Educating the Next Generation of Makers - On Supporting Children's Needs in Tools for Digital Fabrication

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ABSTRACT

We introduced children from different backgrounds to 3D modeling and printing utilizing playful tools like Minecraft and accompanied them ethnographically during their first weeks of appropriation. Based on this, we report on issues with current tools for digital fabrication in educational settings along social and technical dimensions and derive design implications to help alleviate those issues.

Author Keywords

3d printing; making; constructionism; 3d modeling; computer clubs; education; children; innovation

ACM Classification Keywords

K.3.1. Computer Uses in Education

INTRODUCTION

Digital Fabrication and, more generally, *Making* [9] have been gaining traction steadily over the last years. Drivers of these trends are Maker-cultures and -scenes that have been building and establishing communities in the form of Makerspaces, Fab Labs and similar structures [4]. The technology for digital fabrication is rapidly getting cheaper and more accessible for non- or semi-professional users with 3D printing as the spearhead for this development (Some 3D printers are as cheap as 300 USD as of 2014).

It has been argued that this harbors significant potential for socio-economic disruption, end-user empowerment, distributed innovation as well as creative expression. In order to be successful on a broad basis, (early) education about digital fabrication is important – for one thing to give the next generations well-founded access to this field in the sense of improving their digital literacy and for another in that digital fabrication is a match made in heaven for innovative, bottom-up forms of creative learning.

However, there are issues, which lie in this path – some of the most important ones relate to the available tools on hard- as well as software levels. They generally do not lend themselves well to educational purposes with children since they are e.g. too complex, too expensive, too domain-specific or too hard to use [cf. e.g. 4]. Many of those issues are closely related to HCI which can help alleviate them. We want to contribute to this stream of work by conducting field studies with children, letting them work with 3D modeling and 3D printing, observing them, their evolving practices, interactions and especially the points of error or incident in order to work towards tools for digital fabrication that are more suitable for education of children.

Given the world-wide ramifications of digital fabrication, we are working on doing this in different socio-cultural and socio-economic settings through utilizing the international infrastructure of the come_IN computer clubs [1]. Due to our focus on children, we work with expressly playful, creative tools like Minecraft. This contribution is a first more in-depth look at and analysis of our work and culminates in some implications for design for better educational tools for digital fabrication.

STATE OF THE ART

The notion of Making through digital fabrication technologies marks a paradigm shift regarding the design and production of physical artifacts. The possibilities for end users in utilizing advanced digital fabrication technologies are growing and projects and applications span a huge variety of areas ranging from DIY electronics [12] through wearable projects [14] and ICT for development projects [13] up to DIY prosthetics which are orders of magnitudes cheaper than commercial products, making them available to a much broader audience in need [8]. The mindset of communities in this domain is often related to a movement (in reasonable parts) away from mass-manufactured goods and dependency on industrial complexes. The assumption is that end users are empowered to create their own physical artifacts, customize them to the individual needs and wishes, express own values, exploring, acting out the own creativity and cater to local needs and specifics.

Given those rapid developments and perspectives, the increasingly common analogy of digital fabrication as the next step in the digital revolution, potentially bringing similar disruptions as the Personal Computer did to the digital domain to a digital-physical one, seems sensible and almost graspable [5]. Scientific communities such as HCI increasingly seem to view this field as highly relevant, arguing for new and more advanced interfaces [15] to facilitate the Maker movement as well as for a "critical reflection, paired with a sensibility for materials, tools and design methods" [10].

Such changes and paradigm shifts as well as the complex technologies bring with them a necessity for related education, especially for the coming generations. CSCL offers a substantial body of work on how to approach this in a way fitting to the creative, situated and evolving Maker spirit: Paramount is the notion of constructionism [6] which sees learning as a creative process of constructing knowledge through the playful construction of physical artifacts [6]. An excellent overview about the application of such principles to digital fabrication can be found in [2]. However, the field is still in its infancy – e.g. regarding the tools which can actually be utilized in education for digital fabrication: Due to the quite recent shift from professional to more amateur domains, digital fabrication hard- and software are often quite complex, sometimes very expensive (e.g. traditional CAD suites) and generally not built with the needs of children in mind. This is a gap in which HCI can help and towards which we aim with our research: Exploring different tools for digital fabrication in the field, considering evolving practices and characteristics of the actual learning users in order to adapt them to education and appropriation purposes for children.

METHOD

Given the dynamic and fluctuating nature of Making, we favor an action research motivated approach [7] where we go into the field, implementing change by way of introducing 3D modeling and printing technology to children. We did this in three come_IN computer clubs [1] which are constructionist computer clubs for children aiming to foster education and integration via ICT by bridging the digital divide. One of the clubs we worked with is associated with a German elementary school, two are located in refugee camps in the West Bank, Palestine. In both countries, we gave a very basic introduction to 3D printing and subsequently offered the children the opportunity to digitally model their own creations, which then could be printed. Instead of traditional and hard to learn CAD tools, we drew on inspiration from playful approaches and utilized the video game Minecraft[1] in Germany (DE) and the browser-based CubeTeam[2] in the West Bank (PS), since Minecraft requires a server infrastructure that would not have been possible. In both tools the models are built from square blocks, one such block at a time with a focus on collaboration in that participants can act in the same "world", even working synchronously at the same models. For 3D printing, we used composite-based full color printing (Z-Printer 650) in DE as well as Fused Deposition Modeling (Printrbot Simple and Makerbot Replicator Dual) in DE and PS.

The children were age 8-14 and usually worked in groups of 4-5. We worked with 30 kids in Germany and 20 in the West Bank. We attended all sessions (28hrs in DE, 12hrs in PS) observing and interacting with the children, giving support if necessary. In DE, we also used remote monitoring to map onscreen interactions to real life situations and compiled server logs. Furthermore, we took photos, videos and detailed field notes as well as two interviews (25 and 45min) in DE and many smaller, informal interviews in PS (due to the language barrier). All data was transcribed if applicable and analyzed following a pragmatic thematic analysis approach [3], based on which we then derived design implications.

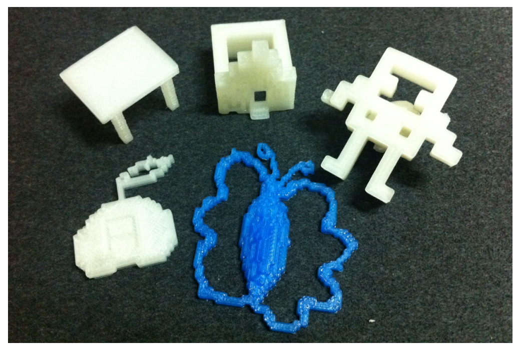

Fig. 1: 3D prints, designed by children in PS

RESULTS AND IMPLICATIONS FOR DESIGN

Our results can be roughly grouped in two categories, *social* and *technical.* For the sake of brevity, we will couple the results with the design implications.

Technical

Minecraft and CubeTeam, despite limited scopes of operation when compared to traditional CAD tools, turned out to be surprisingly efficient for creating simple, 3D printable models. The children quickly figured out the basic controls through exploration and managed to construct simple models from scratch (see Fig. 1), often in less than two hours. However, we also observed problems - the most notable are listed in the following:

Orientation and camera control

The mapping of orientation in 3D space to the intended task seems to be very difficult for children. We repeatedly observed attempts of children placing a building block at locations e.g. semi-occluded by other structures. The task would have been made easy by moving the camera to a different angle but this usually only happened after multiple failed attempts or through tutor support. Minecraft only offers a first person perspective controlled by the "WASD" or arrow keys and the mouse while CubeTeam additionally has a control mode similar to traditional CAD tools where

[1] See www.minecraft.net

[2] See www.cubeteam.io

the viewport is moved by clicking and dragging as well as scrolling for zoom. We observed that zooming seemed to result in more problems while the more direct “movement” through the WASD-keys seemed to do better, especially for children who had experience with first person video games (a gender bias here was noticeable, with male children reporting more first person game experience).

As implications for the design of educational 3d modeling tools, we would argue for the inclusion and exploration of alternative ways of navigation: e.g. utilizing 3D mouses, which map directly to three axes, or even game controllers to support familiar appropriation patterns. Furthermore, the exploration of virtual reality with higher degrees of immersion in the 3D-space (e.g. utilizing an Oculus Rift) might be sensible. Switches between navigation modes either should be avoided or introduced especially carefully and with appropriation support in mind.

Coordination and collaboration features

We observed much need for coordination between the children, which was not well facilitated through the tools. An example is the fact that it is often unclear who “owns” or works on which structure. If, e.g., a child wanted to expand on or copy an existing model, discussions were necessary, which was especially problematic if the original creator was not present in that moment. Furthermore, since discussions could not be mapped to specific structures, the in-game chat either became quite confusing or did not get used at all by some children.

As implications, more advanced and automated ownership signifiers (color, signs) as well as the mapping of discussion “threads” to specific structures would be worth exploring.

3D printing limitations

Current 3D printers have certain limitations regarding overhangs, granularity or floating structures. Those limitations are technically complex, can vary from printer to printer and are highly relevant to the outcome of a 3d print. Since the children can not be reasonably expected to know or learn those issues quickly, we frequently observed attempts at building structures with problematic elements (like the letter “i" in a name). We usually resolved this by explaining the very basic issues (usually hard to understand for the children) or, in some cases, applying small fixes ourselves before printing.

Future tools should be aware of those device-specific limitations. They should not only attempt to correct them automatically or simply do not allow certain operations but rather provide a more gentle appropriation supporting mode in that they should make the user aware of why something like a significant overhang probably will not print well. Automated notifications and animations (such as a printing process simulation) might be a way to achieve this.

Interface

We frequently observed problems with the interface, especially in the more complex CubeTeam where icons for certain operations were not understood. Random clicking around on the UI until something happened was observed quite frequently. Furthermore, in some instances, children left the world, usually by accident, and got lost in the tool, sometimes creating a new world containing only them.

Future tools should support a centrally configurable interface in which e.g. leaving a project could be remotely disabled – at the very least, there should be a very simple “bring me to my group”-control. The actual modeling UI should be as minimalistic as possible and also configurable, offering only basic operations (e.g. placing and deleting a building block) and subsequently getting more complex (undo, copying blocks, etc.). As we can see in CubeTeam, internet-based technology is growing powerful enough for entry-level 3D modeling and such adaptable and configurable interfaces are generally easier to build using web technology.

Disruption between modeling and printing

The children constantly proved to be quite successful regarding 3d modeling and found it engaging and fun. However, there is a big gap between the finished model and the actual printout: Models have to be translated into machine toolpaths (*g-Code*) through separate software, which also has to be configured to lots of different parameters (printing speed, temperature, material, etc.). This highly technical process can not be expected to be done by children. The printers themselves are also complex, need calibration, have dangerous (moving and hot) parts and operation needs some knowledge. This leads to some parts of the learning and appropriation process, which are black boxes to the children and can hamper motivation.

Future educational tools should offer more integrational features (speaking overly simplified: Offering a *print now* button), integrating the printer, modeling tools, control software and print material to a denser ecosystem. Actual printers for education should be designed safer, more encapsulated and offer basic *it just works*-settings, based on which exploration can be initiated (unlike the current state of affairs where a significant amount of configuration and knowledge has to be done / acquired before the first print). A printing simulation (see above) could serve as an intermediate step in such a process.

Social

Not all children were interested in the actual hands-on construction of artifacts. Given the collaborative nature of our tools, we could observe and identify many emerging practices and social roles: Some children tended to *instruct* others, some concentrated on *orientation* in that they tried to ascertain and allocate positions or 3D structures in the world, others *supported* their friends in case of problems and were also frequently asked for help and some tried to *arbitrate* conflicts (e.g. about ownerships of certain models). Some children rather acted as *executives*, carrying out instructions or suggestions of the leaders, others rather emerged as *creatives,* thinking about new structures and new designs (e.g. by using pen and paper first to sketch).

Like the technical aspects, those social roles and practices should be considered in future tools. One example of such consideration which is also taken from video games might be a bird's eye view of the world for those who rather act as coordinators or even, to take the metaphor further, a class-based specialization and reward system as is common in online-games. Another example might be the option to easily import a paper sketch (e.g. via a photo) into the modeling tool, which then could be used as a blueprint.

DISCUSSION AND OUTLOOK

In a general sense, we could, like other researchers in the field [e.g. 2], see that digital fabrication in educational settings is a very exciting and promising field. The intervention of bringing 3d modeling and printing to children with no expertise proved a huge motivational and inspiring factor for the kids in a variety of cultural backgrounds. We will report on more long-term, appropriation-focused and socio-cultural aspects in more publications, but for this contribution, our focus was on the tools: It is quite possible to achieve notable and quick learning and understanding successes [cf. 4] with currently available, playful and collaborative tools like Minecraft or CubeTeam. However, there are hindrances and significant gaps in the learning and appropriation processes given the limitation of those tools as well as the current 3D printer ecosystems. Those problems are mainly related to *technical* and *social* dimensions and could, we believe, alleviated by implementing some of our design implications as listed above in future tools for educational digital fabrication. Speaking more generally, a higher degree of integration, standardization and development of a more extensive infrastructure for appropriation support into and between the hard- and software levels [cf. 11] would be very helpful, not just for early education but also for a generally broader adoption of digital fabrication.

We argue for HCI to consider those issues more deeply and will also do so ourselves – after the introduction and initial projects we reported on in this contribution, we will focus deeper on the long-term appropriation as well as the emerging and consolidating practices of 3D printing in the come_IN clubs together with the arising challenges over more time and their additional implications for better educational tools for digital fabrications.

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