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Technology and Human Capabilities in UK Makerspaces

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ABSTRACT *The relationship between technology and human capabilities is an ambivalent one. The same technology can expand capabilities for some users under certain circumstances, whilst diminishing capabilities for others situated differently. In this paper we analyse human capabilities in relation to digital design and fabrication technologies as configured, sociotechnically, in makerspaces in the UK. Through a combination of methods, the study identifies how some of the capability benefits claimed for makerspaces are experienced in practice, whilst noting that other capabilities claimed appear absent. Q-method in particular enables the study to examine systematically the plurality in these expansions and absences. We discuss how capabilities might be expanded, how our methods might be of wider use, and we draw some conclusions for theory regarding sociotechnical configurations and human capabilities.*

KEYWORDS: Capability approach, Technology, Makerspaces, Innovation policy, Q-method, Sociotechnical configurations

1. Introduction

With the development and use of technologies shaping our lives in increasingly profound and pervasive ways, the salience of technologies in human capabilities rises. Yet the relationship between technology and human capabilities is ambivalent (Fernandez-Baldor et al. 2014). The same technology can expand capabilities for some users under certain circumstances, whilst diminishing capabilities for others situated differently. Technologically-mediated capabilities are influenced as much by the social circumstances under which the technology is designed, developed, accessed, and used, as influenced by any affordances inherent to the technological artefact (Hutchby 2001; Matthewman 2011). Making general claims about the capability effects of a technology is difficult without considering

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the overall sociotechnical configuration in which it is situated (Oosterlaken 2011). In this paper we analyse human capabilities in relation to digital design and fabrication technologies as configured, sociotechnically, in makerspaces in the UK.

In studying makerspaces empirically, we make use of, and advance, recent theoretical developments concerning the analysis of technological contributions to human capabilities. However, our primary contribution in this paper is methodological. We develop methods for the appraisal of human capabilities facilitated through the provision of technologies in relatively stable and mobile sociotechnical configurations—irrespective of the specific situations and contexts in which those configurations sit. Using Q-method, we demonstrate a technique for appraising the plural ways in which capabilities are commonly experienced by technology users. Noting differences amongst the capabilities available to makerspace users, and accounting for absences of expected capabilities in particular, we draw a theoretical conclusion about attending to collective action and structural change to the practical provision of potential capabilities.

Makerspaces are workshops where people can access a variety of digital design and fabrication technologies (DFTs), as well as traditional tools, and learn how to use them in personal and collaborative projects for making, hacking and repairing objects. Makerspaces come with a variety of labels, which indicate differences in origins, purposes and institutional positions. Hackspaces and hackerspaces for example tend to be more member-driven workshops (Davies 2017), whereas FabLabs adapt a model pioneered in an outreach programme of the Massachusetts Institute of Technology (Gershenfeld 2005). At 6th January 2018, the fablabs.io website listed 1211 FabLabs in 107 countries, while the hackerspaces.org website listed 1381 active hackerspaces in 43 countries. Other workshops use terms like Tech Shops, Citizen Innovation Labs or, indeed, makerspace. We use makerspaces as an envelope term for the general configuration that these diverse spaces have in common: providing a space in which people can access technologies for design and making, and providing training and activities which enable people to use those technologies (Davies 2017).

The shared features of technology provision that makerspaces have means we can conceive them as providing users with a common sociotechnical configuration of DFTs. We explain and justify this conceptualization in Section 2, but for now it is sufficient to state that the sociotechnical configuration is the way technologies are made available to people for use. The way availability is organized will affect how potential technological advantages (and disadvantages) are experienced as expansions (or reductions) in capabilities. In the case of makerspaces, the sociotechnical configuration of digital design and fabrication technology involves:

- A physical workshop space accessible by the public and equipped with the materials for making things;
- A suite of technologies and materials available for use, including digital design and fabrication technologies, electronics and sensors, computer-aided design and other software, but also in combination with traditional hand tools;
- Provision of both informal and formal training and skills acquisition;
- Online repositories where designs, instructions, and advice are freely available for download, adaptation, and where makers can upload and share their work too;
- An ethos of peer-to-peer collaboration, sharing ideas, openness, and ideas about design and knowledge as a common good;
- Connecting and collaborating with other workshops through decentralized networks.

A 2015 survey of UK makerspaces undertaken by Nesta found information about the technologies available and organization within 97 makerspaces (Sleigh, Stewart, and

Stokes 2015). That survey portrays a general configuration like that above, but does not report user experiences.

In this study we are interested in how the sociotechnical configuration of UK makerspaces offers users, or makers, a set of enhanced capabilities for design and fabrication. Individual makers realize specific functionings through their particular projects and activities in the workshop. Examples of things made, hacked and crafted range from street-furniture to prosthetics, from looms to book-scanners, from eco-houses to agricultural tools, environmental monitoring networks to jewellery, and beyond. However, as the capabilities approach reminds us, it is not simply these objects, goods or services that are important, but also how the act of making itself affects well-being, through its effect upon peoples' identity, community relationships, and sense of agency and place in the world (Jiménez and Zheng 2018). It is these empirically-identified kinds of capability that is important in our analysis. Thus, the unit of analysis is the makerspace as a sociotechnical configuration, and the phenomena we analyse is the capabilities experienced and valued by makers. We ask, how do users of digital design and fabrication technologies in makerspaces actually experience expansions in human capabilities?

Through a combination of methods, the study identifies how some of the capability benefits claimed for makerspaces are experienced in practice, whilst noting that other capability claims appear absent. We discuss how attending to absent capabilities requires investigation into: (a) collective actions that alter the sociotechnical configuration in makerspaces; and, (b) changes in the structural position of makerspaces in societies. We reflect upon the potential of our methods for studies of other technologies, and we draw some conclusions for theory regarding sociotechnical configurations and human capabilities.

The next section explains how we conceptualize technology in our sociotechnical analysis of human capabilities in makerspaces. Section 3 explains our methods. Section 4 presents the results. In Section 5 we discuss what the results tell us about human capabilities in makerspaces, which leads into some reflections regarding sociotechnical configurations and expanded capabilities. We conclude by considering how the methods used in this study might be of wider applicability.

2. Theorising Technology and Human Capabilities in Makerspaces

The Capabilities Approach (CA) argues well-being is best understood through the character of the human capabilities available to people to determine their own development (Sen 1999; Robeyns 2005). Our analysis follows Sen in seeing the capabilities available to people as a matter of empirical identification. We are interested in learning what people are able to do and to be through the provision of technologies in makerspaces.

Technologies are intimately tied up in the capabilities approach. Technologies affect people "in their quality of contributing (or not contributing as the case may be) to people's capabilities to lead flourishing human lives" (van den Hoven 2012, 33). Users harness the affordances of technologies in order to realize an extended capability (Hutchby 2001; Lawson 2010). Makerspaces can be conceived as organizing the provision of technologies in ways intended to be "agentive amplifiers … [that] create possibilities [users] would not have without them" (van den Hoven 2012, 35).

Lawson situates technologies in relation to other artefacts as those that extend or add to our means to "change the world so that it conforms to our intentions" (2010, 211). But how precisely can we conceptualize technology-derived expansions in capabilities in makerspaces? Our analysis follows contributions by Oosterlaken (2011) and Kullman and Lee (2012) by understanding makerspaces as *sociotechnical configurations* available to users and that expand their human capabilities. We explain and justify this conceptualization as follows.

Drawing on Actor Network Theory (ANT) (Callon 1984; Latour 2005), Lawson (2010) suggests that technologies can be understood fully only within their social and technical network of relations. Building on these ideas, Oosterlaken writes that "the relational ontology of the CA should ascribe causal efficacy not only to individuals and social structures, but also to technical artefacts. All three form a constitutive element of human capabilities" (2011, 431). As such, technology is "an important factor in expanding valuable human capabilities … **in their networks of interdependencies with people, other artefacts and social structures**" (Oosterlaken 2011, 425; emphasis added). In other words, it is what we call, after Rip and Kemp (1998), the sociotechnical configuration that expands human capabilities through the way it makes the technology available to users and orientates its use, and not the technology artefact in isolation. Thus, we can conceive of makerspaces as affording certain capabilities thanks to the way technology is related to people in makerspace settings. This means we take seriously not merely the role of new technologies as materials in a makerspace, but the configuration of the technology in those spaces.

Technologies in makerspaces include the physical tools such as 3D printers, digital CNC machines and laser cutters, as well as software such as Sketchup and Fusion, and networked design platforms freely available on the internet such as Instructables and GitHub. Social media and online video platforms are also used by makerspace users. However, in practice, the makerspace presents these technologies to users in relation with the other technologies and through activities and norms, such that a social context is produced in which users are encouraged to explore new creative, social and economic possibilities. These possibilities and preferences are informed by ideas and practices in commons-based, peer-produced socio-economic activity, and an open culture that sees knowledge, hardware and design as a commons (Diez 2012; Barandiaran and Vila-Viñas 2015; Kostakis and Bauwens 2015; Vila-viñas and Barandiaran 2015; Zwanenberg et al., 2017). Many makerspaces subscribe to this ethos, which works as a preference formation mechanism, as well as countering, to a degree, consumerism through the promotion of caring about how things are made, and encouraging people to participate actively in design, fabrication and repair (Schor 2010).

With makerspaces deliberately designed to open access to a highly versatile suite of design and fabrication technologies, so a very wide range of objects, services and creative acts can be accomplished. The variety of functionings people can choose to express is therefore considerable. However, we argue the capabilities makerspaces offer users is by comparison more bounded and can be defined empirically and generically owing to common patterns in the sociotechnical configuration of technology evident across the networks of particular makerspace workshops, users and the setting of each of those workshops (Section 3).

Makerspaces are located in neighbourhoods, in libraries, at schools, universities, co-working spaces and elsewhere, and they are promoted through meet-ups at events, fairs, open evenings, camps, and so forth (Braybrooke and Smith 2018). Makerspaces are also promoted by national- and city-scale policies, innovation agencies, libraries, schools, universities and other institutional actors eager to promote the benefits of access to makerspaces.

Specific makerspaces have histories, cultures and locations that will influence the kinds of functionings favoured by users. A radical hackerspace committed to an ethos of democratizing technology, or a workshop committed to prototyping social projects, is more likely to encourage choices about capabilities that lead into different functionings compared to, say, a FabLab whose rationale is to promote design entrepreneurship and business start-ups. The backgrounds of the individual users and their purposes will also shape the way capabilities are turned into actual functionings.

Our analysis does not go that far: we do not inquire into functionings. Rather, we are interested in the capabilities made available by the general makerspace sociotechnical configuration. In practice however, we suspect there is some subjectivity and variety in how capabilities are experienced in makerspaces. We wish to learn what capabilities are typically experienced and valued in UK makerspaces. We consequently adopted methods that permit analysis of a general picture whilst noting the range of differences (Section 3).

3. Methodology

Based on our theoretical conceptualization of makerspaces, we need a methodology that accomplishes a series of analytical tasks.

- Stage one: identify inductively a set of capabilities associated with the general makerspace sociotechnical configuration. Here we combine analysis from prior fieldwork and a literature review and recode the benefits claimed for makerspaces in terms of human capabilities;
- Stage two: appraise how the capabilities claimed for makerspaces are actually experienced in UK makerspaces amongst a diverse selection of makers. Here, we use Q-method because it permits the analysis of plural patterns of capabilities commonly experienced amongst diverse users;
- Stage three: compare the capabilities in stage one with those analysed in stage two in order to identify differences amongst users and the absence of expected capabilities.

We report the results of our appraisal in Section 4, and in Section 5 we explain the implications for theory of the absences in capabilities revealed by our analysis.

3.1. Stage One: Identifying a Capability Set for Makerspaces

In the first-stage we developed a list of generic makerspace capabilities from a combination of in-depth qualitative interviews, participatory observation and a literature review (Hielscher and Smith 2014; Smith 2017; Smith and Light 2017; Smith et al., 2017). This primary research was prior to the project reported here[1], but we returned to the empirical material generated and re-analysed it in order to identify how makerspaces potentially expand human capabilities.

Adapting the capabilities approach for analytical purposes requires careful explanation and justification of the relevant capabilities identified. It should be clear by now that we understand capabilities in inductively observed terms. We made use of Robeyns' (2003) five criteria for identifying capabilities when reinterpreting makerspace research as the production of a capability set:

- The list should be explicit, discussed and defended
- The method generating the list should be transparent and justified
- The level of abstraction should be appropriate to the study context and project objectives
- Ideal lists of capabilities must become a pragmatic list that can be studied
- The list of capabilities should include all important elements non-reducible to the other elements, even if there are some overlaps

Guided by these criteria we identified a list of generic capabilities, arrived at inductively from the literature and our prior research on diverse makerspaces globally. We then piloted and refined the set through discussions with six critical users of UK makerspaces targeted specifically for that purpose. We recruited these users on the basis that peers identified them as having a good oversight of the makerspace scene in the UK; either through the research they had done themselves into makerspaces, through the organization of events about making in the UK, or through their coordination of makerspaces prominent in UK networks. The results of this stage, our initial list of six makerspace capabilities, are presented in Section 4.1.

3.2. Using Q-method to Analyse the Capabilities Experienced in Makerspaces

In the second stage of our analysis we wanted to assess whether and how actual makers in different UK makerspaces experience the hypothetical capabilities identified in the first-stage analysis. To be clear, our interest here is not with explaining the functionings realized in specific making, hacking and fixing projects (which might be done by analysing, for example, the context of social conversion factors in each makerspace workshop); but rather we wish to appraise the extent to which users recognize, experience and value a set of capabilities identified in stage one. We used Q-method for this because it allows the analyst to identify patterns of how capabilities are experienced across a diverse set of users.

Q-method comes from social psychology research and is used to systematically analyse the experiences and subjective positions of research participants (Stephenson 1953; Brown 1980). Q-method has been applied to empirical research investigating capabilities (Lelli 2001; Schlosberg, Collins, and Niemeyer 2017; Simpson 2018). The research presented in this paper closely followed the analytic procedure outlined by Watts and Stenner (2012, chap. 4). In describing the method, we focus on the major decisions taken in following that procedure.

Q-method mixes qualitative and quantitative analysis. It works by initially developing a concourse of statements that capture the full range of subjective perspectives on an issue, which in our case was statements elaborating the list of six capabilities from stage 1. This meant we developed a set of statements that captured different aspects of each makerspace capability although, as per Robeyns' fifth point above, some overlaps exist. In practice, we developed a concourse of 265 statements[2] in parallel with our identification of the initial capability set (stage 1) and using the same empirical materials. In practice, this meant that each capability was elaborated into a series of self-evident statements about practical aspects of working in a makerspace. We were careful to ensure the wording was grounded in maker experiences and made sense to participants. The concourse was refined and considerably reduced to an operable Q-set of statements that is representative of a range of subjective experiences relating to the phenomenon of inquiry (Watts and Stenner 2012). The refined Q-set of 42 statements was iteratively tested with our pilot participants.[3]

Thirty-six makers from 20 makerspaces in the UK performed a Q-sort, distributing the 42 statements in the Q-set according to the instruction:

> Based on your personal experiences of using digital fabrication technologies: to what extent are the statements on the cards like your point of view?[4]

By way of example, Table 1 illustrates the distribution pattern created by participant P14. The three statements that are most like P14's subjective experience, s14, s24 and s18, were put in the right most column, and the three least like their experience to the left, and so on.[5]

Participant selection criteria were based on requirements for variance in subjective experience of making activities. We sought that variance by selecting a diversity of

Table 1. Q-sort distribution for participant P14.

← Least like my point of view								Most like my point of view→
s35	s23	s25	s27	s15	s09	s17	s34	s14
s19	s13	s04	s08	s20	s29	s26	s11	s24
s03	s06	s02	s28	s33	s12	s16	s41	s18
	s01	s22	s40	s07	s38	s21	s10	
		s39	s31	s05	s42	s36		
			s32	s37	s30			

makers active in different kinds of makerspaces. Diversity was further expanded by selecting people with different ages, backgrounds, locations (social and geographic) and whether they got into making via coding and a digital milieu or through crafting and material practices.[6]

The next step of Q-method is factor analysis. The purpose here is to identify similarities within a complex set of data (36 Q-sort distribution patterns of 42 statements each). Through factor analysis we identified statistical correlations between each of the 36 Q-sort distribution patterns and produced a reduced number of representative Q-factors; in this case three (following procedure for factor extraction outlined in Watts and Stenner 2012, 92).[7]

Q-factors are similar to participant Q-sorts in that each Q-factor consists of a distinct distribution pattern of the 42 Q-set statements. Crucially, each Q-factor represents different but common ways in which capabilities are experienced amongst a sub-set of participants. This is because each of the three Q-factor distribution patterns is similar to the participants' Q-sort distribution pattern to varying degrees of significance.[8] In this way, each Q-factor represents different but common ways in which capabilities are typically experienced in UK makerspaces.

The final step of Q-method qualitatively accounts for the distribution pattern of statements in each of the three Q-factors. Each Q-factor is characterized empirically by building up an account from the statements. This was aided by field notes, participant profile data and transcripts of discussions and reflections from each participant as they considered each statement during and after their sorting. The three Q-factors are reported in précis form in Section 4.2.

3.3. Stage 3: Comparing Common Maker Experiences with the Initial Makerspace Capability List

In this stage we compared the results from stage 2—the three Q-factors—with the capabilities identified in stage 1. There were two motivations for this comparison. The first was to see which of the notional capabilities claimed for makerspaces in the research literature were actually experienced in the UK, and in what ways. Secondly, to identify which, if any, capabilities were not experienced in the UK, and to consider why that might be the case. Stage 3 analysis serves as a bridge into a discussion of the results in Section 5. To facilitate this analysis, narrative accounts of each Q-factor are provided in Section 4.2.

To recapitulate, our methodology first constructs a list of capabilities made available to users of digital design and fabrication technologies through a common makerspace socio-technical configuration. Second, the method moves to an inter-subjective mode of analysis, using Q-method to appraise how the list of capabilities is actually experienced in practice amongst diverse users of different makerspaces. We then make use of theoretical concepts regarding technology, collective capabilities and structural societal change to explain differences between potential and actually experienced capabilities in Section 5.

4. Results

4.1. Analytic Stage 1: Capabilities for Makerspaces

The sociotechnical configuration of makerspaces formed our unit of analysis. Our first analytical stage was to identify empirically the human capabilities claimed to arise within such a configuration. Following the procedure described in Section 3.1, our research identified the following list of makerspace capabilities:[9]

(1) The capability to skilfully make and do
(2) The capability to assume and perform a valued maker identity
(3) The capability to establish and maintain maker community
(4) The capability to sustain livelihood
(5) The capability to modify one's place in the world
(6) The capability to participate in material culture.

4.2. Analytic Stage 2: Capabilities Experienced in UK Makerspaces

Our second analytical stage was to assess whether and how actual makers in different UK makerspaces experience these capabilities. As part of the Q-method analysis, we extracted three Q-factors—each understood as a distinct set of experiences typical in UK makerspaces. We present these in précis form below. For each we identify and selectively discuss distinguishing statements: these are the statements that lie at the left- or right-most poles of the distribution, or represent a relatively extreme position vis-à-vis their corresponding positions in the other two Q-factors.[10] We return to issues of difference and similarity in Section 4.3 and discuss implications in Section 5.

4.2.1. Q-factor A: Personal creativity. Based on the reported experiences, *Personal Creativity* represents a generally optimistic and positive orientation. More than half of the participants (19 of 36) load onto *Personal Creativity.*[11] That is, their experiences of using digital fabrication technologies (DFTs) in makerspaces match those of *Personal Creativity* to a statistically significant degree. These participants represent a mix of crafters and coders, and use DFTs in a variety of ways for professional and hobbyist pursuits. The distribution of statements for *Personal Creativity* is illustrated in Table 2.

Makerspaces afford makers loading onto *Personal Creativity* the freedom to express themselves, and cultivate their own creative identity (**s07,** Table 2). Although some critics of digital design and fabrication draw attention to losses of creativity that comes with a move from analogue to digital, these experiences are the opposite; users experience the sociotechnical configuration of makerspaces as expanding their creative possibilities (**s05**). Experiences do not give rise to concerns about losing jobs through automation (**s34**). *Participant 16's* view is representative:

> Creativity doesn't come [only] through computers and automation, so they are not going to destroy jobs … there will be new jobs that need filling.

These experiences are congruent to ideas that it is not simply the availability of tools which afford creativity in practice, but rather the broader configuration of makerspaces. From this point of view, makers value community capabilities afforded by makerspaces for their

Table 2. Q-sort distribution for Q-factor *Personal Creativity.*

← Least like my point of view						Most like my point of view →		
s19	s33	s32	s17	s16	s23	s21	s24	**s12***
s03	**s41**	s01	s38	s11	s13	s02	s29	s14
s05*	s04	s39	s35	s06	s27	s22*	**s07***	**s36***
	s10*	**s34**	s25	s26	s20	s09	s37	
		s31	s28	s18	s40	s15		
			s42	s30	s08			

*Indicates distinguishing statement. Statements in bold feature in the précis discussion.

ability to contribute towards education and skills development (**s12**). Participant 02 suggests that it is the accessibility of technologies and collective community motivations that are important:

> There is something about learning and community, and access that intersect. It's the location of the technologies, and the motivations of the community.

Furthermore, personal fulfilment can be attained in makerspaces in two senses. First as sites of alternative activities free from labour relations and formal institutions. The use of DFTs need not be motivated by the possibilities of financial gain (**s10**). Second as a configuration which offers future prospects; learning to master digital tools is a gateway to experiment with new tools (**s36**). For participant 16 for example, makerspaces "open up more possibilities than [they] shut down" (**s41**).

4.2.2. Q-factor B: Entrepreneurial making. Seven participants load onto *Entrepreneurial Making*. Six of the seven told us they had knowledge of craft practises prior to using digital fabrication technologies. Interview and questionnaire data indicate that all of these participants support—to some degree—their livelihood through activities in their makerspace. Participants value makerspaces for instrumental reasons—for extending capabilities that fulfil completing complex or repetitive tasks. The statement distribution of *Entrepreneurial Making* is illustrated in Table 3.

From this point-of-view it is inevitable that knowledge of some older making processes will be lost, however participants are pragmatic; some skills will be preserved and new skills are already emerging (**s18** in Table 3). Intriguingly, these participants hold the view that digital fabrication can revive and expand manufacturing capabilities within the UK (**s16**) but ultimately configurations of DFTs will destroy jobs through automation, and undermine livelihoods (**s34**). The following comment from participant 25 provides some nuance, suggesting these makers differentiate between industrial and non-industrial sociotechnical configurations:

> I don't necessarily think *those* tools will be the ones that destroy jobs. They're just tools that fabricate. They have a relationship with the individual, you need the idea. [Automation] will have an impact, but also create opportunities.

For these reasons, the government must support the creation and maintenance of spaces where digital fabrication technologies are available to people (**s11**).

Formal education and training is not needed to master tools. In part this is because these makers do not think that mastery of tools is required for use: one can learn-by-doing. However, another explanation lies in the fact that these participants already have high

Table 3. Q-sort distribution for Q-factor *Entrepreneurial Making.*

← Least like my point of view								Most like my point of view →
s06	s25	s19	s12	s08	s33	s36	s24	**s18***
s01	**s35***	s39	s42	s09	s20	**s16***	**s26***	s14
s03	s04	s32	s28	**s02***	s05	**s34***	**s41***	**s11***
	s23	**s13***	s31	s30	s17	s38	s37	
		s27	s40	s15	s21	s29		
			s22	**s07***	**s10**			

levels of formal education[12] (**s13**), five had formal education or training directly related to their making activities such as university degrees in furniture making, jewellery or fine art, meaning they entered makerspaces having already developed relevant tacit knowledge and confidence.

These makers have an instrumental and practical orientation towards digital fabrication. In principle, makerspaces do open up new possibilities for adopting new material cultures such as sustainability (**s41**), but in practice, making is seen as wasteful. Participant 25's view is illustrative

> It's easy to laser-cut. I didn't really think about that stuff as waste but it is. I've gone from being very environmental, to being very wasteful. It's partly through a lack of options, or partly though the kind of work, workshops with kids … .

Nor do makerspaces encourage making with explicitly social aims, such as sustainability and social inclusion—participants have noticed that other users of digital fabrication technologies are motivated more by making cool projects than by any social values in what is made and how (**s26**). This instrumental orientation is further explained by the high proportion of participants who earn their living in whole or in part from their activities in the makerspace. They value the sociotechnical configuration of makerspaces for the ways in which they enhance tasks which contribute to commercial projects and they value the possibility of financial remuneration (**s10**).

4.2.3. Q-factor C: Social innovation. Six participants load onto *Social Innovation*. These participants are orientated towards professional applications in makerspaces, and prior expertise in software and coding is common. *Social Innovation* has an awareness of social possibilities with makerspaces, and an openness and an appreciation of collaborative capabilities. The statement distribution is illustrated in Table 4.

These makers are optimistic about the potential for inclusiveness of maker communities and they highly value participating in both online and real-world communities. They particularly value increased visibility gained from participation in open online platforms and communities (**s08**). However, these experiences also inform a critical awareness of exclusions in makerspaces (**s24**; **s28**; **s31**). Participant 26 said:

> I don't know if it is specifically around the tools. I think that is very intimidating for people coming from outside that. With the gender and race sort of stuff when you walk into a room full of middle-aged white men you can [think], "I don't belong here." With the [makerspace] when we were setting that up, we saw lots of people who came once and never came back again.

Table 4. Q-sort distribution for Q-factor *Social Innovation.*

← Least like my point of view						Most like my point of view →		
s23	s01	**s07***	s27	s17	s36	**s31***	**s39***	**s08***
s06	s03	s22	s35	s33	s26	**s42***	**s20***	s14
s24*	**s30***	**s15***	s05	s12	s13	s02	s29	**s28***
	s40*	**s11***	s41	s10	s32	s18	s37	
		s19	s34	s04*	s21	**s25***		
			s16	s09	s38			

Open design possibilities are appreciated; makers can easily create new objects through modifying or re-using digital designs (**s20**; **s39**). For participant 07:

> Objects can be made in the workshop to suit my individual needs, because I can easily modify designs using digital technology. Yes. For example, now, instead of buying a TV mount, we'll just quickly design it and 3D print it, and we'll have it. It's really cheap.

Yet these makers are concerned that personalized manufacturing with digital tools uses relatively more energy and materials than mass production (**s42**) because of prototyping practices, material waste and (dis)economies of (small) scale (**s35**). Digital fabrication does not necessarily reduce human error, if poorly coded (**s30**), and neither is moving from prototype to producing at scale an easy transition to make (**s40**). From this point-of-view, personalized manufacturing will never be a mainstream activity (**s25**).

Notably, these makers strongly oppose support from government (**s11**). Primarily, they value independence and making on the terms of the community, while some participants suggested there are pressing needs for public-support elsewhere. Participant 26 said:

> I think there are more important things for them [government] to support and very top down kind of organised spaces can be quite stifling sometimes. I would like to see better support for arts and culture generally and production spaces within, not digital necessarily.

4.3. Analytic Stage 3: Comparing Common and Absent Experiences of Capabilities in UK Makerspaces

In this section we relate how each of the initial six makerspace capabilities are experienced by the Q-factors, or not, presented in Table 5. All the participants in our research were willing users of makerspaces. That common ground means some of the differences between our Q-factors are quite subtle, whilst the fact that there are differences amongst lead users is significant. In drawing comparisons across Table 5 and relating them to the claims made by makerspace advocates that informed the initial list of six makerspace capabilities, analysis brings nuance and opens discussion about the expansion of capabilities in makerspaces.

4.3.1. Similar capabilities experienced differently. The three Q-factors present the same human capabilities—most notably skills, identity and community—but each is experienced differently. Skills is a human capability enhanced by technology across all three. However,

Table 5. Elaboration of how makerspace capabilities are experienced by each Q-factor.

	Personal creativity	Entrepreneurial making	Social innovation
The capability to skilfully make and do	• **Experiences of personal agency through enhanced control of tools.** • **Acquiring new skills is straightforward** • **Developing skills in one area of making opens-up possibilities for further skills acquisition.** o *Ambivalent towards the societal value of skills which may be lost due to automation.*	• **Experiences personal agency through ability to reduce error during fabrication processes** • **Formal knowledge acquired through training makes acquiring digital skills easier** o *Acquisition of new skills required to use digital tools often takes time and considerable effort to master.*	• **Experiences the ability to create by easily modifying or reusing designs** o *Learning new digital skills is not trivial* o *Learning skills needed to master individual tools is not a gateway to further experimentation with new tools precisely because of the need to also learn about new materials*
The capability to assume and perform a valued maker identity	• **Experience the capability to cultivate their own creative identity as a maker, this capability associated with using the makerspace.**	• **Highly values their own personal identity as a maker** o *Other aspects of identity such as age, gender, sexuality recognized.* o *Ambivalent towards capabilities in makerspaces that cultivate new maker identities.*	• **Experiences and values ability to enhance online identity** o *Ambivalent towards other capabilities DFTs afford in the workshop regarding identity*
The capability to establish and maintain maker community	• **Highly values community capabilities built around explicit social purposes of makerspaces e.g. internal makerspace aims that are educational or social.**	• **Community building capabilities that bring together makers with similar professional identities or requirements are especially valued**	• **Experiences collaborative capabilities of maker communities.** o *Attentive to inequalities that may exist and influence users' experiences. Sceptical these inequalities can be resolved in makerspaces.*
The capability to sustain livelihood	• **The education enhancing capabilities of makerspace are experienced and valued.** o *Ambivalent towards other capabilities afforded by DFTs that might enable new ways of supporting businesses and livelihoods*	• **Makerspaces can be usefully configured to facilitates tasks for commercial projects.** o *Uncertainty over future livelihood capabilities and expectations of future job losses.* o *Supports government intervention to support workshops.*	o *Does not agree that it is easy to move from prototyping to producing at scale.* o *Ambivalent about the possibility that digital fabrication can revive and expand manufacturing capabilities within the UK.*

(*Continued*)

Table 5. Continued.

	Personal creativity	Entrepreneurial making	Social innovation
The capability to modify one's place in the world	o *Does not experience and not motivated to affect wider societal change through using DFTs*. o *Configuration of makerspace does not open up the possibilities that these capabilities might exist*	o *Configuration of makerspace does not enhance the capabilities required to alter place in the world*	o *Experiences pragmatic limits to the possibilities of social, personal and material change from individual fabrication that might influence their place in the world*
The capability to participate in material culture	• **Configuration of makerspace does not prevent makers from considering new possibilities for material use.** o *Ambivalent towards aspects of material culture*	o *Configuration does not overcome the constraints materials introduce to fabrication processes*. o *Makerspaces limit users to certain materials e.g., polymers; closing-down creative agency*	• **Configuration of tools valued for contribution to reusing, remixing and redistributing designs and objects.** o *In their experience, knowledge of materials is as important as knowledge of tools or processes.*

Note: Strong experiences in bold. Absent or ambivalent experiences in *italics*.

there are differences in the form this capability takes for each. Skills are specific to digital technologies for *Personal Creativity*. *Entrepreneurial Making* appreciates skills in a similar way, but this appreciation is offset by the loss of traditional skills displaced by digital technology. Whereas *Social Innovation* views skills in terms of a broader set of fabrication skills arising from the conjunction of technologies—digital and traditional—offered by the overall makerspace configuration.

There are more notable differences evident in how each of the Q-factors experience capabilities that cultivate maker identities. The configuration of the makerspace can help foster new creative identities (*Personal Creativity*, and in part *Social Innovation*), or it can sustain and enhance traditional maker identities (*Entrepreneurial Making*). What it cannot do, is make irrelevant the characteristics of identity, such as gender, race and class, noted by makers loading onto *Social Innovation*. We pick up this point in Section 5.

Community capability is also experienced commonly yet differently. In *Personal Creativity*, community capability means drawing upon a collection of people knowledgeable and skilled in using digital fabrication that one turns to for information for one's own projects. *Entrepreneurial Making* construes community capability in terms of mutual help, reciprocity and collaboratively in projects. In *Social Innovation*, community capability is experienced more normatively and generally as an expression of free culture, commons-based activity, and a new way of being.

Recalling the theory in Section 2, skills, identity, and community all appear to be relatively accessible capabilities from within the makerspace. The sociotechnical configuration expands these capabilities so that the capabilities appear to be intrinsic to makerspaces: new skills, assured identity, and sense of community seem to arise from the technology. But it is actually the provision of other resources in the makerspaces (e.g., an ethic of collaboration, learning-by-doing, and so forth) that enable people to acquire skills and forge community through technology use.

4.3.2. Elusive capabilities and structural impediments. Livelihood capabilities are experienced most differently across Q-factors and prove to be elusive to all for different reasons. *Personal Creativity* values makerspaces as sites from which they can escape concerns of earning a livelihood—livelihood capabilities are of little interest. However, *Entrepreneurial Making*, and to a lesser extent *Social Innovation*, experience productivity gains that contribute to their livelihoods. These capabilities go hand-in-hand with anxieties over automation in manufacturing and currently precarious economic prospects for smaller-scale, decentralized fabrication.

The capability of securing a place in the world through makerspaces is not evident in any of the Q-factors. *Personal Creativity* and *Entrepreneurial Making* see little in the sociotechnical configuration of makerspaces that either motivates them or opens up possibilities to transform aspects of the wider world. In *Social Innovation*, pragmatic limits constrain any potential capacity to initiate change, even if participants recognize possibilities in principle.

Similarly, the possibility of a more sustainable material culture was either not recognized as a capability (*Personal Creativity*), or seen as a distant improbability (*Entrepreneurial Making* and *Social Innovation*). This is despite claims from individual participants that the goals of making are often motivated by societal concerns like sustainable development. Digital tools such as laser cutters and 3D printers, even when sociotechnically configured in makerspaces, do not lead automatically to sustainable practices.

Appraising Table 5 and the underlying participant Q-sort data, it is clear that there are complex and even contradictory experiences between each Q-factor. Each capability is experienced differently, and somewhat ambivalently by each Q-factor. This is an important finding that supports the paper's theoretical entry-point; that how users are situated and relate to each other and to technologies within a sociotechnical configuration matters.

5. Discussion

Why are some of our six inductively arrived at capabilities absent amongst the Q-factors in Table 5? And what might be done strategically to address those absences? Recalling Section 2 and studying the transcripts of discussions with participants during and after their Q-sort activity, we see in the absences a requirement for the establishment of additional relations within the makerspace sociotechnical configuration that are beyond the agency of individual participants to bring about. The configuration itself needs expanding and articulating with wider social changes for these absent capabilities to become available in makerspaces.

In the case of the capability to develop one's identity, the wider social context beyond the makerspace exerts its influence in identity cultivation within makerspaces, which in this case brings a wider start-up culture and design entrepreneurialism in society to the fore in UK makerspaces. This supports the theory in Section 2—the sociotechnical configuration of the makerspace is not separate from wider preference formation mechanisms. Makerspaces can mediate wider cultural and social influences, but the latter's continued presence depends upon how actively they are countered or encouraged in the makerspace itself, and thus set the parameters for who can identify as a maker, and in what ways (Fox, Ulgado, and Rosner 2015). So, while UK makerspaces positively extend valued capabilities of identity, they cannot as currently structured, remake a world where race, class and gender cease to matter (see Nagbot 2016 for analysis of feminist makerspaces that attempt to reduce such barriers).

Similarly, the creation of things such as stores and flows of reclaimed materials, institutions for repaired and upcycled products, labour markets employing sustainable making, investment in local circular economy enterprises, or other elements like infrastructure and training, all need to connect to the sociotechnical configuration of makerspaces if the latter's sustainability potential is to be realized. The necessary articulations that can realize capabilities for, say, livelihoods and sustainability, are impossible for makerspace users to forge on their own.

These observations beg the question of whether strategic work to realize more elusive capabilities requires changes internal to the sociotechnical configuration of makerspaces, perhaps through collective activities amongst participants? Or, whether more structural changes to the wider society are required, in which the creativity prototyped in makerspaces can be taken up and used more widely?

Where the degree, differentiated distribution and quality of human capabilities is shaped by social contexts such as institutions and environmental factors, the expansion of capabilities has to be realized through collective actions that change those social contexts (Robeyns 2005; Zheng and Stahl 2011). In the study, we approached capabilities as related to individual protagonists and identified how they generally (yet plurally) experienced them. However, the expansion of capabilities absent to individuals in any situation is linked to the character of prevailing group and social structures as well as material conditions (Stewart 2005; Ibrahim 2006). Capabilities are expanded, attained and experienced as much through collective action and structural reforms as through individual effort. Users of makerspaces, with their appreciation of community, skill building and shared identities appear well-suited to build or extend (collective) capabilities through group mobilizations.

Our analysis suggests three promising areas for collective action and policy intervention. *First, building on existing community capabilities as a means to strengthen and establish relations between diverse users.* In this manner, collective action might be fostered from within makerspace networks themselves: building strength from community and enhancing collective capabilities. Sennett (2008) argues that a craftsperson's potential value is fully realized only within a community of like-minded practitioners; that craft is not primarily an individual experience but a collective one. This is evident from our Q-factors and corresponds to findings from Jiménez and Zheng (2018) who stress that communities are dynamic entities that are configured and reconfigured by their members and the contexts in which they are embedded. Furthermore, a mixture of technical appreciation and community ethos is central to almost all experiences of this study's participants. Personal investment is matched by common values. Communities of users together hold potential to bring different capabilities into a collective endeavour.

Strengthening community and collective capabilities connects to a second strategy for action: *expanding the configuration of people, resources and technologies available within the makerspace*. A virtuous cycle may be established, in which inclusive community capabilities enhance the capacity to configure a greater diversity and number of (influential) users and resources within makerspaces. Makerspaces are highly networked already and permit collective action, but they tend to do so with respect to the first three capabilities only. More purposeful networked activity in relation to the absent capabilities is required with this strategy: configuring people and resources that offer possibilities for livelihoods, improved standing in the world, and sustainability.

Configuring sociotechnically for a broader set of capabilities will require social learning, embedding and institutionalizing amongst makerspaces. Exactly how is a matter for future research (Braybrooke and Smith 2018), but producing common visions and sharing practices in alternative, more socially transformational uses of makerspaces could be a strategic point of departure. As it is, however, it is often simply too demanding on maker collectives to disentangle themselves sufficiently from powerful social and economic relations that root people into precarious livelihoods and unsustainable practices.

The third area for action is therefore gaining appropriate support from policy actors and institutions for changes in the social and economic structures to which makerspaces aspire to connect. With the distribution of some capabilities significantly differentiated, or absent entirely, across all three Q-factors, structural interventions become necessary. Here policy changes can help. When it comes to issues of waste and energy reduction, the use of environmentally responsible materials, or precarious leasing situations for workshops and livelihoods for their users, our research participants felt makerspaces could do little unilaterally to change the situation. In such cases, waste and energy education activity in makerspaces can help inform the design of policy for appropriate changes in society more widely. Makerspace activities cannot alter the infrastructures, investment and institutions required for deeper sustainability capabilities, but the prototyping that goes on in makerspaces and potential capabilities therein generates valuable lessons for what kinds of changes to infrastructure, investment and institutions might work (Smith 2018). Appropriately supported, makerspaces could help prototype policies focussed on regulation (e.g., the *Right to Repair*), planning and zoning (e.g., so that neighbourhoods have access to workshops), infrastructure provision (e.g., for citizen innovation), education programmes (e.g., about hands-on, sustainable material culture), and so on for a variety of policy areas.

Yet as we have seen with *Social Innovation*, direct government support is not always welcomed. Institutional support that is welcomed by other participants, serves to diminish capabilities for these makers. Collective action mediated through links to social movements might seem more strategically sensible for some groups (Smith 2017). Commons and peer-to-peer movements may, for example, offer an alternative to state and market logics, and instead configure makerspaces as sites for commons-based modes of "designing globally and making locally" and that drives different kinds of sustainability (Kostakis et al., 2018). As with policy links, however, the strategy remains one of using makerspaces as spaces where prototyping can inform wider institutional changes, though this time aligned with the aspirations and demands of social movements (Smith et al. 2017).

6. Conclusions

Using Q-method, we deliberately worked with a diversity of makers, so that we could identify the range of capabilities. The analysis presented in Table 5 illustrates two important findings. First, as discussed extensively in the previous section, the range of capabilities typically experienced in UK makerspaces is not as expansive as the range of six capabilities claimed for makerspaces generally in our initial list. Second, the study highlights the differentiated expansion of capabilities for people in the same or similar makerspaces and how these expansions rely on wider structures.

The results are noteworthy for policy-makers, firms, educators and activists interested in opening makerspaces and making use of the capabilities generally claimed for this sociotechnical configuration. Ensuring the full presence of capabilities, and expanding capabilities further (and who has access to them), requires changes to the wider social structures in which makerspaces are situated, and the creation of new articulations between makerspaces and those structures.

Transforming those structures is challenging. From within the sociotechnical configuration, building maker community capabilities enables collective mobilizations for changes that expand, unevenly, the other capabilities available—effectively by enrolling new elements into the configuration. From beyond makerspaces, broader policy programmes and social mobilizations can alter the social structures that value and reward new forms of livelihood, or alter infrastructures for sustainability. However, interventions must pay close attention to differentiated capability expansion. Careful considerations of sociotechnical configurations, conversion factors and participant diversity are required not only to better distribute expanded capabilities, but to mitigate potential harms from those who whose capabilities may be diminished. Future research in this regard might adopt an explicitly structural and institutional approach to capabilities (Ibrahim 2006; Stewart 2013).

In drawing conclusions from this study, it is important to bear in mind that we analysed capabilities typically experienced by users of UK makerspaces. Obviously, such analysis does not include the wider population, nor makerspaces elsewhere. There are theoretical reasons for suspecting absences identified in our UK study could be repeated elsewhere, since the sociotechnical configuration of makerspaces is similar globally. Empirical studies suggest workshops in other countries also experience difficulty articulating with local contexts for effective social change; and a general lack of (policy) support and strategy in mobilizing spaces for collective capabilities in social and economic change: livelihoods; agency and place in the world; and sustainable material cultures (for examples of empirical studies, see Coban 2018; Dias and Smith 2018). Important as capabilities for developing skills, identities and community undoubtedly are, they may be susceptible to capture in a gig economy for design and prototyping (Braybrooke and Smith 2018), rather than emancipating people through more collaborative material cultures.

Of course, only comparative empirical research can say if this really is the case generally. Here, the Q-method procedure we developed for analysing the situation in the UK could be repeated elsewhere. The method usefully identifies differentiated patterns of capabilities experienced within a general sociotechnical configuration—in this case, the makerspaces configuration of digital design and fabrication technologies. In that respect, the method provides an approach for working with the ambivalent ways in which technologies enhance or diminish human capabilities. General yet differentiated capability experiences can be identified that bring more nuance than universal claims about the human capability expanded by a technology. The method could be applied to other sociotechnical configurations beyond makerspaces. For example, how human capabilities are experienced by farmers relying upon genetically modified crops and high-input agriculture, or alternatively with agro-ecological configurations. Applications are limited only by the extent it is reasonable to conceive of a mobile, generally applicable sociotechnical configuration.

More generally, Q-method offers a means by which to open up the inputs of assessment to a diversity of participants, their experiences and points-of-view. Simpson (2018) in this journal uses this methodological feature to broaden-out who gets to rank what well-being capabilities matter in environmental assessment decision procedure. He does this using factor analysis to identify similarities amongst rankings of competing capabilities from a diverse set of participants. The analytic emphasis in our study is different; here Q-method is used to assess similarities, differences and also absences in how capabilities are experienced in real-world settings. We use Q-method to open up the situated context of capabilities, making a virtue of a plurality of participant experience. Furthermore, we used a secondary feature of the methodology, qualitative material gathered during Q-sort activities, to further explain differentiated and absent experiences. Common to both of these studies is an emphasis on recognizing plurality. Apprehension of plurality, differentiated points-of-view and subjective experiences is an integral property of the capability approach, the core evaluative logic of which seeks to be attuned to the actual complexity of the world. As such, Q-method seems to be particularly compatible with the capability approach.

Specifically, with makerspaces, we think it unlikely and unreasonable for everyone to become a maker. Consequently, the associated human capabilities may not be experienced directly by all individuals, but the capabilities available to some groups may still have some social affect beyond makers. Society is enriched by the diversity of spaces in which people can prototype new material cultures, and by the diverse social values makers introduce into technology design and use (Smith and Stirling 2018). If public agencies wish to promote makerspaces, whether as sites for new forms of production, incubators of sustainability prototyping, or laboratories for citizen innovation, as some agencies do already, then the expansion of human capabilities intended for participants needs careful consideration. As do the broader processes of social change in which those developments are placed.

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Notes

1. The research for this stage involved interviews with long-standing coordinators at 26 makerspaces, and who had an overview of activity and networks. Observation and discussions were also undertaken with participants at those makerspaces, as a way of corroborating claims. These makerspaces were located in diverse urban settings in the Netherlands, Chile, Spain, UK, Argentina, Colombia, Germany, Denmark, Finland, and India. In three cases, visits included our own participation in making activity. In sum, the empirical material covered a diversity of makerspace types, histories, experiences and purposes. That diversity was important for abstracting a general overview of the makerspace sociotechnical configuration and the kinds of capabilities provided by that configuration. We manually re-coded benefits associated with makerspaces from earlier research as expansions in different kinds of human capability for the research here.
2. Sufficient coverage was achieved when further research did not contribute additional statements of significant novelty.
3. Supplemental empiric and analytic material is available in an online appendix to this paper available at https://doi.org/10.1080/19452829.2019.1704706. The final 42 statements in our Q-set are listed in the online appendix, Table A1.
4. We validated the adequacy of the range of our capability set and Q-sort statements at that stage by asking each participant if any topic was missing. None said anything was missing, which suggests we captured the envelope of maker experience.
5. The nine-column normalised distribution is strategically chosen (Watts and Stenner 2012) to accommodate the relatively high experience level of the participants, all of whom had to have at least one year's experience in makerspaces, ensuring our cohort were all to some degree 'lead users'. So, for example, statement s14 from the online appendix, Table A1, reads "*In my experience, open design and collaboration processes lead to improvements in design and production*" – which is most like their point of view.
6. Details of participant profiles including age, gender and educational attainment are set out in the online appendix, Table A2.
7. It is important not to confuse Q-method factors with 'conversion factors' in human capabilities. Q-method factors represent distinct yet commonly occurring experiences of capabilities – what can be called framings

of the capability set – rather than the conversion of an individual capability into a specific functioning. In order to avoid confusion, we use the term Q-factor throughout.

8. These similarities and differences are shown in the online appendix, Table A3.
9. These capabilities are elaborated and justified in the online appendix, Table A4.
10. The analysis of the three Q-factors involved close inspection of each of the 42 statements and their relative positions within and between each Q-factor (Watts and Stenner 2012). Space constraints compel us to focus our discussion on the distinguishing statements that illustrate notably different experiences between each of the Q-factors. Indeed, a useful feature of Q-method is its ability to distinguish heterogeneity in seemingly ambiguous data. Direct comparison of statement positions between each Q-factor is illustrated in Figure A1 in the online appendix. The respective statement distributions are presented in the online appendix, Table A2.
11. See the online appendix, Table A3.
12. See the online appendix, Table A2.

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Supplemental data

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