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An exploratory study into everyday problem solving in the design process of medical devices

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ABSTRACT

We investigated accounts of how individuals in public and private organisations operating in the medical device industry use different forms of capital (social e.g. networks and cultural e.g. knowledge) to solve design based problems. We define capital as resources embedded in social networks, knowledge or economic wealth [Bourdieu 1986. "Forms of Capital." In *Handbook of Theory and Research for the Sociology of Education*, edited by J. Richardson, 241–258. New York: Greenwood]. Data were collected from interviews and written diaries from individuals involved in the design process of medical devices using interpretative analysis. Inferences made from our analyses suggested that individuals working in organisations who successfully solve problems may do so by using both social and cultural capital and so may be more likely to engage in innovative activity than others. These exploratory findings suggest workers in large organisations may have the capability to use a greater level of in-house social and cultural capital, whereas those in smaller organisations may be more reliant on high levels of social capital in order to 'tap into' cultural capital beyond organisational boundaries.

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KEYWORDS
Problem-solving; innovation; Bourdieu; social capital; cultural capital

1. Introduction

Problem-solving is an important influence on innovation (During 1986; Scott and Bruce 1994). Problems can stem from changes and uncertainty in the external environment, and organisations respond in different ways using a mix of different types of capital (Levinthal 2000; McMullen and Shepherd 2006). We define a problem as: 'an unknown entity in some situation (the difference between a goal state and a current state) . . . ' (Jonassen 2000, 64), and problem-solving as: a 'goal-directed sequence of cognitive operations' (Anderson 1980, 257). Problem-solving is a complex process that involves interacting processes of initial problem-framing, followed by finding and scoping solutions (Nickerson, Yen, and Mahoney 2012; Nickerson and Zenger 2004). Problem-solving effectiveness is important for superior organisational performance (Nickerson and Zenger 2004; Nonaka and von Krogh 2009). In order to solve problems, individuals need access to resources/capitals (Daniels and DeJonge 2010), and problems can require solutions that combine the knowledge, efforts,

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and abilities of people with diverse perspectives (Brown and Eisenhardt 1998; Brusoni and Prencipe 2013; Felin and Zenge 2014). We focus on one class of problem – design problems: Design problems are often complex, ill-defined and do not have obvious solutions (Jonassen 2000; Hsu 2009). Dorst and Cross (2001) suggest that designers treat all problems as ill-defined: We take their viewpoint and as such the problems described in this paper are ill-defined problems. For a detailed discussion on ill-defined and defined problems we direct the reader to Simon (1973). In the present paper, we are simply interested in whether designers experienced a problem rather than determining the type of problem (e.g. well defined, ill-defined etc.) in order to examine the role of capitals in designers' problem-solving. Problem-solving can include cognitive based operations such as decision making, categorisation and application of expertise (see Newell and Simon 1972 for a detailed account of problem-solving and knowledge expertise). However, we must contend that the process of design is more complex than is assumed by a traditional cognitive approach because it involves various cultural-historical, contextual, and situational processes (Seitamaa-Hakkarainen 2000). Therefore we do not focus our attention merely on cognitive aspects of design problems.

Successful problem-solving can be linked to an increase in innovative activity in organisations, (Lundvall 1992; Lundvall and Nielsen 2005; Felin and Zenge 2014); as well as enhanced learning in organisations (Daniels et al. 2009). Innovation is important for organisational survival and growth (Drucker 1985). Innovation essentially starts with the process of creativity which requires the generation of new and useful ideas leading to the implementation of those ideas (Amabile 1996). We follow a broad definition of innovation as: 'any idea, practice, or product that is perceived as new by the potential unit of adoption' (Zaltman, Duncan, and Holbek 1973, 50).

We use medical device design as the context to study design problems principally because these activities occur in different working environments: large and small private organisations and public sector organisations such as hospitals and universities (Eatock, Dixon, and Young 2009; Medina, Okudan Kremer, and Wysk 2013). New medical device technologies may offer potential benefits in terms of health gain or the relief of suffering, but on the other hand: there may be risks to health; social or economic costs may be incurred; or ethical issues raised (Lenzer 2009).

Our primary focus is on how the individual solves immediate design related problems in his/her particular working context. We draw a link between successful problem-solving and innovation to address the call from the innovation literature for more exploration of the processes (or inputs) that influence innovation; Crossan and Apaydin (2010) argue strongly for research studies that conduct micro-level analysis of the innovation process (1179): 'it is at this 'micro level' that the managerial reality enfolds every day, therefore a theory of innovation needs to connect the action (*praxis*) with the managerial and academic theories (*practice*) by understanding the role of agents (*practitioners*)'. To assist with this call, we draw on the seminal work of Pierre Bourdieu on capital theory, and so address invitations to exploit the theoretical and empirical base of Bourdieu's work to analyse the ways in which organisations evolve (Emirbayer and Johnson 2008; Vaughan 2008).

Thus, there is growing interest in capital theory. However, little is known about how different forms of capital are utilised in everyday working life and in the case of this study, how different capitals are used in solving everyday design problems and specifically how different capitals are used for problem-solving in a regulated market. Most research focusing

on capitals and/or innovation has concentrated on the private sector, and has examined both large (e.g. Lester et al. 2008; Mortara and Minshall 2011) and small organisations (e.g. Aarstad, Haugland, and Greve 2010; Kang and Park 2012; Tolstoy and Agndal 2010; Walsh 2012). By concentrating on the utilisation of different capitals for problem-solving and innovation, this study makes an important contribution to the literature on individual problem-solving and innovation in different working contexts. The work also addresses recent calls for the exploration of using capitals in everyday problem-solving and innovation (Glover et al. 2016); and analysis at the individual level is becoming increasingly important in organisational research (Greenman 2013).

The paper is structured as follows: We next examine capital theory focusing on social capital and cultural capital. We then explore the problem-solving and innovation literature in relation to solving everyday design problems. We detail literature on capitals, innovation and problem-solving in different organisational contexts before moving to the empirical sections of our study where we examine how these relationships play out in medical device design. The specific contribution of the paper is to explain how day-to-day use of capitals is used by individuals to solve design problems in different organisational contexts. In this study, the contexts we examine are small private firms, private multinationals and public sector organisations in the medical device sector.

2. Capital theory

Whilst acknowledging that a number of scholars have developed the notion of different types of capital (e.g. social, human, intellectual) and capital theory, particularly in relation to social capital (Coleman 1990; Lin 2001; Putnam 2000 to name a few influential works), we focus specifically on the work of Pierre Bourdieu. Bourdieu is concerned with what people do in their daily lives (Jenkins 1992). This premise is a key rationale for choosing his body of work to explore the micro-level analysis of innovation and problem-solving. It was impossible, Bourdieu (1986) argued, 'to understand the social world without acknowledging the role of "capital" in all its forms, not just the one form recognised by economic theory' (422).

Bourdieu's main theoretical contribution has been to develop the concepts of: habitus, field and capital. For the individual player, habitus refers to a combination of perception, thinking, feeling, evaluating, speaking, and acting (Bourdieu 1991). For Bourdieu, field is a social space in which players are positioned with given resources. An industry or industrial sector is an example of a field. The field provides a structure (and rules of the game) where actions enable players to gain control over resources. Bourdieu defines resources as four forms of capital: economic; cultural; social; and symbolic (Bourdieu 1986). In this study we address calls for further research investigating the use of social and cultural capital in individual problem solving and innovation (Glover et al. 2016).

According to Bourdieu, cultural capital can exist in three forms. Firstly, in the form of long-lasting dispositions learned from family or gained from personal experiences, for instance mannerisms. Secondly, in the objectified state, in the form of cultural goods: pictures, books, dictionaries, instruments, and so on, including exposure to these goods through cultural experiences by visiting museums, art galleries and theatres. Lastly, in the institutionalised state, for instance educational qualifications (Bourdieu 1986). Bourdieu sees cultural capital as knowledge, expertise and experience embodied in individuals, and derived from one's social origins (Bourdieu 1986, 1991). Previous work has highlighted

the critical importance of expertise in solving design problems, however the focus of the investigation was on well-defined problems (Newell and Simon 1972).

Bourdieu and others argue that social capital consists of resources embedded in social relations and social structure (Field 2003). Social capital depends on the social setting and social circumstances of the people involved. Social capital is an investment on the part of an actor to increase the likelihood of success in purposive actions (Lin 2001). Social capital is thus defined by Bourdieu (1986) as: 'the aggregate of the actual or potential resources, which are linked to possession of a durable (long-standing) network of more or less, institutionalised relationships of mutual acquaintance and recognition' (248). Some social ties (networks), resulting from their location and position (status), carry more valued resources and exercise greater power on decision-making (Lin 2001). Networks, both personal and business, can impact upon the firm (Vissa and Bhagavatula 2012). Increased networks of relationships, reciprocity and levels of trust act as viable mechanisms to enhance levels of social capital (Lin 2001). Overall, the amount of social capital that one possesses depends on (1) the size of network connections that the individual 'can effectively mobilise' and (2) the amount and type(s) of capital (e.g. economic, cultural, or symbolic) possessed by each of those to whom he or she is related (Bourdieu 1986, 249). Social capital can be used to obtain resources in tandem with, or in the absence of, other forms of capital (Bourdieu 1986). We now turn our attention to innovation and problem-solving.

3. Capitals, problem-solving and innovation in large organisations, SMEs and public sector organisations

Bourdieu (1986, 1991) suggests that those who occupy powerful positions in the field will, by definition, have more influence over the rules (hence regulation) of how that field operates. This draws close parallels with the difficulties individuals face working in small and medium sized enterprises (SMEs) when faced with competition from larger organisations. Individuals working in public sector organisations will face different challenges to small and large firms, particularly in relation to who holds powerful positions over that organisation (e.g. policy makers) and how the individuals working for the organisation are able to respond to, or resist, change. As small, large and public sector organisations hold different positions in relation to each other, a comparative study of the individuals working in these provides an opportunity to explore how capitals are utilised by different types of organisations in the medical device industry.

For example, cultural capital can be influenced by an individual's workplace. In small business start-ups (or entrepreneurship), previous employment in a highly recognised company (institutionalised cultural capital) may allow an entrepreneur to incorporate these experiences in the previous company into the new venture, or display various artefacts, such as plaques or awards from the former company (objectified cultural capital) to make the venture more compelling to investors (De Clercq and Voronov 2009). For established small firms, the business owners' accumulated knowledge and experience of their firm and the market becomes an important element of cultural capital. In a large organisation, individuals may have the opportunity to extend their cultural capital through working in different countries or different departments of the same organisation during an individual's experience of work (Bourdieu 1986; 1991). Cultural capital is thus important in the innovation process (De Clercq and Voronov 2009).

Social capital in the form of intra-firm relationships is important for innovation processes as well as inter-organisational relationships (Laursen, Masciarelli, and Prencipe 2012). The role of social capital as a facilitator to innovation and creativity stems from the ability of individuals to access embedded resources within and from networks (Baker, Grinstein, and Harmancioglu 2016; Nahapiet and Ghoshal 1998). In terms of social capital, there are some interesting similarities between Bourdieu's (1986) interest in individuals' networks, the strength of these ties and the recent interest in networked innovation, seen to be beneficial to develop relationships within and between organisations (Swan and Scarbrough 2005). New product development teams are often used to bring together networks of knowledge when unexpected problems occur in the innovation process (Durmuşoğlu 2013). Networked innovation can fall under three main groups: external collaborations, collaborations with intermediaries and co-innovations with customers/end users (Berasategi, Arana, and Castellano 2011). On the other hand open innovation demonstrates how it is possible to use networks to gain access to knowledge outside of the boundaries of the firm. Open innovation refers to 'the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for external use of innovation, respectively' (Chesbrough and Crowther 2006). Huizingh (2011) suggests the need for case study research to explore 'how things work' i.e. open innovation processes. Another avenue for exploring 'how things work' from a different perspective is by examining the relationship between social and cultural capital, in particular if and how individuals use these two capitals in their daily working lives to solve problems.

For small firms to engage in problem-solving and innovative behaviour may be more challenging than their larger counterparts: namely lack of skills in the workforce, lack of systems for measuring innovation, difficulty accessing external information, and dealing with government regulations (Freel 2000; Vossen 1999). Successful problem-solving and hence innovations in the design of medical devices require a combination of capitals, which is arguably easier in larger organisations, with different departments having individuals with specialist knowledge e.g. accountants, marketers etc.

The individual is an important source of knowledge (cultural capital) in SMEs, who relies on a much smaller pool of individuals. Corti and Storto's (2000) study of technical problem-solving in SMEs found that the role of the wider business and social community must be considered, such as suppliers and customers. This is important if SMEs are trying to access networks (social capital) for specific purposes e.g. knowledge, product markets, and so on. As such through using different capitals, SMEs can seek to accumulate capital, in this case cultural capital, from outside the organisation, for example employ consultants, or seek advice from accountants. Networks can be formal and informal (Shaw 1993). Linking this line of reasoning to Bourdieu's (1986) work, it would be expected that more innovative organisations would have higher levels of cultural capital and access to networks offering greater access to social capital.

Organisations' operating in the public service sector often have to deal with competing demands, diffuse power structures and divergent objectives (Lockett et al. 2012); this can impact on individuals' ability to solve problems. Change, and hence innovation, is often resisted in healthcare, as medical professionals strategically respond to reforms in ways that maintain their own influence over emerging services (Currie, Finn, and Martin 2010; Martin, Currie, and Finn 2009). However, innovation is also important for all firms and seen as imperative for competitive advantage (Tidd, Bessant, and Pavitt 2009). Albury's (2004)

report on innovation in the public sector indicates that well implemented ideas (innovations) can lead to valuable new services or increased efficiency of existing ones at a time of financial pressure on public services.

What is not known in the literature, and what the study addresses, is how individuals working in different types of organisations utilise different forms of capital to solve problems and engage in innovation within the medical device sector. We focus on addressing calls for investigating the individual (micro level analysis) (Crossan and Apaydin 2010; Glover et al. 2016; Greenman 2013) and the problems they encounter (Daniels et al. 2013) in the design process of medical devices; these problems can involve technical, social and financial issues.

4. Setting the scene and methods

The exploratory and interpretative study is designed to address the identified gaps in the literature. Despite comprehensive literatures on social capital, innovation and problem-solving, little is understood about how individuals use different forms of capital, in this case social and cultural capital to solve design problems, in the day-to-day interactions and situations that occur in different types of organisations. Design problems are characterised by being complex and unstructured (Jonassen 2000). We chose the medical device sector as individuals work in a variety of organisational contexts from large multinationals to small and very small companies from a range of backgrounds with a wide customer base spread across public and private sector organisations (Eatock, Dixon, and Young 2009). In relation to context, medical device designers in the UK include NHS-based clinicians, as well as designers working in small bioscience and engineering firms and large multinational companies (Hourd and Williams 2006).

The design and production of medical devices is highly regulated (Chowdhury 2012; Clarkson et al. 2004). Regulation is an important topic, those who are advocates argue that it is necessary to sustain a market (Kitching 2006); whereas those who are critics argue that it imposes costs on businesses, including impeding innovation (Nicoletti and Scarpetta 2003). Some authors go further to suggest that regulation constitutes an excessive burden on SMEs in particular (Carter, Mason, and Tagg 2009; van Stel and Stunnenberg 2006). In highly regulated industries, for example medical devices, there are often issues concerning patient safety at the source of regulation (Dougherty and Dunne 2011; Iedema 2009; Yeung and Dixon-Woods 2010). Large private organisations have more available resources to devote to developing the necessary strategies to overcome regulation or even use it to their advantage, whereas SMEs may find it harder to access the expertise, time and financial capital (Marlow 1998). Organisations in the public sector are often restricted in terms of regulation and experience high levels of bureaucracy to ensure compliance with safety and mandated standards, bureaucracy affects how they are able to respond to change (Lockett et al. 2012).

Effective design can reduce or eliminate many problems associated with medical devices (Clarkson et al. 2004). The act of designing requires engineers to transform initial abstract ideas into the final usable product following a number of actions involving individuals and the system (Hales and Gooch 2004). Therefore, the design process of medical devices is often a complex and multifaceted involving a diversity of participants with the ability to solve problems (Blume 1992; Dixon et al. 2006; Farley and Rouse 2000; Faulkner

2008; Lehoux et al. 2011). The medical device industry is characterised by high levels of problem-solving demands: Designers of medical technologies have to produce novel solutions to complex engineering problems, and are subject to compliance with regulators to ensure the safety of a product. The focus of this study is on the small, design innovations rather than the challenges of introducing a new medical device which has been the focus of previous work (Clarkson et al. 2004). We now turn our attention to describing our research methodology in order to answer our research question of how do individuals solve immediate design problems in their particular working context.

We used a case study approach to explore the role of social and cultural capital in individuals' design-related problem-solving in the medical device sector. To capture data on everyday problems requires a multi-method approach and provides justification for a case study approach that comprises interviews with stakeholders and individual designers, and written diaries completed by designers. Case studies offer a way to organise multiple sources of data from multiple context (Yin 2003). Although the level of analysis is the individual, we use case studies to group these individuals according to the type of organisation they work for (small, large or public sector). A case study strategy is ideally suited to explain, describe, illustrate, explore, and evaluate (Yin 2003). Yin (2003) suggests case studies are useful for inductively developing understanding of the relatively unexplored. Case studies also provide a mechanism to structure data from multiple sources (Miles and Huberman 1994; Yin 2003). We use cases to explore individual's capital usage in three different types of organisations: public sector, and private sector – both multinationals and small firms, to gain a deeper understanding of how individuals in organisations use social and cultural capital when solving design problems. This study uses approaches and ways to identify capitals that is consistent with other works and follows Bourdieu's (1986) thinking on items that constitute social and cultural capital.

The three case studies include a total of: 20 semi-structured interviews with medical devices industry stakeholders; 17 semi-structured interviews with medical device designers: ten from public sector organisations, four from multinational corporations and three from small firms; and finally qualitative diary entries from 29 medical devices designers from 12 different organisations, four large private organisations, three public sector organisations and five SMEs. Participants were recruited through contacts at industry and regulatory bodies concerned with medical devices. The data were then re-assembled so that each sample was divided into either: Case study one: Individuals working in public sector organisations; Case study two: Individuals working in large private organisations; and Case study three: Individuals working in small private firms. This was important as it allowed us to explore any similarities or differences in the use of capitals to solve problems.

4.1. Sample 1, industry stakeholders

Data were collected from interviews with twenty industry stakeholders from the medical devices sector, including four from regulators and advisory bodies, six from university-based public sector organisations, four from managers and designers in large private organisations and six people working in small medical technology firms. We wanted a broad spectrum of stakeholders having spent differing amounts of time in the industry and with different backgrounds to ensure we gained a wide range of opinions. All of those contacted agreed to participate. Semi-structured interviews focused on the design process,

the general problems individuals faced, solving problems and innovation (see Appendix A for interview questions). Data were collected mainly through face-to-face interviews (13 participants), the remaining interviews were conducted over the telephone (seven).

4.2. Sample 2, medical device designers

We conducted 17 semi-structured interviews with designers from private organisations four from large, multi-nationals, five from small; and ten from public sector organisations. These interviews were concerned with individual design problem-solving. Ten interviews were conducted face–to-face and the remainder by telephone. First, participants were asked questions about how they usually went about solving design problems and how their organisation helped them develop innovative and safe solutions to problems. Then participants were asked to think of a specific design problem and how they went about solving that problem (see Appendix B for diary questions). This provided information about how people solved problems both generically and for a specific design problem.

4.3. Sample 3, diary procedure

Qualitative diaries are particularly useful for uncovering the conditions, behaviours, and thought processes that surround phenomena close to where they occur (Bolger, Davis, and Rafaeli 2003). Twenty-nine designers provided data in the form of answers to open-ended questions in qualitative diaries. Participants were recruited from ten organisations, eight of which were concerned with the design of medical devices, one with the design of product packaging for medical devices, and one with the design of major healthcare facilities such as hospitals. Three organisations were from the public sector, three were multinationals, and the rest were small firms (number of employees ranging from one to 20).

Participants were given a diary booklet with ten sets of open ended questions. Participants were not financially rewarded for completing diaries, but were offered bespoke feedback. Participants were asked to record incidences of design problems in their work and answer the open-ended questions. The questions in the diary covered features of the design problem; approaches to problem-solving and reasons for choosing those approaches; emotional reactions to the design problems; regulation of emotional reactions to these problems and reasons for choosing those approaches; and implementation of ideas to solve design problems. Participants were asked to cease completing the diaries after four weeks or until they had completed ten entries, whichever was sooner. The sample provided descriptions of 80 design problems and participants provided data on one to six problems.

4.4. Data analysis

The interviews from each case study were tape recorded and transcribed. Diary entries were written by participants and subsequently entered into word processing documents for analysis. For reasons of confidentiality, real names have been omitted. Data were analysed using constant comparison and thematic analysis. Glaser and Kaplan (1996) state that 'the process of constant comparison continually compares data to data, concept to data, concept to concept, and linking concepts back to the data' (98). Analysis involved the first author reading the transcripts to familiarise herself with the data. She then read the transcripts and made notes on factors that stood out. On the third read, she purposefully

sought codes which related to Bourdieu's (1986) social and cultural capitals, for example social capital included the following codes – social connections, networks, team working, and so on, see Table 1 below codes and sample evidence.

Prior to formal analysis of the data we familiarised ourselves with the data and presented our preliminary descriptive findings to a steering group drawn from a range of stakeholders in the medical device industry. Having received comments from the steering group, we then developed and used a preliminary coding template as a first pass to understanding the data, the first author coded using the template codes and the second author checked consistency with the codes, selecting a random sample. This ensured both authors had a good and common understanding of the data. The first author then analysed the data using Bourdieu's capital theoretical framework, with all extracted quotes and interpretation checked, discussed and amended as appropriate with the second author. In the final phase of analysis, the first author read through all the diary entries and interview transcripts once more to check the interpretation of the theoretical themes. Although these did not change, the theoretical interpretation was then checked by second author using a random sample. Finally, the analysis was discussed between the two authors to ensure there was a consensus on the interpretation of the data. An independent member of the research team then checked a random sample of data to verify consistency in coding and theoretical interpretations. The development and application of Bourdieu's theory is grounded in the voices, actions and experiences of those studied to provide a new perspective on everyday design problem-solving and innovation. We define successful problem-solving as one where a solution is found and this is indicated by respondents in the interviews or diaries. In this paper we provide illustrations from our data, which are not stand alone instances.

From the diary data (recorded incidences $N = 80$) individuals used social capital either through working as a team or through using networks to solve problems (notably clients), this was important in solution implementation, there were also instances where there would be a mix of different types of social capital used. Social capital in all its forms was found in 35 of the diary entries. Of the problems recorded, 10 were not implemented despite using social capital. Five design problems were implemented despite no explicit evidence of using social capital. Four of the problems recorded did not have a solution implemented and did not explicitly use any form of social capital.

Using skills gained and seeking external knowledge to solve a problem, a solution occurred in 42 of the problems recorded in the diaries. Where individuals did not seek knowledge to solve problem and there was no solution or implementation of solution was identified 3 times in the data. One of the problems had solutions that were implemented despite no explicit evidence of using cultural capital. Eight of the problems recorded were not implemented despite using cultural capital. From the data collected from the diaries, 16 of the problems that were solved used both social and cultural capital to implement solution to problems. The table below provides sample evidence from the interview and diary data from which we developed themes that emerged from the data and based our interpretative findings from.

5. Findings – analysis of the capitals

Social Capital: The Figure 1 below shows our interpretation of the different levels of social capital identified in the data, discussed later in the findings section. In solving problems

Table 1. Codes and sample evidence.

	Interview data	Diary data
Social Capital		
Personal network	'before anything else I will ask my friend who also works here because I trust their judgement' Public 3	P2 – 4 Many possible solutions spoke to a friend who had worked in the industry MNC3
Professional network	'Where necessary we will always consult with the relevant professional network whether that is the regulatory bodies or whoever, just to make sure' SME1	P1 – 4 Client had a definitive idea about what he wants but in current format clients idea is impractical – so it won't work Developed design to complete operation that will work while incorporating client ideas Regular updates with client to confirm he is happy with progress Design development Applied past experience to design Managed to get alternative design/equipment options that more closely resembled client vision – from other engineers MNC2
Work Colleagues	'You'd probably share it and bore people to death with it. So, yes, you'd try and share it and obviously, you know, you've got people within the company who you'd go to first of all and just maybe bounce an idea off them and say have you come across this'. MNC1	P2 – 4 Many possible solutions – Talk to colleagues, Looked at CAD, Came up with a simple solution. Spoke to supervisor who agreed. MNC1
Team work	'we identify an issue, or a problem we need to solve, umm certainly within the environment that I work in, and I promote that we all together, you know, as a group even though we might be working on multiple projects, the whole team comes together umm to sort of try and help solve the problem'. MNC2 Designer	P3-2 Due to lack of experience of the effects of the environmental influence Brainstorming a range of ideas as a team share knowledge MNC1
Seek specific individuals	'I think the most important thing we do is collaborate with the right people' SME 2	P1-2 Reviewed original design brief notes, device draft specification Stress analysis consultant provided a list of alternative materials, I then checked these for availability with material suppliers Emailed the stress engineer and discussed the options with him SME2
Cultural Capital		
Information	'So if you've got very high quality umm information, and it's a well constrained product design spec that is very well detailed, err then it's much easier to make the right decisions . . . ensure that we've got the best quality information we can before we start the process'. MNC3	P1 – 2 . . . explored original manufacture of system [then] arranged meeting MNC 1
Skills	' . . . the acumen of some of the people we have here, we have more ideas than we know what to do with type of thing . . . it is a global team' MNC3	P1 – 2 Use of key scoring to select ideas Training and experience and leading the team Multiple design options presented MNC 1
Acquired general knowledge	' . . . the experience we have accrued over many years by working with similar projects we can really suggest where potential issues may be . . . ' MNC 4	P6 – 1 Used previous experience to resolve the issue quickly – knew about the potential problems and was able to avoid them MNC 2
Specialist knowledge	' . . . you can have all the calculations, all the variables nailed before they'll then commit to a final solution'. MNC3	P1 – 2 Drew up a plan on paper from experience of designing other small mechanical devices Public 1
Education / qualifications	'We recruit a lot of scientists' MNC5	
Understanding of value	' . . . what we try to do is energize employees to the degree that they feel empowered and therefore they can also generate ideas' MNC5	

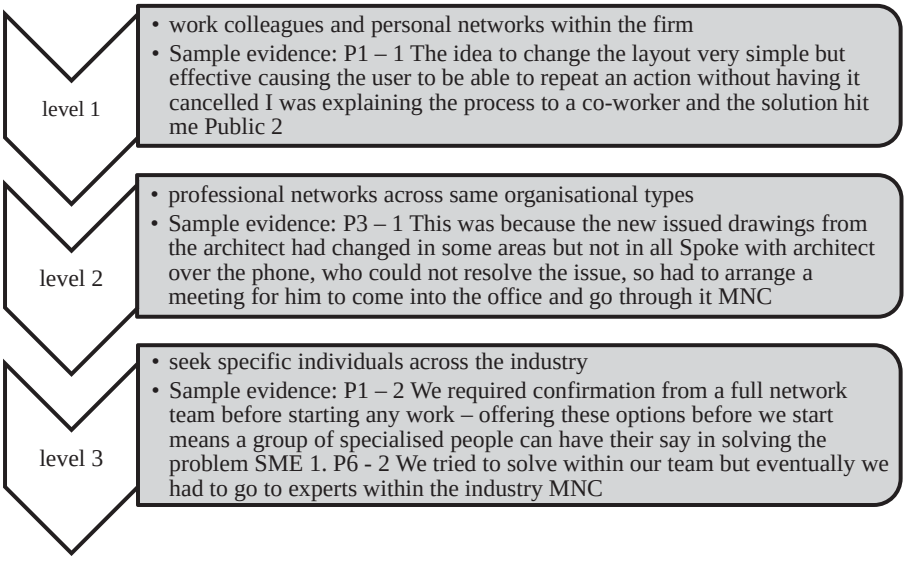

Figure 1. Social capital levels.

in the design process, individuals may seek assistance first from their own personal networks within the firm, as this may provide a quick solution to the problem and also can retain knowledge gained within the firm. If the problem remains unsolved then individuals may seek to explore networks across the same organisational types or other organisations involved in the design process. Seemingly as a last resort to solving the problem, individuals may then seek assistance from across the industry in order to find a suitable solution. Our data analyses indicated that this process was followed in a number of the problems identified. However, the data appeared to indicate that the designers always seek to solve the problem 'in-house' before looking for solutions or assistance to solutions beyond the organisations boundaries.

The Figure 2 below shows our interpretation of the different levels of cultural capital identified in the data, discussed later in the findings section. The Figure 2 shows that designers may first seek to solve problems using their own knowledge and expertise. If this is not possible, our data suggest that then designers may use the knowledge of others within their own department or organisation, if this is not possible then individuals may look for knowledge and expertise in other organisations. They may then use knowledge gained throughout the design process to inform their decisions to solve the problem in a 'cyclical process' of knowledge acquisition and problem solving. We propose that as knowledge and expertise is acquired by the individual for each subsequent problem they will start at level 1 and then proceed through the levels as described above.

5.1. Case study one – public sector organisations

Social Capital: One respondent, although acknowledging the benefits of working in a large multidisciplinary organisation (a university), also felt that networking and team working were not always encouraged:

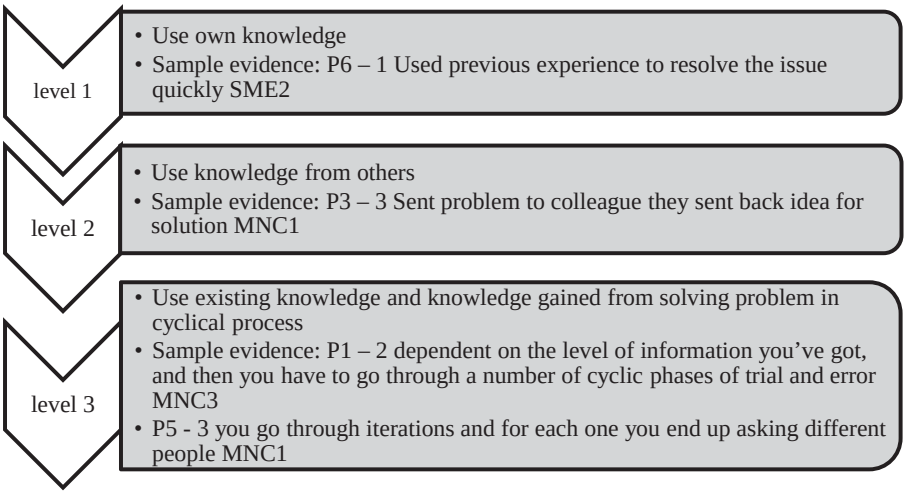

Figure 2. Cultural capital levels.

> I think that it is having a multidisciplinary team within the department does help in terms of getting some of the answers. However because we are, within the academic institutions, still not encouraged to do team working in many cases because you have individual papers, you have individual guidelines and, you know, you're pretty much a lone contractor working within an institution, then it isn't always easy to get the information that you need at the right times Unipublic2.

Cultural Capital: Public sector organisations appeared to face additional design problems when project leaders, with high levels of knowledge, left projects. We found that within the public sector there was an incidence of changes in personnel and these often led to problems for design projects, along with changes in budgets or available budgets, which would affect the ability of projects to attract the right calibre of individuals.

> Part of the problem we experienced, and this is something that is not uncommon within the [British] National Health Service (NHS), we started with one overall project champion who was a great advocate of what we were doing. She left within three months, the person who took it over didn't really have any understanding of, or enthusiasm for, the project, and managed it at arm's length, therefore we never really had the support internally within the hospital departments we wanted to gain access to get the variety of people we wanted HCpublic3.

On the other hand public sector organisations may also 'buy in' expertise.

> I signed more partnership agreements than anything else in the *** and we'd have a technical consultant, we'd have maybe a university person in there if the university had some role in the invention, which often they have. But in my role as Technical Consultant, we'd have all sorts of people in there. You'd have an engineer, a manufacturer, so you'd have . . . these people with all these skills, gave you a much better idea . . . HCPublic2.

5.2. Case study 2 – private large organisations

Social Capital: Informants from large private organisations described the importance of working with people either within the organisation or from their wider social network.

> we identify an issue, or a problem we need to solve, certainly within the environment that I work in, and I promote that we all together, you know, as a group even though we might be working on multiple projects, the whole team comes together to sort of try and help solve the problem MNC2P1.

Collaboration with the 'right people' appeared to be an important key element of solving both social and technical design related problems:

> I think the most important thing we do is collaborate with the right people . . . the design process, or the innovative process, will always be the steps required to work on the supply chain, which is always a collaborative process . . . what we have done, is getting the academic, who is thinking of it, connected to the clinician and connected to the people who will supply the product MNC1P2.

Cultural Capital: For large organisations that can employ a variety of technical specialists, it may be relatively easy to access knowledge and individuals often already possess 'expert' levels of knowledge in their particular area, with people having degrees and in some cases doctorates. Therefore, we inferred that cultural capital could be easily accessible from the workforce of large multinational organisations, where team working was important.

> It's so important to have a multidisciplinary team MNC3.

5.3. Case study 3 – small private organisations

Social capital: A diary entry from a respondent in a small firm suggested networks are used to find people with the right skills, often suppliers. 'Always believe is easier to find someone who knows the answer than embark on long and expensive research by those with little technical knowledge in field i.e. ourselves. We are not spring design engineers' SME3.

In small firms, individuals sought assistance from outside the firm for solving design problems when this could not be done in-house and whether they could access the right network of people.

> It was a small company, most of the work was done on my own and there weren't many others who were designers such as myself. So I think it depends on a variety of things as to how much you'd consult others, the ease of consulting others, the convenience, and also whether I felt it was necessary to consult others, how confident I was in my own decision making. So there would certainly be times where I would deliberately ask for the opinions of others on certain things SME2.

This quote highlights the staging process of different levels of social and cultural capital we presented in figures one and two. There is emergent evidence from the interviews and the diaries to suggest it might be possible for individuals with higher levels of social capital as an available resource has the potential to facilitate design problem-solving in public sector organisations and private organisations both large and small firms.

Cultural Capital: SMEs would use the cultural capital they had available to them within the organisation, or individuals would learn 'on the problem'. If this was not possible they would rely on individuals' professional networks (social capital) in order to access specialised knowledge.

> Very often we brainstorm with a group of engineers, if it's a tricky technical problem SME1.

In summary, we inferred that social capital, either through working as a team or through using networks, may have assisted people in solving problems. Participants appeared

to classify the right people as having particular skills or knowledge (cultural capital), or, involved in the problem-solving process either as client or end-user. This appeared to be the case especially for larger organisations. For larger organisations, whether public sector or private, accessing other opinions appeared to be easier due to the size of the organisation and often the size of the team working on the problem. From the interview data it was well documented by respondents that they utilised relationships with colleagues, collaborated with people and used their networks to discuss problems with other people. We found 30 cases from the diary data that individuals sought support and used social capital; either through working in a team i.e. brainstorming meetings, or through using networks to solve design problems, including contacting clients to solve problems. Contacting clients and using colleagues to brainstorm or talk about design problems was the main way individuals in small firms used social capital especially in the initial phases. Large organisations and public sector firms would have access to, and had often already developed multidisciplinary teams for the initial design phase.

This leads us to propose that social capital could facilitate successful problem solving; individuals in any organisation may utilise a variety of different socially based actions to solve problems through access to social capital particularly networks. From our analyses, we have inferred that social capital may be used to solve problems rather than problem-solving activity leading to increased levels of social capital. We reached this proposition because our inferences from the data suggested that designers that were able to access and utilise networks either within or outside of the organisation seemed to actively engage in solving design problems more than those who did not.

Interpreting the data, we imply that solving design problems may enable individuals to engage in innovation, which in turn builds individuals knowledge (cultural capital). This might then act as a positive cycle as increased problem solving knowledge results in individuals being able to apply this to future design problems. It is also evident that safety is critical to the end product and procedures need to be in place to ensure the safety of the end-user. The design stage involves creativity and innovation; as one designer said 'innovation is about challenging convention earlier on but within the constraints of safety' MNC2P4. These views on safety and innovation were echoed by those working in small firms and public sector firms. Therefore, in overcoming barriers to solving design problems, innovation might be used as a mechanism to reach a suitable solution, regardless of organisational size. Regulation (and hence patient safety) may shape and control the design process and hence may be a construct of the problem solving process. Therefore, individuals might use resources (capitals) in a way to ensure the construct of regulation (and patient safety) is part of the design problem solving process (see Figure 2).

Summarising, cultural capital was indicated by educational qualifications, skills, personal experiences, and possession of cultural items. The nascent results point to an emerging trend that high levels of knowledge may be required in terms of the regulations surrounding the specific industry (medical devices) and the skills required to design a device that meets surgeons' and patients' needs.

The emerging constructs from the interview data suggest that cultural capital may be important in solving design problems. Using skills gained and seeking external knowledge to solve a problem successfully were found in just over half of the interviews. This often involved working in teams of individuals with a wide range of skills, knowledge and expertise. This was particularly evident in larger organisations where it seemed common that

individuals with specialist knowledge would be involved in teams working on a particular problem. It also seemed common for larger organisations to employ people with varied skills. In larger organisations, there seemed more consultation with people throughout the supply chain on new designs such as surgeons, consultants and patients. As well as being consulted on their opinions, in some cases, others outside the organisation might be asked to participate in the design process. Involving others outside the organisation in the design process seemed more common in multinational corporations. There is sufficient emerging evidence from the interviews and the diaries to postulate cultural capital may facilitate individuals' abilities to solve design problems. This leads us to suggest that, as is the case for social capital, cultural capital may facilitate successful problem solving, which in turn may increase the likelihood that a firm might utilise skills and knowledge either within the organisations or from outside.

Solving design problems was often seen as a learning curve, whereby knowledge (cultural capital) used and gained during the process could be used for future design problems. For the organisation this might only be beneficial if they retained those specific personnel. Organisations used cultural capital from different sources to solve problems, including within the firm and beyond the firm. We could not find any salient differences in where individuals sought additional cultural capital to solve the problem in hand. However, public sector firms and large private organiations seemed able to access internally numerous individuals who possessed high levels of cultural capital, whereas small firms appeared limited by their size and appeared to seek cultural capital from individuals outside of the firm if required. Otherwise, individuals in small firms seemed to rely on the expertise of a few key individuals.

Figure 3 represents our conceptual thinking on the relationship between social capital, cultural capital, successful problem solving and innovation. Interpreting the data using capital theory leads us to put forward the notion that social and cultural capital may be collegiate in that the active presence of one may enable individuals and organisations to access the other. We acknowledge that this may only be relevant in relation to specific problems, certain types of organisation and any replication study may prove challenging. Nevertheless, we introduce the 'amplification effect' as a concept which we believe is appropriate given the dynamic nature of solving design problems where a one rule fits all concept would not be appropriate. We put forward the proposition that these two forms of capital might be inherently linked, for example higher levels of social capital may increase firms ability to access high levels of knowledge (cultural capital) from individuals outside the organisation. It may also be possible to use networks of high worth to access very high levels of specialist cultural capital (Table 2).

Small firms also collaborated with their clients to fully understand the design problem to be solved. In large organisations, capitals may be internally or externally sourced, in small organisations it may be the case that specialist cultural capital is purposefully sought from outside the organisation. The data indicated that larger organisations purposefully sought to use networks across the supply chain to seek knowledge and opinion on device design. Larger organisations also seemed to have better levels of cultural capital and were less reliant on high value networks (social capital). Data suggest that smaller firms were able to access the supply chain to engage in knowledge exchange, but not on the same scale as large organisations, and this seemed more dependent on the individual than the organisation. Smaller organisations may need the right network in order to fully benefit from

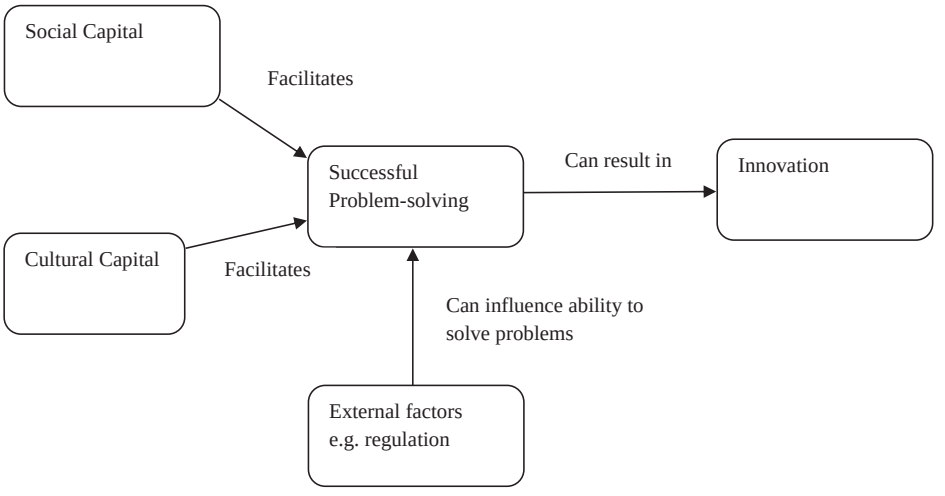

Figure 3. Relationship between capitals, problem-solving and innovation.

Table 2. Example evidence of 'amplification effect'.

Case study 1 – Public sector organisations	Case study 2 – Private large organisations	Case study 3 – Small private organisations
'I think getting input from other people you are working with is important. Especially when you are working with a team who have very different skills, I think getting input from different people . . . is something the university does quite well . . . bringing people from different specialities together' Unipublicp1.	'One of our core strengths is our scientific base, we have got strong links to numerous universities, plus also a bit of out sourcing that goes on for the development of ideas. So we have got the gears to change it. If anything only to validate the acumen of some of the people we have here, we have more ideas than we know what to do with' MNC4.	'Got client to email as much info as possible and a drawing (hand sketch) because my interpretation of a description over the phone may not have been the same as the clients' SME2.

accessing cultural capital; therefore it could be argued that smaller organisations needed higher social capital per employee in order to access their shortfall in cultural capital to successfully solve design problems.

We suggest from the emerging data that the two capitals may combine to enhance design problem solving. In medical device design, people often worked in multidisciplinary teams with highly educated individuals; this was particularly evident in larger organisations. If these individuals experienced difficulties in solving a design problem, knowledge could be sought from outside that team. Larger organisations were able to source social and cultural capital, more often than not, from within the organisation; large organisations were also at an advantage over their smaller counterparts, as they were able to seek expert advice from across the globe.

We found from the diary data that roughly 14 of the entries recorded explicitly used both social and cultural capital to implement solution to design problems. However, we believe this percentage underplays the nature of the relationships between social and cultural capitals. This is because there was evidence from the interviews and diaries to support the notion that social and cultural capital may be collegiate, leading to increasing levels

of both capitals (amplification effect). For example, using networks (social capital) to find specific knowledge resources (cultural capital).

This amplification effect is important as it might explain how individuals to improve their access to resources to engage in solving design problems. Further, it leads us to suggest that firms need a variety of quality resources (i.e. they must be specific to the needs required to solve that particular design problem, such as specific knowledge or a certain network) in order to solve design problems and innovate.

We found evidence for the existence of the amplification effect across all three cases. However, there were differences between the three cases. For example, social and cultural capitals appeared to be used extensively to solve problems, but there were differences in how capitals were sourced (as illustrated in the quotes used above). We suggest that the findings indicate that for large organisations cultural capital may allow individuals to source high levels of external social capital. In public organisations, it appears that cultural capital may lead to high levels of internal social capital. For small firms we suggest that external social capital may lead to increased external cultural capital.

6. Discussion and conclusion

Our primary focus was to explore on how the individual involved in the design process of medical devices solves immediate problems in their particular working context. Applying Bourdieu's theory of capital has allowed us to show how social and cultural capital might be used in a cyclical process to solve problems and in this process we identified different levels of capital (see Figures 1 and 2). Our work contributes to the literature calling for work to apply Bourdieu's theory to organisation studies (Emirbayer and Johnson 2008) and more specifically in exploring problem solving (Glover et al. 2016). Bourdieu might be particularly useful in that his work allows for the exploration of practice, i.e. what is the practice of successful problem solving and what resources individuals use. His work allows use to explore the 'micro' level of organisations so we are able to explore the complexity of design related problems. Individuals may need access to a variety of quality resources (i.e. resources must be specific to the needs required to solve a particular problem, e.g. specific knowledge or a certain network) in order to solve design problems and, hence, innovate. Our research supports the notion that both problem-solving and consequently innovation might benefit from high levels of social capital stemming from specialist external networks. However, we would caution that in an industry such as medical devices, it may also be important for firms to have high levels of social capital within the boundaries of the organisation, (e.g. colleagues talking to one another), as seen more readily in large private and public sector organisations in our sample.

6.1. Limitations and future research

As with all exploratory studies this work has focused on only one industry and a small part of that sector. More studies are needed to further explore the amplification effect now we have uncovered evidence of this micro-level phenomenon through using more structured and larger scale methods. Our analysis has focused on everyday design problems that can be considered to be complex (Jonassen 2000) because we were interested in the relationship between different forms of capital, problem-solving and innovation in different

organisational contexts, we did not differentiate between different forms of problem. However, design problems arguably have a number of generic features that would render our main conclusions robust in relation to many sorts of design problems. Even so, it is possible that different organisational and governance structures are more suited to promoting solutions to problems that are less complex (Felin and Zenge 2014). Therefore, future research may uncover further distinctions in how capitals influence design related problem-solving and innovation.

It may be worthwhile investigating what happens to firms that lose resources (social and cultural capital), especially firm's reliant on individual's with highly specialised levels of social and/or cultural capital, for example a surgeon working with a small firm. In line with our findings of an amplification effect, a reverse attenuation may be predicted in which the loss of one form of capital leads to the loss of more capital (for example project partners may withdraw). How organisations respond to such capitals' losses and how successful they are in recovering capitals may be a fruitful area of enquiry. Future research could also look at whether use of capitals is dependent on the features and types of design problem or whether our findings in relation to context are generic to all types of design problems (Brusoni and Prencipe 2013).

To conclude, we found Bourdieu's theory of capital a suitable tool to enable us to explore the complexity of design related problems and possible explanations of some aspects of problem-solving in engineering design. His theory enabled us to explore the potential roles of different types of capitals in problem-solving and a potential relationship between social and cultural capital through our conceptual notion of the 'amplification effect'. We encourage scholars to further explore these relationships between the different levels of different capitals and how they facilitate successful design related problem-solving.

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Appendix A – Interview Questions

Solving design problems: We would like to ask you some open-ended questions about how you go about solving design problems. Please place your answer in the space provided below each question.

1. Please describe how you usually go about solving design problems?
2. Can you describe how you feel about design problems when you first come across them?
3. Can you describe how you usually try to deal with any feelings concerning design problems?
4. Does your organisation help you develop innovative ideas? Please explain your answer.
5. Does your organisation help you develop safe products? Please explain your answer.
6. Do people outside your usual team help you develop innovative ideas? Please explain your answer.

Med Device design (analysis_ round 1)
1. Design process (is made up of)
(i) Conceptualisation (is determined by)
(a) End-user:
Interrelating to user needs
Understanding user interaction with device
Practitioner needs
Patient needs
(b) Safety standards (provides framework)
(ii) Innovation (is affected by)
(a) Existing products and practices
(b) Feedback
End user feedback
Practitioner approval
Relationships with manufacturers (not usually maintained, ie. Lack of des involvement)
Marketing processes
Sellability of end-product
Practicality of innovation
Safety standards
(c) Funding available for innovation (enhancing)
(c) Machine (CAD) vs human design (inhibiting)
(d) Incremental vs rapid (mostly incremental)
Practicality/ sellability
(e) costs of manufacture/ production (inhibiting)
(iii) Designer error
(a) Eliminated through trial and error (seen as bog standard in med device design)
(b) Humanness
(c) Inexperience
(iv) Safety standards (have their effect)
(a) provide guidance for design

(b) Inhibits when at the implementation stage (accept or reject)
(c)Increase costs of implementation (medical device trials are expensive)
(d)Can have legislative implications
(e) are standardised

(v) Unforeseen risks are a given (eliminated through trial and error)

(vi) Decision making/ problem solving (is effected by)

(a) How the team interacts
Communication
Relationships
Interaction
(b) The disciplines/ stakeholders directly involved

Appendix B – Diary Questions

Incident number 1 Date: . . . . . .
Time Now: . . . . . .

1. Please describe the issue briefly?
2. When did you encounter the issue? (please circle)
Before 9am Between 9 am and 11 am
Between 11 am and 1 pm Between 1 pm and 3 pm
Between 3 pm and 5 pm After 5 pm
3. Where you were when you encountered the issue? (please circle)
At work Travelling
At another organisation Working at home
Other (please state) . . . . . .
4. Can you explain why it had no obvious solution (if not covered in 1)?
5a. Briefly describe how you went about resolving this issue?
5b. Why did you choose this course of action (If you decided not to attempt to resolve the issue, please also explain why).
6a. Briefly describe your feelings about this issue when you first came across it.
6b. Please describe how you dealt with your feelings about the issue
6c. Why did you choose this course of action. (If you decided not to react to your feelings about the problem, please explain why. If you had no feelings about the problem, please leave blank.
7a. Please describe any ideas you had that helped you deal with the issue.
7b. If you can, please describe how you got these ideas?
7c. If you were able, can you explain how you were able to implement these ideas?
8a. Please describe any ideas that others had that helped you deal with the issue.
8b. If you can, please explain how you came across these ideas?
8c. If you were able, can you explain how you were able to implement these ideas?
9a. Were there any occasions when you were addressing the issue when you had difficulty concentrating or making decisions about your work?
YES NO (please circle)
9b. If so, please explain when these occurred and why you think they occurred.