Material Agency in User-Centred Design Practices

High School Students Improvising (with) Smart Sensor Prototypes

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Abstract

This paper investigates (digital) materiality through an analysis of the "sociomaterial configuration" (Orlikowski 2009) of the participatory design project SensorLab *(2010). In* SensorLab*, users were enrolled as designers: a group of high school students developed and tested smart pollution-sensing prototypes in a public park in Amsterdam. Concepts from science and technology studies, specifically the notion of the "dance of agency" (Pickering 1995), are used to trace how 'smartness' materialises in the form of the* SensorLab's *prototypes. The exploratory case study draws conclusions about (1) how materiality performs its agency and invites improvisations during prototype design and (2) how the student-designers use their tacit knowledge as situated expertise to improvise with construction materials and technology. The deconstruction of the assemblage of human/material agency suggests that while the student-designers are readily accommodated to develop prototypes, the material agency of the sensor technology resists improvisation as compared with the other available materials. The extent to which the black-boxed sensor technology allows the student-designers to become 'smart' is therefore debatable.*

Introduction

The overarching theme of this first issue of *Digital Culture & Society* is digital materiality as a critical issue in current media and cultural studies. This article investigates how the materiality of media performs its agency, following Kirschenbaum's (2008) argument for a focus on the often overlooked materiality of electronic media, and in line with Drucker's (2013) suggestion to investigate materiality not in terms of what it 'is' but what it 'does'. By focusing on design processes where digital technologies are 'in-the-making', the analysis of digital materiality moves away from questions of representation to questions of agency. It focuses on how, from a performative perspective, material agency comes to the fore in practice. Recent work in media studies highlights how the academic field of science and technology studies (STS) can contribute to research into

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digital devices (e.g. Marres/Gerlitz, forthcoming) by emphasising how technologies gain shape and meaning as sociotechnical or sociomaterial assemblages (Bijker/Hughes/Pinch 1987, 2012). Analyses in STS describe how technology and society mutually shape one another. This perspective sees agency "not simply [as] the product of either persons or things but rather at the 'materialisation of subject, object, and the relations between them as an effect [...] of sociomaterial practices'" (Suchman 2007: 286 in Wajcman/Jones 2012: 675). In relation to digital materiality, STS scholars Ruppert/Law/Savage (2013) call for studies that underline how digital devices 'mobilize and materialise social relations' (ibid.: 22); digital materiality manifests in how it acts in the world and how, in acting, it shapes social worlds.

The expressed importance of digital devices in shaping and, furthermore, improving social worlds is underlined in studies that focus on the development of so-called 'smart technologies': technologies that establish smart environments through pervasive computing, embedded devices and sensors and actuators (Klein/Kaefer 2008). In urban environments, referred to as 'smart cities', smart technologies connect telecommunication systems and the city (Weening 2006) to increase standards of living by focusing on the development of ICTs and ICT infrastructures. Smart cities aim to enhance social capital and create wired cities, which can foster public-private business partnerships and create employment opportunities (ibid.). The role of the ('becoming-smart') citizen is essential in these smart environments: smartness carries strong overtones of an ideal type of future city where citizens take part in participatory governance (Caragliu/Bo/Nijkamp 2009) by investing in social capital, and the co-development of smart technologies. Digital smart technologies are thus seen as constitutive of smart cities that facilitate smart citizens; in a very direct way, these technologies seem to shape perceptions of an ideal urban landscape.

The implementation of smart cities calls for "a participatory approach in decision making and designing smart policies" (Tranos/Gertner 2012: 186) to increase social inclusion, but not only in the shape of participatory governance. The movement towards smart cities seemingly goes hand in hand with design practices set to include future users of smart technologies during multiple design stages. In so-called 'living laboratories' (living labs) foreseen end users of (smart) technologies co-create new technologies. Positioning users as co-creators reverses traditional 'top-down' *Research and Development*-processes and stimulates 'bottom-up', locally-specific innovation. Furthermore, living labs that include users throughout ICT development empower technology users by enhancing their digital literacy (CoreLabs 2007), effectively making users 'smarter' as they contribute. User-centred design practices innovate by treating users as experts (Steen 2008), embracing their 'sticky' knowledge (Von Hippel 1994) and local expertise (Stewart 2007) as essential preconditions for developing, in this case, smart technologies in 'lived' as opposed to 'artificial' spaces. By including users in this manner these labs not only shape social worlds through new digital devices but also through the development process, ideally producing two matters, namely smart technologies and smart citizens. Relating this to the notion of material agency, studying these design practices grants insight into how digital 'technologies-in-the-making' produce social relations, and how, in these processes, the performance of material and human agency shapes sociomaterial relations.

Whereas user-technology interactions take centre stage in living lab-practices, the actual role of (technological) materiality in the shaping process is often-overlooked. Björgvinsson et al. (2010) have criticised how participatory design methods, used in living labs, privilege user needs and product-centric issues, while ignoring the labs' sociomaterial working relations (2010: 42). Van Dijck and Nieborg (2009) in turn, have raised more general concerns about the economic and cultural discourse surrounding the participatory nature of co-creative practices, arguing that more attention needs be paid to the commodification of so-called democratised design practices. It seems that the performative dimension of materiality, the role of technologies-in-the-making on the eventual design itself is disregarded in favour of a focus on developing the final technological product. This is an important oversight. By 'black-boxing' the agency of technological materiality, its (deemed central) role in shaping social worlds (future 'smart cities') seems to be nullified.

This article contributes to the theme of the agency of (digital) materiality by investigating its role in a specific user-centred design practice: a living lab-project which includes users as designers of smart sensor prototypes. The case in question is the *SensorLab*; a one day event that took place during the multimedia festival *PICNIC's PICNIC YOUNG* in an Amsterdam public park in 2010.[1] The goal of the workshop was to learn about sensor technology, develop smart sensor prototypes and measure pollution levels in an urban setting. The largest part of the group consisted of high school students, acting as designers for a day. Their assignment was to build smart sensor pollution-measuring prototypes together with their teachers and sensor experts. The groups worked collectively with different construction materials, sensor technologies and a number of machines to develop their prototypes and to test them.[2] The central question of

1 PICNIC is a "leading European platform for innovation and creativity. [It functions] as an incubator and accelerator for game changing ideas, concepts, products and services. Through […] activities, [it addresses] the mega trends of our time and [explores] how to creatively apply technology in order to meet business, social and environmental challenges" (https://www.facebook.com/picnicfestival/info?tab=page_info).

2 One of the organising actors of *PICNIC* and the *SensorLab* was *Waag Society*, a Dutch institute for art, science and technology. *Waag Society's* overarching innovation agenda is to stimulate social innovation where users are perceived as designers and research is 'disruptive, practice-based, iterative and intuitive in its approach and open in terms of its results' (Van Dijk/Kresin/Reitenbach/Rennen/Wildevuur 2011: 10). The organisation uses methods such as emphatic conversations, exploratory play and context mapping to involve users in new ways in the design process, and allows users and designers to collaborate by letting them both take on multiple roles throughout the design process (ibid.). *Waag Society's* educational department, *Creative Learning Lab*, focuses on citizen science and embodied learning. This means that youngsters, as non-scientists, contribute to science via

this article is how 'smartness' materialises in technological form in a setting that seeks to empower technology users by making pollution visible and by teaching users about technologies. Answering this question allows for an investigation of practices of prototype production: How do human and material agency interact, and what is the role of material agency in this particular practice?

This article grapples with digital materiality by focusing on how the students engaged with sensor experts, sensor technology and other materials to develop working pollution-sensing technological artefacts. The project's "sociomaterial configuration" (Orlikowski 2009) of intertwined human and material agency – that is, 'the capacity to act that is discovered when studying how worlds become constructed in a certain way' (Cooren/Taylor/Van Every 2006: 11 in Orlikowski 2007: 1438) – is analysed to establish what materiality 'does' in this case; how digital smart sensor devices are produced and what this stipulates about 'smartness.'

This case study concludes that the materiality of technological artefacts performs its agency by inviting improvisations during the design and testing of the prototypes through the user-designers' tacit knowledge and situated expertise. Theoretically, the article seeks to articulate how human and material agency interact or 'dance' together during the workshop, to be able to draw attention to specific tensions between material and human agency. Improvisation works as a conceptual tool to articulate how the dance unfolds. While the analysis grants insight in this specific case study, it is also of more general interest: What do the

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digital and mobile technologies and that learning takes the shape of experiential instead of theoretical learning so that technologies are non-intrusive and support learning experiences that involve more than only cognitive competences. The *SensorLab* unites *Waag Society's* goals of stimulating thinking through making and citizen science. *Waag Society's* approach to citizen science is described as follows: "With the advent of digital and mobile technologies scientific knowledge production has changed profoundly. As interactive, affordable, networked and ubiquitous technologies they invite people to engage with, alter and probe scientific "facts". Play is essential to think about this new kind of engagement with science. It offers citizens powerful ways to become involved with and knowledgeable about scientific practices and offers subversive and exciting possibilities to actively contribute to and transform them." (http://www.citizenscience.nl/) *Waag Society's* take on citizen science fits a broader view on citizen science that specifies that citizens become part of scientific data collection to manage and monitor their surroundings (Lakshminarayanan, 2007). Citizen science is also referred to as community-based monitoring (Conrad/Hilchey, 2011) and is associated with citizen empowerment. Yet it is not uncontested. Brossard, Lewenstein and Bonney argue that while the 'need of encouraging public understanding of science is rarely contested' (2005: 1099), direct statistical change in participants' understanding of scientific processes and attitude towards science is hardly changed after participation, whereas participants' knowledge does increase. They suggest that in order to facilitate a change in attitude towards science, participants should be made aware of the scientific processes underlying their involvement (ibid.: 1117).

improvisations that take place in the *SensorLab* suggest about the role of materiality in other 'messy' design processes?

The article is divided into five sections. The second section presents the theoretical framework and research methodology, after which the sociomaterial configuration of the *SensorLab* is described in the third section. The fourth section presents an analysis of the mangle of human and material agency during the students' design practices. The concluding section discusses insights into what these findings stipulate in terms of the situated expertise of the students, user and material agency, and improvisations with new technological artefacts.

Theoretical Framework and Research Methodology

The participatory design process[3] of the *SensorLab's* sensor prototypes is analysed in terms of agency: this paper addresses how the prototypes are developed as a continuous improvisational negotiation between actors within the workshop's sociomaterial configuration. "Sociomaterial configuration" here refers to how social and material agencies emerge, and how these are performed and entangled in practice (Feldman/Orlikowski 2011: 16).[4] Agency is therefore understood as performative; echoing actor network theory notions about technologies as "choreographies of human and non-humans" (Pottage 2012: 167), and also STS scholar Andrew Pickering's concept of "the dance of agency" (1995), where material and human agency temporally *emerge* through a 'dance' or 'mangle'. This mangle is a process of resistance and accommodation: resistance denotes the failure to achieve an intended capture of agency in practice, while accommodation refers to an active human strategy of response to resistance (ibid.: 22). This active strategy can take the shape of a revision of plans, an amendment to

3 Approaches where users become part of design practices are often referred to as participatory design. Participatory design originated in Scandinavia and covers theories, practices and studies where end users are treated as participants in software and hardware computer products design (Muller, 2002). As noted above, *Waag Society* aims to follow a 'users as designers' approach. Its overarching innovation agenda is to stimulate social innovation where users are perceived as designers and research is "disruptive, practice-based, iterative and intuitive in its approach and open in terms of its results" (Van Dijk/Kresin/Reitenbach/Rennen/Wildevuur 2011: 10). *Waag Society's* educational department, Creative Learning Lab, focuses on citizen science and embodied learning. This means that youngsters, as non-scientists, contribute to science via digital and mobile technologies and that learning takes the shape of experiential instead of theoretical learning. In the context of the *SensorLab*, this approach combines embodied learning foreseen by combining learning-through-making and a citizen science approach.

4 Feldman and Orlikowski, in reference to practice theory (Feldman/Orlikowski 2011; Schatzki et al. 2001), draw attention to how meanings and materialities are enacted in everyday practices and how the study of sociomaterial configurations allows for a deconstruction of these entanglements.

the material form of a technology or of human practices surrounding a technology. The mangle is contingent on situations whose outcomes are not predetermined (ibid.: 57). In fact, Pickering argues that throughout the struggle with material agency, some things *just happen*; when studying real-time practice, sometimes no explanation can be given as 'the world of the mangle lacks the comforting causality of traditional physics or engineering, or of sociology for that matter, with its traditional repertoire of enduring causes (interests) and constraints' (Pickering 1995: 24).

Sometimes things *just happen*. In order to be able to articulate matters that simply seem to happen, the analysis views the prototype development process in terms of improvisation practices. Improvisation can simultaneously be related to expertise – in relation to for example jazz improvisation, where musicians can only creatively improvise once they master an instrument (Sawyer 2000) – and to makeshift practices of "making do" and "letting go" (Seham 2001) in direct response to (unforeseen) situations. In this analysis, it serves as a concept to catch emergent and unforeseen performances in a setting where actors work together, or are 'mangled', and produce two matters: a designer role performance and a physical artefact.

The relatively short *SensorLab* workshop offers an opportunity to take a close look at what happens in the mangle; how sociomaterial relations are performed, what kind of routes are taken, how different agencies resist and accommodate one another and how these culminate in technological artefacts. An analysis of the sociomaterial practices that shape how students become designers also gives insight in how – to refer back to Steen – users become 'experts' in participatory design projects and how these students are granted the agency to improvise with their situated expertise based on local, contingent knowledge.

Methodologically, the research outcomes are based on document analysis and data gathered through an ethnographic study of interactions between different actors during the *SensorLab's* design activities on September 22, 2010. Publications by *Waag Society* about their educational department and about their users as designer approach were analysed, as were documents about their citizen science projects. Voice and video data were collected during the *SensorLab* workshop, and these data were then transcribed and coded using a grounded theory approach. The data were subsequently organised into labelled segments to provide handles for comparison (Charmaz 2006: 3).

To analyse how agencies resist and accommodate each other in the mangle, the actors in the setting are first artificially separated, after which it is assessed how they are, in practice, mangled together in the design process. This means that the analysis works through how the students engage with the assignment in the *SensorLab* setting (their design challenge), with the other human actors in the setting (sensor experts and teachers onsite), with the available materials that are used to build their sensor prototypes, and with the environment of the public park as they test their prototypes.

SensorLab's Sociomaterial Configuration

The goal of the *SensorLab* workshop was two-pronged: to educate students by allowing them to collaborate with experts in order to collect and interpret environmental data with self-built 'smart' sensor prototypes; and, to alert people in the park to nearby pollution levels. The workshop should therefore raise environmental consciousness of both the students and the people onsite, as well as teach the students about technology.

Designing sensor prototypes and learning about sensor technology were not the only objectives of the organising parties. The *SensorLab* workshop itself was presented to the participating students and experts as a test case. The students were therefore included in two different roles: as designers of new smart sensor prototypes and as 'guinea pigs' to test a workshop format. Throughout the workshop, five groups of, in total, 21 high school students created working smart prototypes to measure pollutants in the air, earth or water. The students had to design a prototype, keeping in mind explicit future users (themselves) and implicit users (people walking by).

The students worked on their own group table, supervised by a teacher and a sensor expert. The sensors, pre-programmed by *Waag Society*, measured pollutants in the air (humidity, polluting gas levels and magnetic fields), water (light strength to measure oxygen levels) and earth (salts as indicators of fertiliser and seawater in the earth). The other construction materials were presented on a table at the back of the tent, including balloons, toy cars, duct tape, plastic shovels, toy parachutes, cardboard, coloured paper and an inflatable seal, as well as construction tools such as Stanley knives, scissors and soldering equipment. While most of the building took place inside the workshop tent, the main hall of the *PICNIC* festival provided extra tools with which to build such as a 3D laser cutter and a 3D printer. By the end of the *SensorLab*, the students had built and tested five pollution-sensing prototypes (see Figures 1-5 for an overview of the prototypes).

The students are configured, as stated above, as designers of prototypes and as testers of an educational format. The *SensorLab* asks the students to work with certain materials and machines, which demands that they express their ideas in physical forms and in doing so they become empowered to collaboratively design prototypes, and collect environmental data. Another role they are attributed in the context of the workshop is that of informer: the students should – via their prototypes – inform and alert the public about pollution levels in the park. The students are thus configured as designers and referred to as collaborators and informers, and at the same time, as learners and as testers. Becoming designers in this context thus means that they engage in the practices associated with these activities; they should collaborate, inform, learn and test. How did they, in becoming designers, engage in these activities? How, in other words, did human and material agency 'dance' and stabilise into technological artefacts?

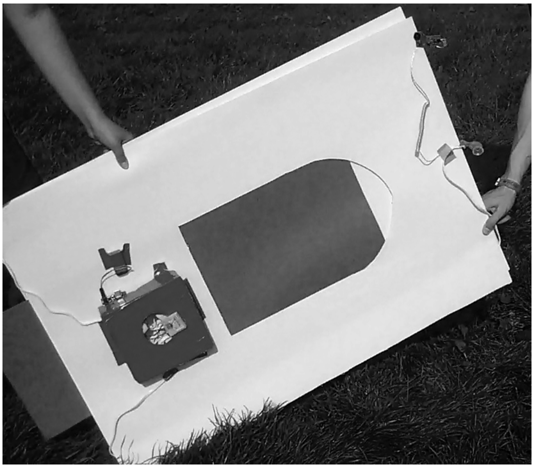

Fig. 1: Prototype created by group 1 during the *SensorLab* workshop (photo taken by the author)

Group 1 spends quite some time discussing what they want their prototype to draw attention to: the realisation that pollution is everywhere. To reach this goal, different means of drawing attention to pollution are discussed, e.g. the beeping sound of the sensor, walking around with a laptop that displays graphs or a red colour, red and green balloons and red paint. Related to their aim to draw attention are the ideas for the shape of their prototype. The first idea is to build a digging mole (pollution in the earth), followed by the idea of a seal that measures water quality and a nose on wheels (air pollution). In the end, they settle on the idea of building a thermometer that shows – in real time – air quality. The prototype is built using cardboard, duct tape, scissors and sensors.

Fig. 2: Prototype created by group 2 during the *SensorLab* workshop (photo: taken by the author)

In group 2 students start by asking the sensor expert about the available sensors and are split into two groups: one discusses the ideas and the other looks for materials. They settle on measuring air quality and air moisture. Ideas of building a paper aeroplane, a kite, a parachute or an airborne football using plastic bags and balloons are discarded in favour of creating a car with balloons that allows two types of measurement to be taken (air moisture at the level of the car, air quality at greater height). They discuss the way in which the prototype should be built at great length while they build, with a focus mainly on how balloons both symbolise air and draw the public's attention. The 3D laser cutter is used to cut a hole in the roof of the toy car that forms the basis of the prototype (to fit the sensor in the car) and the 3D printer is used to create stickers to make the prototype stand out even more.

Fig. 3: Prototype created by group 3 during the *SensorLab* workshop (photo: Marco Baiwir for *Waag Society*)

In group 3 the students argue that to draw public attention, they need to use balloons, a paper aeroplane or the inflatable seal. When one of the sensor experts questions the link between the look of the prototype and its functionality, ideas shift towards creating a floating ear that measures sound levels. When this does not seem possible in terms of sensors, the idea changes into creating a floating nose that measures air quality. To draw extra attention to the nose, a moustache is added. Materials are collected to build a flying nose. However, as there is not enough wind to make the nose fly, they carry the prototype around. The nose design is drawn in different ways on the piece of 'brainstorm paper'. They call it "Snuffelneus" ("Snifflenose").

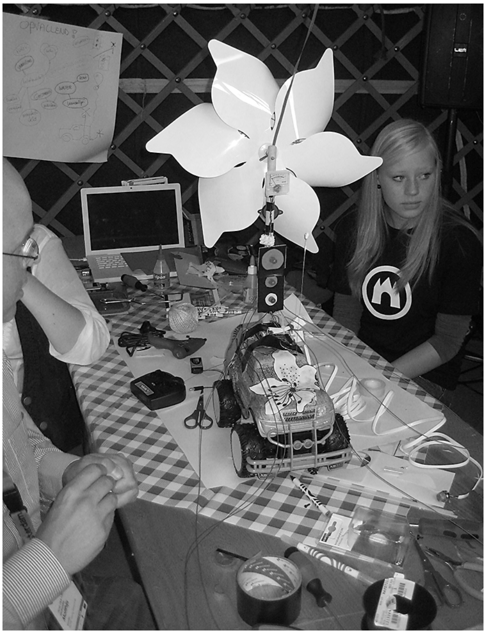

Fig. 4: Prototype created by group 4 during the *SensorLab* workshop (photo taken by the author)

Group 4 starts by jotting down the main indicators of pollution and settles on measuring air quality. In order to build something that grabs the attention of people passing by, they want to create a prototype that shows the air quality at two different heights: those of a child and an adult. The claim is that air pollution is worse close to the ground, which makes the environment of a city more damaging to children than to adults. As they look around the tent, they spot toy cars and balloons. They attach the first sensor to the car and the second to the balloons. To show people the quality of the air, the group builds an automatically operating set of traffic lights where a red light indicates bad air quality. To make the prototype more 'attractive', they create flower stickers with the 3D printer. A windmill is furthermore attached to the car. The car is steered with a remote control.

Fig. 5: Prototype created by group 5 during the *SensorLab* workshop (photo taken by the author)

In group 5 the students have many ideas, ranging from a worm that measures air quality to equipping a car with light sensors or measuring the salt in the pizzas that are available nearby. Once the teacher steers the group towards the goal of the assignment, they want to draw attention to pollution with a dragonfly made of aluminium foil and balloons. They decide that both air and water quality sensors should be included. This leads to the idea to create an amphibian creature. Once they see the inflatable seal, the group immediately starts to build, attaching the air quality sensor to the seal's nose and the water sensor to its back. To make the seal mobile, they connect it to a toy car. Stickers are printed (with the words 'No animals were harmed in this project' and the names 'Mario' and 'Luigi'), and attached to the prototype to draw attention.

The Dance of Agency in Practice: Improvisation in the SensorLab

The Assignment: Configuring the Setting

The design assignment provides the goal and the structure – the *how* and the *what* – of the workshop. The assignment frames the design activities and encourages the students to behave and think as designers with a specific design problem. *Waag Society*'s strict design requirements specify that the prototypes should be 'outrageous' enough to draw attention from people in the park and are required to measure pollution levels. The students are presented, onscreen, with two examples of Natalie Jeremijenko's *Health Clinic*[5] – a robot dog and swan that measure pollutants in the air and water respectively – to give them concrete design examples.

The workshop needs to be completed within a set amount of time and in clear-cut design phases: ideation, conceptualisation, building and testing. Much like a traditional design process (Eger/Bonnema/Lutters/Van der Voort 2004: 49), the workshop is divided into set phases; an introduction (15 minutes), a group brainstorm (ideation and conceptualisation phase of 60 minutes), a building phase (90 minutes), testing/measuring time (45 minutes) and closing presentation (30 minutes). The groups are given an overview of what is expected in the design stages, and what is available to complete the assignment: expert knowledge, diverse materials and various sensors. They are also guided in possible ways to comply with the assignment, as they are given two illustrations of what they could design. These combined observations create a rather constricted image of the *SensorLab*. The students need to work fast to design an answer to the design problem and test a functioning prototype with a limited availability of time and other resources.

At the same time, the students are in charge of prototype design. The setting accommodates their designer performance and resists design possibilities: there are limited sensors and materials available, and there is a limited

5 cf. http://www.environmentalhealthclinic.net/environmental-health-clinic.

amount of time. The assignment and the available materials set the stage and the boundaries for the students. Although the students are guided by these boundaries, they are not limited in their interpretations of the assignment, or in their use of the available materials. So how do the students 'make sense' of the assignment and the sensors?

Group Discussions of the Assignment: Resisting and Accommodating Ideas

The examples of the robot dog and swan that are presented during the introduction shape the agency of the available materials and have an immediate effect on the student group discussions. As answers materialised for the design problem, these examples configure the group ideas to such as extent that almost all groups start their brainstorm session by discussing animal designs; the groups generate ideas to build a dragonfly (group 5), octopus (group 4) and mole (group 1), or question whether they want to build an animal similar to Jeremijenko's examples (group 2). They translate the examples into possible ideas, ideas that fit their surroundings and that are also materially informed; on the table with materials an inflatable seal is plainly seen. Groups 1 and 2 immediately refer to the seal.

However, after these initial ideas, discussions shift to questions about the location: How to connect the assignment to something that can be used in this specific location? Furthermore, they wonder how to make their prototypes 'outrageous'. Locations are referred to in terms of how these accommodate the assignment; the possibilities they offer in measuring (contrasting levels of) pollutants (e.g. to show how air quality may be better in the park than alongside the road) and how they can relate their prototype to specific elements in the setting (group 5 wants to build a car like the Tesla on display outside). At the same time, locations are also seen as resisting the assignment; for example, the plan to build a kite to measure air pollution is cast aside once it becomes clear that there is not enough wind to fly a kite.

A clear motif during the ideation phase is how the prototype, in this location, should draw the attention to what it is measuring of people passing by. For example, students exclaim: "if we build it close to the ground, no one will see it" (group 3) and "we need something to trigger an alarm when the pollution is too high […] to trigger people" (group 1). To accommodate the design assignment specification that the prototypes should draw attention, the students envisage prototypes that have both visual and aural triggers.

In practice, no group strictly adheres to the preset design phases: one group spends considerable time on brainstorming (group 1) whereas others either split the group in two (in group 2, one delegation brainstorms while the other looks for materials) or focus on the materials or sensors to come up with ideas (group 5). The students resist the given structure of the workshop; they are accommodated by the setting to decide when to do what and in this way reshape the design practice.

The groups thus follow the *what* of the assignment more closely than the *how*. In this mangle, the groups are facilitated to improvise; they are granted agency to shape how they will build their prototypes, as long as they adhere to the *what* of the assignment. What they do with this choice is what grants creative agency to the groups and provides insight into how material agency comes to the fore in this design practice.

Resisting and Accommodating the Agency of Experts and Teachers

Initially, the sensor-experts are presented as *guides*, available to answer questions and help with the design process. The various 'uses' the students make of the experts can be described in terms of (1) empowering and encouraging the students as designers; and (2) the contribution of knowledge about materials. Effectively, the experts work as coaches, brainstorm facilitators and knowledge providers: they support the students in their exploration of material agency, within the sociomaterial configuration.

In their role as coach, the experts stimulate the group by asking design-related questions: What kind of environmental issue do they want to tackle? What kind of sensor would work best to do so? Asking these questions draws the students further into the design assignment while seemingly boosting their confidence.[6] At other times, when the students seem too reliant on the expert, he/she underlines that they are in charge and asks what they want him/her to do. The experts thus accommodate the students' role as designers by stimulating them to generate ideas and execute their own plans. Meanwhile, the teachers listen to the experts' questions and become fellow team members rather than guiding actors. The roles of the experts and teachers are therefore flexible; they both inform and steer, after which they become part of the building teams.

The sensor experts' material knowledge becomes clear when the students are in the process of choosing a sensor. They provide information and guide sensor choice (e.g. the magnetic field sensor is described by two experts as unstable, which results in the groups opting for a more 'stable' sensor instead). The students attentively listen to expert advice. For instance, when group 5 glues a toy car to the inflatable seal, an expert exclaims that the glue will dissolve the plastic of the seal. As a result of this, the students find another way to attach the two by using gaffer tape and rope. In this case the agency of the experts is accommodated and translated into a different approach by the students. The experts are thus trusted as knowledgeable sources of information.

As the workshop progresses, the experts become more involved in the building process through design suggestions (which are then either resisted or accommodated) and through prototype construction assistance, especially with tools like the solder equipment. The students use the experts' knowledge of the materials to complete their work. Once building commences, the initial coaching and knowledgeable position of the experts and teachers shifts: they become team members who work for the students as the latter take charge. Together, they play with predetermined roles and in doing so redefine their role

6 For example, when one expert suggests that it *is* possible for group 3 to build a flying ear, the group decides to pursue the idea and builds their version of a flying nose.

as expert. The flexibility in the roles played by the experts allows the students more agency in the design process.

The gap between the more specialised knowledge of the experts and the more general knowledge of the students (in regard to, for example, the design process, the sensors and materials) stresses the 'lay-ness' of the students, but at the same time works to stimulate the forming of new ideas. The expert accommodates and facilitates ideas and grants the students space to formulate and reflect on their own ideas. The sociomaterial configuration of the *SensorLab* therefore grants the students decision-making agency; the experts respond to this by stepping out of their expert role and becoming team members – which shifts the need for agency and expertise to the students via the construction materials. In effect, the roles of the experts, teachers and students continuously mangle, especially via the 'dance' with materiality.

Mangling Material Agency

The agency of the workshop materials is largely connected to the versatility of the improvisations that the materials can accommodate. The materials' performances were shaped not by what they are but, instead, what they can do. The workshop materials shaped the groups' ideas with a currency of versatile potential, and the groups in turn shaped the materials with representational strategies developed through improvisations with the material's potential. The representational strategies are not nearly important in terms of what they present, but rather how the representation focused the purposing of the material and prompted its newly intended use.

The first decision each group makes is to choose a sensor. Unlike the rest of the construction materials, the sensors, based on *Arduino* open hard- and software,[7] cannot be tinkered with because these are preprogrammed.[8] Consequently, apart from primarily choosing a sensor based on what it measures, the students also use the sensors as a raw material with which to build. Group 2 for example uses the weight of the sensor to balance their prototype and to keep it from falling over. By improvising with the functionality of sensors in this

7 "*Arduino* is a tool for making computers that can sense and control more of the physical world than your desktop computer. It's an open-source physical computing platform based on a simple microcontroller board, and a development environment for writing software for the board. Arduino can be used to develop interactive objects, taking inputs from a variety of switches or sensors, and controlling a variety of lights, motors, and other physical outputs." (http://www.arduino.cc/en/Guide/Introduction).

8 Philippe Ross refers to this type of "user-as-designer" perspective, where users are presented with "technologies that already exist (as prototypes or as configurable software)" (Ross 2011: 254) as neglecting the ideation phase of innovation. Students in this empirical case are then not the designers. However, they do design and create prototypes, using the black- boxed technology of the sensor as part of the artefact.

manner, the students move beyond the 'technological' use that these digital devices offer to include the physical characteristics of these artefacts instead. The versatility of the sensors grants the students agency to embrace the sensors' materiality instead of underlining their 'lay-ness' when it comes to sensor-knowledge. This mirrors the way in which the experts accommodate the students to become designers; both experts and sensors accommodate the configuration of students as designers in their design practices.

The sensors' functionality triggers many design ideas. For example, immediately after choosing to measure air quality, group 2 collects as many balloons as possible; balloons are what they associate with air. Because of this sudden balloon scarcity, group 3 decides to build a kite to fly their air quality-measuring sensor. Once it becomes clear that weather conditions will not permit them to fly a kite, they abandon this idea and start building a nose prototype (to smell the air) instead. Due to material and contextual resistances they need to generate new ideas to accommodate the design assignment.

The fact that they are building something 'technological' also guides the students' use of materials. The third group, in a move to communicate that this is a 'technological' prototype, visibly incorporates as many wires in their design as possible. Group 4 even builds a traffic light on top of a car to make the clear connection between pollution, cars and traffic flow (once pollution levels flare up, the red traffic light flashes). Materials are thus used to communicate associations with concepts such as 'pollution' and 'technology'. The materials accommodate these interpretations.

Material choice becomes a topic of discussion at different times in each group. The first group spends considerable time thinking about their design idea, which means that when they finally arrive at the table with the materials there are not many materials left. While this apparent scarcity would seem to resist their design idea, it only causes the group to accommodate their strategy; the versatility of the materials allows them to create a prototype that draws attention because of its size and loud beeping sounds.

Materials also play a catalysing role in the design process. Group 5 for instance starts out with ideas to build an animal-shaped prototype: a mole or a dragonfly. However, once they spot a large inflatable seal among the available materials, this becomes their conceptual starting point. Almost in snowball-like fashion, the group decides to create an amphibian creature that will drive and float. Rapidly, air and water quality measuring sensors are attached to the seal's nose and back. Here, the material of the inflatable seal steers the design; the students use the seal as the centrepiece of their prototype and fit the sensors to their vision of a seal as a pollution-sniffing animal. The shape of the seal is put to representational use as the students repurpose its use.

Some materials are thus clearly more readily accommodated than others. One student exclaimed that 'using balloons is just something practical; it is easy to make something that draws attention with balloons' (group 4). The balloons have multiple functions: to draw attention and to attach sensors to. Other materials seem more difficult to manipulate, such as the unalterable sensors. Some materials are thus more versatile and accommodate the ideas of the students, while others seem more opaque and trigger ideas related to their functionality rather than to their materiality.

The groups therefore use materials to complete, trigger or find alternative design ideas. All groups make representational use of the materials: all prototypes are designed to communicate what they are measuring. The students attribute a symbolic meaning to some materials (e.g. of a car as a symbol for pollution), which subsequently guides the functionality of the designed artefact. Materials are also reshaped to communicate certain measurements in a symbolic manner: a thermometer to note the level of pollution, a traffic light that flashes red when higher pollution levels are measured. The other prototypes use their shape to communicate what they measure: a nose and a car to refer to air pollution.

The meaning that the prototypes communicate is directly related to the assignment and to the location in which this prototype should work; when certain materials will not work in this location, these are either reshaped or discarded. The physical prototype becomes an answer to the assigned design problem. The fact that they subsequently work with the materials to create something of a symbol reflects that materials trigger meanings. By playing with these meanings, and recombining materials to create (new) meanings, the students create their prototype.

Making use of machines such as 3D printers and laser cutters helps the students (re)shape available materials. Group 2, for example, uses the tools to cut a hole in the roof of the toy car they chose as the basis for their prototype, so that they can insert the sensor there. Alternatively, the groups also use the tools to create their prototype out of more generic materials such as cardboard or foam rubber. Apart from this, the machines are used to customise the prototype. Group 5 prints a set of self-designed sunglasses for their seal (which they refer to as '3D glasses' as these are printed with a 3D printer) and texts that they stick onto the seal. The tools are therefore used to adapt the functionality of materials or to customise their prototype further.

Overall, the interactions leading up to the development of the prototypes did not follow a certain design logic apart from the groups' above-mentioned adherence to the *what* of the assignment: the design question and the set design phasing of the workshop. Yet the students' activities as they engage with the assignment, the materials and the expertise on offer alone cannot explain how they created their prototypes. The students bring new meanings, ideas and actions into the setting to integrate materials into a working prototype. They do so by improvising with material agency, by extending existing material meanings or by imbuing materials with alternative meanings and functionalities (e.g. using balloons to carry sensors). These improvisations take the shape of what Seham refers to as 'making do' and 'letting go' (2001) of certain materials, of a reshaping and a play with material form and meaning.

Testing the prototypes in the park, the setting both resists and accommodates material agency.

Testing the completed prototypes involved taking measurements and seeing to what extent the designs would draw attention from the public in the park. The groups took measurements inside a large hall on the park terrain, in public restrooms, inside coffeepots and inside garbage bins. They also ventured outside to measure pollutants, holding their prototypes close to a lit barbecue; to exhaust pipes of stationary but running cars waiting for traffic lights to change on the road alongside the edge of the park; and in the water of a canal in the park. Every time a measurement was taken, the groups took note of the exact time to be able to connect readings and corresponding situations afterwards. At times, people would approach the groups to ask them about their prototypes.

The prototypes did not always work as the students had intended. For instance, one of the cars was unbalanced and kept falling over while the design of the cardboard thermometer made it almost impossible to read pollution measurements. When a passing pedestrian was curious about the measurements taken, one group could not give any insight into the pollution levels at that particular location because the sensor was not giving any significant readings. This was discussed when, at the end of the workshop, each group presented their prototypes and measured results to the PICNIC-audience. They remarked that the sensors did not seem calibrated properly, or were insufficiently sensitive to really generate pollution-level insights of specific locations. They were all surprised that most of the measurements seemed to suggest that every location was quite clean. The sensors only responded significantly when held close to strong triggers such as a burning cigarette or acetone solution.

The environment of the park and the festival terrain accommodated the testing as it allowed the students to roam different locations and test their prototypes. In terms of drawing attention, the prototypes were also readily accommodated: people took notice and actively asked questions. However, the environment also resisted testing: obstacles onsite reduced the mobility of some prototypes. Most notable, however, was the resistance of the sensor technology itself; it resisted fine-grained testing due to its insensitivity to minor changes in pollution. To take measurements, the students needed to improvise and hold the sensor very close to an expected source of pollution.

Conclusion

The guiding question of this article is how ‘smartness’ materialises in technological form as students engage with other (material and human) actors in the setting of the *SensorLab*. It discusses how human and material agency ‘dance’ within the sociomaterial configuration of the *SensorLab*, and how this dance draws attention to questions of (digital) material agency. The analysis suggests that the students’ involvement as designers hinges on how they improvise with the other human and material actors in the setting. Their performance is characterised in terms of a constant repositioning in relation to the other actors. The students are accommodated, in this dance, to use their (tacit) knowledge to make sense of (and an artefact in) the *SensorLab*. But how can this display of knowledge be connected to ideas concerning the materialisation of 'smartness' and (digital) materiality?

The notion of tacit knowledge suggests that knowledge is separable into different types, i.e. mundane knowledge and expert knowledge. De Certeau (1984) even described 'daily knowledge', and characterised it as unconscious, repetitive knowledge used in a tactical way to circumvent larger social structures (strategies). This seemingly unconscious knowledge could be observed in the *SensorLab* by looking at how students position themselves with respect to the assignment, expertise and materials and vice versa. What makes this display of tacit or mundane knowledge so interesting is, however, that it is *treated* as expertise; the students' improvisations are accommodated as situated expertise, tacit and mundane knowledge that leads to the development of smart sensor prototypes. They are configured as experts. The students become designers in the sense that they create their own meaning and use for the prototypes (according to Dourish (2003) the focus of design). While facilitated by the *SensorLab* to improvise, they are enabled to exercise their situated expertise. Their actions are seen in the light of one of the overarching goals of the *SensorLab*: to empower users to become designers. Granting users this role and the agency associated with this role in practice is an important part of the emancipation of these users.

The sociomaterial setting of the *SensorLab* accommodates the students to improvise by mangling their situated expertise with the material agency of the sensors and the other construction objects. As the students (re)combine and shape materials, they engage in an improvisational 'making do' and 'letting go' (Seham 2001), that is accommodated and recognised by the other actors in this setting as *guiding* the design process. The students decide in which manner materials best fit their designs. The *functional* use of a particular material is used to come up with new ideas: balloons keep a sensor in the air, which allows the students to measure air quality. Alternatively, *symbolic* uses of materials also come to the fore: (toy) cars carry sensors measuring air quality and the inflatable seal 'sniffs out' pollution when sensors are attached to its nose. The students combined the functional and symbolic properties of the materials to create something new. These prototypes show that the included materials certainly 'mobilize and materialise' (Ruppert/Law/Savage 2013) the dance of agency.

That said, the only material that resists the students' improvisations is the pre-programmed sensors themselves. The students' only opportunity to delve into sensor technology as such was the choice of what their prototype should measure. These decisions were limited to the actual use of the sensors: a sensor programmed to measure air quality could not be reconfigured to measure sound intensities within the temporal confines of the workshop. Although the design goals were accommodated, the rudimentary sensor technology itself ultimately resisted the precise measuring of pollution levels because of its technological simplicity. With no opportunity to tinker with the sensors' software, the technological artefacts resisted the students' agency as designers by remaining 'black-boxed'.

This black-boxing of the sensors' abilities resisted some forms of improvisation in terms of what could be measured and to what degree of accuracy, but also accommodated improvisations with the other construction materials. The sensors had to rely on the students' functional improvisations with locomotive objects (such as the use of remote-control cars by groups 2, 4 and 5) to travel to and remain in their intended locations. Moreover, the tendency towards olfactory-based symbolic uses, such as the inflatable seal's nose in group or the giant moustached nose in group 3, reconfigured the sensor as a corporeal prosthetic. These symbolic uses not only attracted attention to the sensors, thereby fulfilling one of the *SensorLab's* predetermined goals, but also prompted articulations of the sensors' findings in terms that park users would understand ('the air smells good here', etc.). The 'smartness' that materialises is therefore closely related to an empowerment of improvisation skills, and less to unearthing knowledge about sensor technology or about pollution levels in a public park.

Regrettably, the technological limits of the censors ultimately rendered many of the prototypes ineffective. At the end of the workshop, each group presented their prototypes and measured results to the PICNIC-audience. They remarked that the sensors did not seem calibrated properly, or were insufficiently sensitive to really generate pollution-level insights of specific locations. They were all surprised that most of the measurements seemed to suggest that every location was quite clean. The sensors only responded noticeably when held close to strong triggers such as a burning cigarette or acetone solution. When a member of the audience asked the students whether they felt that their prototypes could be reused or extended in design, the students agreed that they saw possibilities to extend the designs.[9] Overall, the students' response to the workshop was very enthusiastic. However, they would have liked to have had more time to really get to know how the sensors worked and to try and programme these themselves. This comment reinforces the idea that smartness was more tied to improvising with given materials than to learning more about the versatility of this particular (digital) technology.

Even if the sensors' sensitivity fell short of what the prototypes required, the mangle of human and material agency that aspired to support the sensor functions demonstrates how, in user-as-designer practices, users are configured as experts. The students are facilitated to create 'unforeseen' artefacts, within the preset constraints of the *SensorLab*. The designs are the outcome of a process of sociomaterial interactions which are mangled in practice. The outcomes of their efforts seem, however, less important for the organising actors than realising the workshop in the first place. Indeed, the actors introducing the *SensorLab* talk of being excited about testing this workshop format, and not so much about their expectations to realise exciting new technological artefacts. Bearing in

9 Group 4, for example would want to make their car wind-driven; as there was already a windmill attached to the car, the prototype could have been redesigned to run on wind energy rather than batteries, and thus save more energy.

mind the educational context in which the workshop took place, it is possible to see the *SensorLab* in terms of what Brossard and colleagues (Brossard/Lewenstein/Bonney 2005) have criticised in citizens' science projects: citizens become more knowledgeable about a subject, but not about the underlying scientific processes. Here the same can be concluded. The students learn how – by collectively improvising – to design and develop a smart sensor prototype, but are not educated about the sensor technologies that are part of their prototypes. The idea seems to be that equipping the students will generate embodied learning and help transform them into citizen scientists. The actual smart sensor prototypes were a product of the workshop, but the emphasis lay in teaching students to work with 'sensorkits', to become 'sensorkids' – to paraphrase De Vries and colleagues (De Vries/Pathuis/Vonder/Van der Waaij 2010).

What does a case like this stipulate about the role of material agency in user-as-designer practices? As the students' work within the semi-structured practice of the *SensorLab* illustrates, their situated expertise can be said to lie at the basis of practices of this user-as-designer practice. Their 'dance' with material agency is part of the enactments of this expertise. The above analysis shows that the included materials certainly 'mobilise and materialise' (Ruppert/Law/Savage 2013) the dance of agency. Situating design in this particular setting works to trigger associations specific to this setting, and the inclusion of users as designers does the same. The students refer to their experiences and ideas in relation to pollution and materials, reflecting on how to draw attention and how to do this thing called designing. The crucial preconditions for this designer performance are that the students are provided with a clear goal and motivation, have access to enough materials with which to interact, the opportunity to engage with experts, and the tools to transform the materials. Essential for the design practice is, however, that all the actors in the setting interact in a communicative and 'open' manner: this allows for space where user innovativeness can take its mangled form.

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