen in Figure 17 (b).

8. Participants redrafted sequences instead of splicing. Participants found it quicker and more convenient to redraft sequences in blank areas than to splice sequences. This approach enabled them to compare variations.

9. Smell & Paste is modifiable. The two participants with an engineering background (P6-7) found the toolkit customizable. P6 altered the cassette to advance automatically, as seen in Figure 18 (a), adding a motor inside the cassette. P7 prototyped an add-on that adapted their cassette into a VR-ready digital olfactory display, as seen in Figure 18 (b).

Suggested improvements. While participants found the kit useful for lo-fi prototyping (P1-5), participants also provided suggestions for improvement. Three participants (P2, P4, P5) noted that the 3D-printed comb teeth occasionally jammed if several scratchand-sniff stickers overlapped. P5 wished synchronizing movements between cassette advancing or rewinding and interacting with another object were easier. P4 suggested adding tactile markers to the



Figure 18: (a) Two iterations of P6's add-on that automatically advanced their cassette. (b) Progress images from P7's adapter to turn cassettes into automatic olfactory interfaces for VR headsets. Photos by P6 and P7 and reproduced with participants' permission.

tape to allow users to gauge where they are on the tape without looking down.

Fixes. We resolved jamming issues by redesigning the comb to use hook-and-loop fasteners (Velcro) as teeth instead. These fasteners are stiff enough to scratch the stickers' surface and flexible enough to let arbitrarily thick tapes pass.

8 STUDY 3: TOOLKIT IN EXPERTS' ACTIVITIES

Finally, we engaged with olfactory experts to understand their impression of the kit and determine its potential when integrated into their practices. This study was approved by our Institutional Review Board (IRB20-2071).

8.1 Participants

We recruited experts E1 and E3 from Study 1 for their extensive experience designing olfactory experience for diverse audiences (children, people with disabilities, etc.) and because they had reported having enough time to evaluate the kit in their professional practices. Both received a 50 USD gift card for their time. As we were interested in the kit's applicability in expert work, we did not provide prompts. Instead, we asked the experts to experiment with the kit in their olfactory practice for two weeks. Participants then provided documentation (photos and videos) and feedback via Zoom. As the study occurred during social distancing measures, participants received their toolkits by mail.

E1 decided to use the toolkits in a workshop with kids. This participant requested four full toolkits. E1 prototyped a workshop for children (aged 7 and 9.) E1 designed a curriculum with the kits in which children compose scent tracks to train each other's noses and then produce interactive smell stories for their parents. Both children were authorized to participate in the workshop by their parents. Their parents provided permission to reproduce and use documentation. E1 was able to conduct the workshop as their country allowed small gatherings during quarantine.

E3 decided to test the toolkit to prototype olfactory movie experiences. This participant requested a single kit. Over the two weeks, E3 experimented with their kit to uncover its potential use in their olfactory film practice. For this, they recruited their spouse as a participant to iterate over odor sequences.

8.2 Results

Even though the two activities were very different, their results provided common ground. Following this, we decided to cluster the separate findings into three combined themes based on the video, photo, and feedback analysis.

1. Experts would use Smell & Paste in their work. E1 stated that they would use the toolkit again. Likewise, E3 began imagining possible ways to extend the toolkit, namely motorizing the cassette to play in sync with a game.

2. Smell & Paste provides technical and tangible affordances. E3 found that the cassette and comb worked successfully, similarly echoed by E1's successful workshop with children. E3 stated odors "only lingered for a short period after passing the comb" and that "odors directly under the nose were stronger than accumulated odors from the spooled tape" (E1 mentioned this too). For subtle smells, E3 recommended spacing out stickers by approximately 4-6 cm to produce bursts that faded quickly, stating "more complex odors needed additional space". E1 and E3 highlighted Smell & Paste's ability to rapidly draft sequences: "this [toolkit] is really useful [...] because it gives you a sequence" (E3).

E1 and E3 also praised the cassette's design, requiring little to no explanations. E1 did not show the children our tutorials and reported "they had no problem using" it, stating "the mechanical design is straightforward and communicates its functionality." Moreover, both agreed that toolkit assembly was easy: E1 said it was "incredibly simple" and they did so without watching the tutorial.

3. The cassette form factor provided surprise. E3 mentioned they entered the study believing the cassettes "could be really fun as a toy" while being skeptical of the benefits over a typical scratchand-sniff card, which they had previously worked with and designed. However, upon using the toolkit, they "immediately realized a big advantage: the cassette can hide the stickers' visuals." Moreover, E3 raised one more added benefit compared to traditional scratch-and-sniff cards: "even with a scratch-and-sniff card that doesn't indicate the smell, one can sniff around at the card ahead of time and have an idea of what's to come, and who could resist that. But [...] hidden inside the cassette, there's no way to know what scent is coming next." Furthermore, E1 mentioned using this "surprise effect" to let the children train each other's noses, as depicted in Figure 19 (a).

The children created their own odor sequences, which they presented to each other as a smell identification game. They then independently explored which odors worked well and could be integrated into their interactive stories. In just one afternoon, both children drafted and iterated over interactive olfactory stories, sharing their experiences with their mom at the end of the workshop as seen in Figure 19 (b).

Suggested improvements and considerations. Experts noted that the driver's cantilevers could snap if carelessly inserted or removed (E3). E1 reflected on their experience using our toolkit



Figure 19: (a) The kids taking turns testing each other's ability to identify the odors on a tape. (b) Their mom smelling the interactive olfactory story they drafted. Photos by E1 and reproduced with participant and parents' permission.

with the children's workshop, noting that selecting odors took more time than necessary. We provided 41 different scratch-andsniff odors with our toolkit, which E1 found overwhelmingly vast for children to explore in a limited time. Finally, E1 suggested that a thicker and bigger version of a tape (closer to a VHS size) might help those with less dexterity (including children).

We found E1's thickness suggestion important and easily actionable. We made our files parametric, allowing designers to choose their desired tape width and cassette dimensions. All parts will then adjust accordingly. Additionally, E1 and E3's experience with the cassettes proves that they work reliably and do not jam with the new combs.

9 RECOMMENDATIONS FOR USING OR DEPLOYING SMELL & PASTE

Based on insights gained from Studies 2 and 3, we now synthesize eight recommendations for prospective designers interested in using Smell & Paste to prototype olfactory experiences or disseminating the toolkit for their studies:

1. Use Smell & Paste to draft and evaluate design choices quickly and frequently. Smell & Paste works well to lo-fi prototype long or short interactive sequences and quickly compare isolated interactions. For example, a designer can fine-tune which smells are released when the player receives a power-up in *Mario Kart.* To make the most of Smell & Paste, we recommend using the toolkit early and frequently in the design phase.

2. Smell & Paste is easy to use for experts and novices. As evidenced by Study 2 and E1's workshop with two children in Study 3, Smell & Paste's form factor is intuitive. Since Smell & Paste uses scratch-and-sniff stickers instead of liquid fragrances, there is also little need to train designers on *how to smell and handle fragrances* before developing an interactive olfactory experience. Moreover, Smell & Paste may not even need a video tutorial (E1). This ease-of-use contrasts with other kits requiring multipage brochures or manuals [26, 27] and instructions [24]. Additionally, unlike handling fragrances, which require safety practices, commercial scratch-and-sniff stickers are safety compliant for even children. Experts and novices can handle them with no worries.

3. Smell & Paste produces lo-fi olfactory prototypes that can be stored and shared. While the kit supports radical and destructive drafting (e.g., tossing entire sections), the resulting lofi prototypes are long-lasting and keep smelling even after many scratches. For example, Study 1's E3 mentioned their 1981 scratchand-sniff cards still smell, and sequences we produced for pilots smell even two years later. Additionally, both participants in Study 2 and 3 were excited about sharing their prototypes with friends and family. The Study 3 experts also highlighted Smell & Paste prototypes' ability to be shipped without restrictions or special handling. Several mentioned experiencing issues transporting materials for interactive exhibits due to restrictions on fragrances. This problem often prevented them from mailing or bringing early prototypes to museums or theaters.

4. Document directly on the paper tape. Designers can annotate tapes by writing on them, e.g., notes for timing cues, labels for a particular interaction, etc. We recommend this practice to keep track of and draft sequences so that designers can return to their lo-fi prototypes later with context (just like in programming).

5. Scratch-and-sniff stickers provide a great variety of smells but pre-select them for a quick start with children. While adults had no problem smelling and choosing from an extensive library of smells (41 provided in kits), this variety overwhelmed children and had them spend too much time sniffing scents before prototyping. Per E1's suggestion, we recommend designers pre-select relevant odors when working with children.

6. Modify the kit as desired. We encourage prospective users to adapt the kit to their needs. First, the mechanical design of Smell & Paste is parametric. Per E1's expertise with children and disabled people, we recommend printing a version of the cassette with wider tape to let those with less dexterity handle it better. Second, pairing the cassette with braille labels may allow blind and visually impaired designers to use the kit. Finally, designers can extend the cassette with electronics for new applications, such as automated playback. For example, we produced a hyper-low-cost version of our cassette from commonly available corrugated cardboard; Figure 20 shows one made from an Amazon package.

7. Combine or transition to hi-fi smell toolkits. Smell & Paste - and lo-fi methods in general - mark the start of prototyping an interactive experience, not its end. We encourage prospective designers to transition from their lo-fi prototypes, created using Smell & Paste, to hi-fi toolkits or even combine Smell & Paste with hi-fi techniques. We present examples with existing kits. (1) Combine with physical hi-fi olfactory toolkits: In Lai and Cao's toolkit workshop [24], participants used visual sketches as early prototypes prior to engaging with the hi-fi toolkit. By combining a lo-fi toolkit, such as Smell & Paste, participants can couple their lo-fi sketches with lo-fi smell prototypes, allowing them to transition more smoothly to the higher-fidelity hardware. Similarly, combining Smell & Paste in the O&O workflow might provide designers an opportunity to test and iterate on ideas in the early design phases (e.g., in the "Prototype" and "Test" steps of the manual [26]) before committing days to a hi-fi O&O prototype. Additionally, O&O's design manual could be paired with Smell & Paste to provide a structured thought process for designing for the smell in all prototyping stages. (2) Combine with software hi-fi olfactory toolkits: Smell & Paste's linear structure may translate well to OWidgets'



Figure 20: Our variation on the cassette made entirely of commonly available corrugated cardboard, one cardboard craft tube cut in two, paper, and a strip of Velcro. This variation can be cut by hand using an X-Acto knife and assembled with everyday glue.

similar linear timeline editor [31], and – vice versa – a prospective designer might test an OWidgets sequence without hardware to dispense smells.

10 CONCLUSIONS

This paper proposed Smell & Paste, the first prototyping toolkit for olfactory design that enables a structured workflow for lo-fi olfactory prototyping. Our findings suggest that Smell & Paste enables rapid and cheap prototyping of smell experiences, is approachable to people of any technical background, and is extensible. From the studies, we improved the toolkit's design and extracted recommendations for prospective designers interested in using Smell & Paste.

We believe our toolkit might accelerate and make olfactory prototyping more approachable across various fields, including HCI, design, and education. As part of these efforts, we provide our toolkit as open-source with a dataset of 800 commercial scratch-and-sniff stickers. Alongside our expert interview insights and toolkit, we believe these efforts form the groundwork to investigate future research questions, such as how olfactory experience designers could transition from low-fidelity and high-fidelity prototypes to final experiences. Exploring this area is imperative to support the development of new, rich olfactory experiences.

ACKNOWLEDGMENTS

We want to thank the experts (including Tammy Burnstock, Megan Dickerson, Clinton McClung, Simon Niedenthal, Al Lowe, Steve Meretzky, and Heather Kelley), the participants from Study 2, and the children and parents in the workshop who graciously contributed their time, expertise, and creativity to this work. Thanks to our colleagues at the Human-Computer Integration Lab, Alex Mazursky and Yudai Tanaka, for their help and time putting together toolkits for Study 2 amid quarantine and their feedback on the paper, and Noor Amin for her input on the paper. This material is supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. (DGE-1746045). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

- Judith Amores, Mae Dotan, and Pattie Maes. 2022. Development and Study of Ezzence: A Modular Scent Wearable to Improve Wellbeing in Home Sleep Environments. Frontiers in Psychology 13: 791768. https://doi.org/10.3389/fpsyg. 2022.791768
- [2] Judith Amores and Pattie Maes. 2017. Essence: Olfactory Interfaces for Unconscious Influence of Mood and Cognitive Performance. In Proceedings of the 2017

CHI Conference on Human Factors in Computing Systems Pages 28-34, 28–34. https://doi.org/10.1145/3025453.3026004

- [3] Oliver Baus and Stéphane Bouchard. 2017. Exposure to an unpleasant odour increases the sense of Presence in virtual reality. *Virtual Reality* 21, 2: 59–74. https://doi.org/10.1007/s10055-016-0299-3
- [4] Beverly Birns and Dale Hay (eds.). 1988. Mothers Who Are Disabled. In The Different Faces of Motherhood. Springer US. https://doi.org/10.1007/978-1-4899-2109-3
- [5] Jas Brooks, Steven Nagels, and Pedro Lopes. 2020. Trigeminal-based Temperature Illusions. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, 1–12. https://doi.org/10.1145/3313831.3376806
- [6] Marion Buchenau and Jane Fulton Suri. 2000. Experience prototyping. In Proceedings of the conference on Designing interactive systems processes, practices, methods, and techniques - DIS '00, 424-433. https://doi.org/10.1145/347642.347802
- [7] Philip Burnard. 1991. A method of analysing interview transcripts in qualitative research. Nurse Education Today 11, 6: 461-466. https://doi.org/10.1016/0260-6917(91)90009-Y
- [8] Constance Classen, David Howes, and Anthony Synnott. 1994. Aroma: the cultural history of smell. Routledge, London; New York.
- [9] W. Colenso. 1893. Ancient Maori Perfumes. Bay of Plenty Times, 6.
- [10] James A. Covington, Samuel O. Agbroko, and Akira Tiele. 2018. Development of a Portable, Multichannel Olfactory Display Transducer. *IEEE Sensors Journal* 18, 12: 4969–4974. https://doi.org/10.1109/JSEN.2018.2832284
- [11] David Dobbelstein, Steffen Herrdum, and Enrico Rukzio. 2017. inScent: a wearable olfactory display as an amplification for mobile notifications. In Proceedings of the 2017 ACM International Symposium on Wearable Computers, 130–137. https: //doi.org/10.1145/3123021.3123035
- [12] M Falck and D Schaffelaars. 1999. Geur & ontwerp. Zoo Producties, Eindhoven, Netherlands.
- [13] John C. Flanagan. 1954. The critical incident technique. Psychological Bulletin 51, 4: 327–358. https://doi.org/10.1037/h0061470
- [14] Elizabeth Gerber and Maureen Carroll. 2012. The psychological experience of prototyping. *Design Studies* 33, 1: 64–84. https://doi.org/10.1016/j.destud.2011.06. 005
- [15] Paula Hamilton. 2001. Monthly Themes and Learning Centers for Young Children with Visual and Multiple Impairments. U.S. Department of Education Office of Educational Research and Improvement. Retrieved from https://files.eric.ed.gov/ fulltext/ED460561.pdf
- [16] Sadakichi Hartmann. 1902. A Trip to Japan in Sixteen Minutes. Retrieved from https://believermag.com/a-trip-to-japan-in-sixteen-minutes/
- [17] Keisuke Hasegawa, Liwei Qiu, and Hiroyuki Shinoda. 2018. Midair Ultrasound Fragrance Rendering. *IEEE Transactions on Visualization and Computer Graphics* 24, 4: 1477–1485. https://doi.org/10.1109/TVCG.2018.2794118
- Morton Heilig. 1962. Sensorama simulator. Retrieved from https://patents.google. com/patent/US3050870A/en
- [19] David Howes. 2008. Olfaction and transition: an essay on the ritual uses of smell. Canadian Review of Sociology/Revue canadienne de sociologie 24, 3: 398–416. https://doi.org/10.1111/j.1755-618X.1987.tb01103.x
- [20] Benine Janssen and René Toet. 2004. Top of flop: Fred&Ed, zoet broodbeleg uit een tube. *Marketing online*. Retrieved February 24, 2009 from http://web.archive.org/web/20090224013640http://www.marketingonline.nl/ topofflop/case01.2004.html
- [21] J. S. Jellinek. 2004. Proust Remembered: Has Proust's Account of Odor-cued Autobiographical Memory Recall Really been Investigated? *Chemical Senses* 29, 5: 455–458. https://doi.org/10.1093/chemse/bjh043
- [22] Dong Wook Kim, Kazushi Nishimoto, and Susumu Kunifuji. 2006. An Editing and Displaying System of Olfactory Information for the Home Video. In Knowledge-Based Intelligent Information and Engineering Systems, Bogdan Gabrys, Robert J. Howlett and Lakhmi C. Jain (eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 859–866. https://doi.org/10.1007/11893011_109
- [23] Myron Krueger. 1996. Addition of Olfactory Stimuli to Virtual Reality Simulations for Medical Training Applications. U.S. Army Medical Research and Material Command, Fort Detrick, Frederick, Maryland, USA. Retrieved from https://apps.

CHI '23, April 23-28, 2023, Hamburg, Germany

dtic.mil/dtic/tr/fulltext/u2/b220530.pdf

- [24] Mei-Kei Lai and Yan Yan Cao. 2019. Designing Interactive Olfactory Experience in Real Context and Applications. In Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction, 703–706. https: //doi.org/10.1145/3294109.3295659
- [25] Mark Le Fanu. 1998. On Editing. p.o.v. A Danish Journal of Film Studies, 6. Retrieved from https://pov.imv.au.dk/pdf/pov6.pdf#page\$=\$5
- [26] Yuxuan Lei, Qi Lu, and Yingqing Xu. 2022. O&O: A DIY toolkit for designing and rapid prototyping olfactory interfaces. In CHI Conference on Human Factors in Computing Systems, 1–21. https://doi.org/10.1145/3491102.3502033
- [27] Susana Cámara Leret and Valentijn Visch. 2017. From Smells to Stories: The Design and Evaluation of The Smell Memory Kit. International Journal of Design 11, 1: 65–77.
- [28] Al Lowe and Steve Conrad. 1996. Leisure Suit Larry: Love for Sail!
- [29] Emanuela Maggioni, Robert Cobden, Dmitrijs Dmitrenko, Kasper Hornbæk, and Marianna Obrist. 2020. SMELL SPACE: Mapping out the Olfactory Design Space for Novel Interactions. ACM Transactions on Computer-Human Interaction 27, 5: 1–26. https://doi.org/10.1145/3402449
- [30] Emanuela Maggioni, Robert Cobden, Dmitrijs Dmitrenko, and Marianna Obrist. 2018. Smell-O-Message: Integration of Olfactory Notifications into a Messaging Application to Improve Users' Performance. In Proceedings of the 2018 on International Conference on Multimodal Interaction - ICMI '18, 45–54. https: //doi.org/10.1145/3242969.3242975
- [31] Emanuela Maggioni, Robert Cobden, and Marianna Obrist. 2019. OWidgets: A toolkit to enable smell-based experience design. *International Journal of Human-Computer Studies* 130: 248–260. https://doi.org/10.1016/j.ijhcs.2019.06.014
- [32] Anijo Punnen Mathew, Tom MacTavish, Jared Donovan, and Laurens Boer. 2010. Materialities influencing the design process. In Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS '10, 444. https://doi.org/10.1145/ 1858171.1858262
- [33] Haruka Matsukura, Hironori Hashiguchi, and Hiroshi Ishida. 2017. Tracking of a Gas Plume With the Aid of Olfactory Assist Mask. *IEEE Sensors Journal* 17, 16: 5332–5340. https://doi.org/10.1109/JSEN.2017.2721968
- [34] David Maulsby, Saul Greenberg, and Richard Mander. 1993. Prototyping an intelligent agent through Wizard of Oz. In Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '93, 277–284. https://doi.org/10. 1145/169059.169215
- [35] Steve Meretzky. 1986. Leather Goddesses of Phobos.
- [36] Jacquelyn Morie. 2012. The Scent Collar: a wearable scent delivery device. Institute for Creative Technologies. Retrieved from http://ict.usc.edu/wp-content/uploads/ 2012/03/ScentCollarBrochure1.pdf
- [37] Rachel Murphy and David Frohlich. Apparatus and a method for recording and reproducing scent or taste. Retrieved from https://patents.google.com/patent/ US20040077424A1/en
- [38] Simon Niedenthal. 2012. Skin Games: Fragrant Play, Scented Media and the Stench of Digital Games. *Journal for Computer Game Culture* 6, 1: 101–103.
- [39] Marianna Obrist, Alexandre N. Tuch, and Kasper Hornbaek. 2014. Opportunities for odor: experiences with smell and implications for technology. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2843–2852. https://doi.org/10.1145/2556288.2557008
- [40] Marianna Obrist, Carlos Velasco, Chi Vi, Nimesha Ranasinghe, Ali Israr, Adrian Cheok, Charles Spence, and Ponnampalam Gopalakrishnakone. 2016. Sensing the future of HCI: touch, taste, and smell user interfaces. *Interactions* 23, 5: 40–49. https://doi.org/10.1145/2973568
- [41] Harold Ossher, Bonnie John, Michael Desmond, and Rachel Bellamy. 2010. Are Flexible Modeling Tools Applicable to Software Design Discussions? IBM, Austin, Texas, USA. Retrieved from https://dominoweb.draco.res.ibm.com/ reports/rc24949.pdf
- [42] Chomtip Pornpanomchai, Arinchaya Threekhunprapa, Krit Pongrasamiroj, and Phichate Sukklay. 2009. SUBSMELL: Multimedia with a Simple Olfactory Display. In Advances in Image and Video Technology, Toshikazu Wada, Fay Huang and Stephen Lin (eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 462–472. https: //doi.org/10.1007/978-3-540-92957-4_40
- [43] Nimesha Ranasinghe, Chow Eason Wai Tung, Ching Chiuan Yen, Ellen Yi-Luen Do, Pravar Jain, Nguyen Thi Ngoc Tram, Koon Chuan Raymond Koh, David Tolley, Shienny Karwita, Lin Lien-Ya, Yan Liangkun, and Kala Shamaiah. 2018. Season Traveller: Multisensory Narration for Enhancing the Virtual Reality Experience. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, 1–13. https://doi.org/10.1145/3173574.3174151
- [44] Marc Rettig. 1994. Prototyping for tiny fingers. Communications of the ACM 37, 4: 21-27. https://doi.org/10.1145/175276.175288
- [45] Celine E. Riera, Eva Tsaousidou, Jonathan Halloran, Patricia Follett, Oliver Hahn, Mafalda M.A. Pereira, Linda Engström Ruud, Jens Alber, Kevin Tharp, Courtney M. Anderson, Hella Brönneke, Brigitte Hampel, Carlos Daniel de Magalhaes Filho, Andreas Stahl, Jens C. Brüning, and Andrew Dillin. 2017. The Sense of Smell Impacts Metabolic Health and Obesity. *Cell Metabolism* 26, 1: 198-211.e5. https://doi.org/10.1016/j.cmet.2017.06.015

- [46] Emma Rose, Andrew Davidson, Elena Agapie, and Kiley Sobel. 2016. Designing our future students: Introducing User Experience to teens through a UCD charette. In Proceedings of the 34th ACM International Conference on the Design of Communication, 1–6. https://doi.org/10.1145/2987592.2987618
- [47] Jim Rudd, Ken Stern, and Scott Isensee. 1996. Low vs. high-fidelity prototyping debate. *Interactions* 3, 1: 76–85. https://doi.org/10.1145/223500.223514
- [48] Rachel S. Herz. 2021. Olfactory Virtual Reality: A New Frontier in the Treatment and Prevention of Posttraumatic Stress Disorder. *Brain Sciences* 11, 8: 1070. https: //doi.org/10.3390/brainsci11081070
- [49] Jürgen Sauer, Katrin Seibel, and Bruno Rüttinger. 2010. The influence of user expertise and prototype fidelity in usability tests. *Applied Ergonomics* 41, 1: 130– 140. https://doi.org/10.1016/j.apergo.2009.06.003
- [50] Mark Saunders. 2018. U.S. Postal Service's First Scratch-and-Sniff Stamps Evoke a Sweet Summer Scent. United States Postal Service. Retrieved from https://about. usps.com/news/national-releases/2018/pr18_040.htm
- [51] Sue Ann Seah, Diego Martinez Plasencia, Peter D. Bennett, Abhijit Karnik, Vlad Stefan Otrocol, Jarrod Knibbe, Andy Cockburn, and Sriram Subramanian. 2014. SensaBubble: a chrono-sensory mid-air display of sight and smell. In Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14, 2863-2872. https://doi.org/10.1145/2556288.2557087
- [52] Kristen Shinohara, Cynthia L. Bennett, Wanda Pratt, and Jacob O. Wobbrock. 2018. Tenets for Social Accessibility: Towards Humanizing Disabled People in Design. ACM Transactions on Accessible Computing 11, 1: 1–31. https://doi.org/10. 1145/3178855
- [53] Kristen Shinohara, Nayeri Jacobo, Wanda Pratt, and Jacob O. Wobbrock. 2020. Design for Social Accessibility Method Cards: Engaging Users and Reflecting on Social Scenarios for Accessible Design. ACM Transactions on Accessible Computing 12, 4: 1–33. https://doi.org/10.1145/3369903
- [54] Fredrick Y. Smith. 1942. The Cutting and Editing of Motion Pictures: The Physical Aspect. Journal of the Society of Motion Picture Engineers 39, 11: 284–293. https: //doi.org/10.5594/J14295
- [55] R. J. Stevenson. 2010. An Initial Evaluation of the Functions of Human Olfaction. Chemical Senses 35, 1: 3–20. https://doi.org/10.1093/chemse/bjp083
- [56] Graciela Tiscareño-Sato. 2009. Braille for My Baby: Six Things You Can Do at Home for Your Young Blind Child. *Future Reflections 28.* Retrieved from https://www.nfb.org/sites/www.nfb.org/files/images/nfb/publications/fr/ fr28/fr280113.htm
- [57] Daisuke Uriu, William Odom, Mei-Kei Lai, Sai Taoka, and Masahiko Inami. 2018. SenseCenser: an Interactive Device for Sensing Incense Smoke & Supporting Memorialization Rituals in Japan. In Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems, 315–318. https://doi.org/ 10.1145/3197391.3205394
- [58] Philipp Wintersberger, Dmitrijs Dmitrenko, Clemens Schartmüller, Anna-Katharina Frison, Emanuela Maggioni, Marianna Obrist, and Andreas Riener. 2019. S(C)ENTINEL: monitoring automated vehicles with olfactory reliability displays. In Proceedings of the 24th International Conference on Intelligent User Interfaces IUI '19, 538–546. https://doi.org/10.1145/3301275.3302332
- [59] T. Yamada, S. Yokoyama, T. Tanikawa, K. Hirota, and M. Hirose. 2006. Wearable Olfactory Display: Using Odor in Outdoor Environment. In *Proceedings of the IEEE* conference on Virtual Reality 2006, 199–206. https://doi.org/10.1109/VR.2006.147
- [60] Yasuyuki Yanagida, Haruo Noma, Nobuji Tetsutani, and Akira Tomono. 2003. An unencumbering, localized olfactory display. In CHI '03 extended abstracts on Human factors in computing systems - CHI '03, 988. https://doi.org/10.1145/765891. 766109
- [61] 1967. The fragrance of Imprévu is right here, in this yellow strip. McCall's 3.
- [62] 1981. Polyester. New Line Cinema.
- [63] 2016. Kaanga Wai Cured corn 1.0. horiandhorier. Retrieved December 12, 2022 from https://horiandhorier.wordpress.com/2016/03/28/kaanga-wai-cured-corn-1-0/
- [64] 2019. The Beach Bum. Neon.
- [65] 2021. Molly Burke Reviews: Blind Accessibility of Beauty Products. Allure. Retrieved from https://www.youtube.com/watch?v\$=\$u2Xx_C5X9lM