Who talks to whom about what? How interdisciplinary communication and knowledge of expertise distribution improve in integrated R&D labs

Mareike Heinzen[1]*, Eugenia Cacciatori[2], Frank A. Zoller[3], Roman Boutellier[3]

[1]Faculty of Business and Social Management, University of Applied Sciences Koblenz, RheinAhrCampus, Germany
[2]Faculty of Management, Cass Business School, City, University of London, United Kingdom
[3]Department of Management, Technology and Economics, ETH Zurich, Switzerland

*Corresponding author: Prof. Dr. sc. (ETH) Mareike Heinzen, University of Applied Sciences Koblenz, RheinAhrCampus, Joseph-Rovan-Allee 2, D-53424 Remagen, Germany, Email: mareikeheinzen@rheinahrcampus.de

Please cite as:
Heinzen, M., Cacciatori, E., Zoller, F.A. and Boutellier, R. 2018. Who talks to whom about what? How interdisciplinary communication and knowledge of expertise distribution improve in integrated R&D labs. *Ergonomics,* **61**(8), 1139-1153.

Who talks to whom about what? How interdisciplinary communication and knowledge of expertise distribution improve in integrated R&D labs

Abstract: Although several studies have examined the impact of open workspaces, there is still an on-going debate about its advantages and disadvantages. Our paper contributes to this debate by shedding light on three issues: the effect of open workspaces on (1) the flow of communication along and across hierarchical lines; (2) the content of communication; and (3) the specificities of open integrated laboratories. Our findings derive from a longitudinal case in a large pharmaceutical company that has relocated some R&D teams from enclosed to multi-space offices and labs. The relocation has resulted in (a) increased interdisciplinary communication, particularly at lower hierarchical levels, (b) a shift of the location of discussions and the content of conversations and (c) an improved knowledge about expertise distribution.

Keywords: Knowledge work; workspace; integrated laboratory; face-to-face communication; distribution of expertise

Practitioner Summary: Communication is essential in knowledge-driven organisations. This article examines the impact of a relocation of R&D employees from enclosed to multi-space offices and labs on communication patterns. We explain how the new environment fosters interdisciplinary communication, shifts the location of discussions and increases the knowledge of expertise distribution.

Introduction

Organisations have experimented extensively with workspaces, one of the objectives being to identify an environment to support new ways of working, especially knowledge work and its attendant collaborative activities (e.g. Chan et al. 2007). The result has often been a change to some form of open space from the traditional cellular workspaces of the 1950s and 1960s, leading to continuing debate over the advantages and disadvantages of 'open' working environments (e.g. Elsbach & Pratt 2007; Davis et al. 2011; McElroy & Morrow, 2010; Morrison & Macky 2017). The present paper contributes to this debate by shedding light on three issues.

The first is the effect that open working environments have on the communication pathways in organisations, specifically the flow of communication along and across hirarchical lines. Organisational structures channel information both up and down the chain of managerial authority that runs from the CEO to front-line staff, and across such chains through lateral (horizontal) communication channels. Particularly lateral communication has received increased emphasis in the last years as the complexity and uncertainty of the environment increases. Yet, despite one of the primary objectives of open spaces being an increase in communication, we know relatively little of how the spatial layout of the work environment influences the balance between hierarchical and lateral communication.

Secondly, research has focused on the extent to which open space affects the likelihood, frequency and duration of communication in the workplace. While contributing to this body of knowledge, we also look at whether changes from closed to more open work environments affect the content of what is discussed, in an attempt to move beyond the privacy vs. propinquity debate (e.g., Fayard & Weeks 2007; Hatch 1987).

Finally, we shed light on the effect of open working environments in laboratories. Laboratories were the object of some pioneer studies on the relationships between workspace and communication (e.g., Allen, 1970), but most recent research on the effect of open spaces has focused on the office (Elsbach & Pratt, 2007). Yet, in the last years, the structure and shape of laboratories have become the objects of as much lively experimentation as offices (Watch, 2012). Since laboratories play a crucial role in innovation and are environments that are substantially different from office spaces, it is important to include them in our studies - especially in the area of life sciences since most existing studies investigate laboratories in the engineering and information technology (IT) industries (e.g. Allen 1970; Stryker et al. 2012).

We obtain our data through a case study of the relocation of a group of R&D scientists at a large listed private sector multinational pharmaceutical company. The scientists we observed relocated from enclosed spaces located in different buildings, to a single open 'multi-space environment' (Moultrie et al., 2007) which integrates 'bench' (laboratory) and 'desk' (office) space. Quantitative observation-based data is integrated with qualitative data from interviews in a longitudinal research design consisting of three observation periods - three months before, three months after, and two years after relocation.

Our study shows that moving from closed to integrated multi-space environments results in a significant shift of communication activity from along to across hierarchical chains, particularly for junior scientists. The move shifts discussions from the bench (which becomes an area for concentrated, silent work) to the desks (where knowledge is more visible in computer models of the entities experimented upon and charts with experimental results). Our data also suggest that the relocation led to a reduction in the amount of social conversation, in favour of work-related one in the office/lab. Overall, the move resulted in an increase in awareness of who knows what – although this effect appears to tail off in time. We discuss the implication of these findings for what we know about the influence of the work environment on communication in knowledge intensive settings.

The paper is organised as follows. We review the literature related to workspace and communication in R&D settings, particularly in pharmaceutical R&D and laboratories. Then we describe the setting and methods of our longitudinal case study, present the case study, and discuss the implications and limitations of our findings in the final section.

Workspace and communication within R&D settings

Early studies of the influence of office layout on communication among technical professionals concentrated on the part played by physical distance. Allen (1970) showed that face-to-face (FtF) communication increased with decreasing distance between work places, a result that shows remarkable consistency over time and across settings (Allen, 2007).

Following studies broadened the analysis of the effect of movement patterns and visibility. In a quantitative case study within an architectural design office, Backhouse and Drew (1992) found that 80% of FtF interactions were unplanned, and happened as a result of circulation and movement patterns and the perceived 'availability' of colleagues to engage in conversation. People were considered more 'available' when standing up, or looking around or walking around the workspace, as opposed to someone working at their desk, or talking on the telephone. Stryker et al. (2012) show that high-visibility environments encourage FtF communication in teams. These outcomes are in line with general findings in offices, where "visible co-presence" appears more important than movement patterns in predicting FtF interaction (Rashid et al., 2006).

However, the effect of open spaces on communication, behaviour or general benefits is somewhat unclear (Davenport et al., 2002). In a pioneering study of technical professionals, Hatch (1987) found that at least some sorts of interactions among high-tech engineers increased with physical barriers and privacy. In contrast, several others have found that open working environments in R&D settings increase FtF communication (e.g., Allen & Gerstberger, 1973; Boje, 1971; Kraut et al., 1990), because of decreased physical distance between R&D workers (e.g.,Allen, 1970; Van den Bulte & Moenaert, 1998), and proximity to points of passage and encounters (e.g., corridors and meeting rooms) (Boutellier et al., 2008b; Stryker et al., 2012). Open spaces have their own drawbacks and have been criticised for their lack of privacy that facilitates both managerial and peer control (Perrow, 1986) and can lead to crowding, noise and distraction, the inhibition of confidential conversations, decreases in job satisfaction and stress (Davis et al., 2011; Elsbach & Pratt, 2007; Kaarlela-Tuomaala et al., 2009; Sundstrom et al., 1994; Wineman, 1986).

Addressing these problems, over time designers have moved from completely ‘open plan’ to multi-space environments (also called combi-offices, activity-based flexible offices, etc.) offering different options and types of places for working, individually combined for their employees’ needs: quiet areas, teamwork zones, break areas, meeting rooms (e.g. Becker, 2007; Davis et al. 2011, Duffy & Powell, 1997; Moultrie et al., 2007; Wohlers & Hertel, 2016). In one of the few empirical studies of the effect of multi-space offices on communication, Boutellier et al. (2008b) investigate top managers in a pharmaceutical company engaging in office work. They found that managers talked significantly more often and for shorter periods in the multi-space setting.

Overall, while there has been significant interest in how the space in which R&D takes place influences how it is carried out, emphasis has overwhelmingly been on the quantity of communication, while the issue of who talks to whom and about what has been relatively neglected. Additionally, we know little about the impact of novel “multi-space” workspaces that attempt to combine the benefits of privacy with those of high visibility (Wohlers & Hertel, 2016).

Workspace and pharmaceutical R&D in the lab

Before moving to our empirical material, this section describes the characteristics of pharmaceutical R&D that make it an ideal setting to look at the role of the workspace in affecting communication in knowledge intensive and uncertain settings, as well as some of the peculiarities that set 'wet' labs apart from the engineering R&D settings in which most previous research has taken place.

Drug discovery process

In recent decades, drug development processes have become more competitive and riskier. First, higher requirements for safety and efficacy have induced longer clinical studies that increased costs and time to market, while the duration of patent protection remained constant and competition from generic drugs has become heavier.

Second, with a much deeper understanding of disease mechanisms, and much more powerful means to screen molecules, today's process of drug discovery has become more "rational" (i.e. the identification of drug targets has been systemised) (Nightingale, 2000; Sams-Dodd, 2005), which also means that the basic mechanism of a novel drug substance is usually understood industry wide on a molecular level (Pisano, 2006). This, combined with the concentration of R&D efforts on a limited number of targets (Edwards et al., 2011), has resulted in increased competition among firms.

Third, however, looking at diseases and drugs through a molecular perspective has expanded the drug-search-space, while making the search more complex by suggesting many more routes through which diseases and drugs may work (Orsenigo et al., 2001). Despite being more rational, then, contemporary drug discovery is still a very uncertain process.

Fourth, drug discovery processes still have strong tacit knowledge components. Intuition can be important for prioritising experiments, experience is essential for testing hypotheses while interpreting even a routine assay may require extensive know-how (Pisano, 2006).

Fifth, the transition from chemistry-based to biotechnology-based drug discovery requires a process that is necessarily multidisciplinary because of the need to combine understanding of the human body and diseases at the level of molecular processes with knowledge about the chemical properties of compounds. Many new disciplines, often based in the information sciences, have emerged to cope with the large amounts of data generated in research (e.g., bioinformatics) (Dougherty & Dunne, 2012).

Organising R&D in the face of increased uncertainty and multidisciplinarity

To cope with multidisciplinarity and uncertainty, pharmaceutical R&D increasingly relies on open innovation and on complex merger and acquisition activities aimed at acquiring critical competencies (Hughes & Wareham, 2010; Orsenigo et al., 2001; Williams & Lee, 2009).

There is less evidence about how the internal operations of pharmaceutical R&D have changed, although there appear to be conflicting trends. On the one hand, drying pipelines and industry competition have increased the pressure to reduce costs, and this has begun to be felt also in the R&D departments. In many pharmaceutical R&D labs there is a new emphasis on efficiency and the application of lean approaches (IMAP, 2011). At the same time, increases in uncertainty and multidisciplinarity push towards ever more complex organisations with high coordination costs. For instance, the geographical spread of competencies coupled with the need to coordinate disciplinary and disease expertise result in rather complex structures (Boutellier et al., 2008a).

Beyond formal structures, informal FtF communication that crosses organisational and disciplinary boundaries also plays a key role in scientists performance **(**Perry-Smith, 2006; Rothwell & Robertson, 1973; Tushman & Katz, 1980**)**, particularly in a context in which complexity and uncertainty make unclear who needs to be involved in particular research projects even at a late stage. Recent research on the early phases of pharmaceutical R&D has indeed shown how formal and informal structures and communication coevolve and support each other **(**Ben-Menahem et al., 2016**)**. Allen and Henn (2007) identify three categories of communication in organisations, all of which can be formal or informal: communication aimed at coordination, communication aimed at technical developments, and communication aimed at creativity or inspiration.

Working in the pharma lab

But how do pharma scientists use the workspace? Here we discuss some characteristics of pharma R&D, particularly early stage R&D involving laboratory work, that are likely to influence the effect of integrating laboratory and office in an open multi-space environment.

First, scientists often operate both at the desk (consulting literature, writing reports, examining images and data from experiments) and at the bench (carrying out the experiments). The activities carried out at the laboratory bench and those carried out at the desk are usually separated, requiring scientists to move from one lab to offices. Toker and Gray (2008), compare the different spatial layouts of university research centres where the offices and laboratories are separated by a connecting door or accessed via a public space. Similarly to results from research on open offices, they find that accessibility, visibility and walking distance significantly influence informal interaction and innovation process outcomes. Zoller and Boutellier (2013) argue that in pharmaceutical research, the duality of bench and desk allows one workplace to be optimised to maintain strong ties and the other optimised to promote weak ties in interaction (Granovetter 1973).

Second, it is not only the accessibility of people that matters in open spaces - visual accessibility of the objects through which people carry out their work is equally important (Becker, 2007; Elsbach & Bechky, 2007). Research has found that an important promoter of chance encounters is shared laboratory equipment, as people often meet around them to enquire about their availability or to wait for their turn to use them (Andereggen et al., 2013; Merz & Biniok, 2010). In one of the few available studies of engineering laboratories, Stryker et al. (2012) find a positive relationship between high-visibility work environments, the visibility of the individuals' workstations, and FtF communication within the R&D function in high-tech laboratories.

However, most recent research on the role of objects has taken place in engineering settings. Many physical entities manipulated in biomedical research (at the bench) are at a scale invisible to the human eye, and are gauged using tests and assays whose analogical output is then translated into numeric data or data in visual format such as tables, charts or pictures (cf. Knorr Cetina, 1999; Latour, 1987). This generates a movement between desks and bench in laboratories (Latour & Woolgar, 1986). This implies that work at the desk, when visible, is much more likely to be interpretable by others than work at the bench, suggesting that integrating laboratories into the office environment could be important for changing the visibility of scientists' activities and thus trigger multidisciplinary informal interactions (Coradi et al., 2015).

The integration of (wet) laboratories and offices in the same open space is a novel development, whose effects have been investigated only partially (Coradi et al., 2015; Zoller & Boutellier, 2013). Given the centrality of the laboratory to the activities of industrial scientists in science-driven industries, it is a topic that certainly deserves more attention. Building on the literature discussed above, our study seeks to document whether integrating desk and bench (i.e., office and lab) into a multi-space affects the communication patterns of scientists.

Settings and method

This paper is based on a case study within a listed private sector multinational – and therefore large - pharmaceutical company. The case study focuses on the relocation of industrial scientists from cellular workspaces to a multi-space environment integrating open plan offices with the laboratory. The case company has made a significant investment in real estate in the effort to promote – particularly – informal interaction and teamwork, making it a good setting for an investigation.

The study combines quantitative examination of communication events with observations and interviews. Very few studies combine research expertise across traditional methodological boundaries and hybrid methods mixing qualitative and quantitative data are deserving of more explicit attention (Edmondson & McManus 2007). Our longitudinal analysis covers three measurement periods – three months before and three months after relocation in 2010, and two years after the move (2012/13). A longitudinal analysis makes possible to better investigate the dynamic and complex nature of the R&D process (Pettigrew, 1990) and build a more holistic view of it (Perks & Roberts, 2013).

In the first and second measurement period, we observed the same 26 industrial scientists, including molecular biologists, cell biologists, chemists and quantitative biologists on three hierarchical levels: research associates, scientists and unit heads. Research associates are responsible for running bench experiments and analysing and editing data, or recording data at their desks. Scientists usually have modest involvement in the physical realisation of experiments, and major involvement in project coordination, setting up of experiments, and literature searches. Each scientist is responsible for 1-3 associates, and reports to her/his unit head, all former scientists, now occupying managerial positions. Work is performed in projects, but the organisation is essentially functional and there are no formal project level reporting relationships.

Data collection and analysis

Quantitative observation. The first observation phase was conducted over a period of 30 days in May 2010, in the cellular workspaces. The timing was chosen in order to prevent any bias from season, traditional holiday periods or different processes and organisational changes. As the 26 industrial scientists were distributed across three different buildings, we separately observed each cellular workspace on eight half days from 0730 to lunch time, or noon to 1800. In order to observe all communication events of all 26 industrial scientists, we employed multiple observers. They were familiar with the project and recorded communication events using the structured observation protocol discussed below. The observed industrial scientists had received in-depth briefings about the research objective and the procedure of observations. A typical cellular laboratory space was equipped with benches and desks for two research associates and a bench for one scientist who had a desk in another room. The scientist who shared the cell laboratory with the associates always had managerial responsibility for them. In addition to the offices and laboratories, the various floors were comprised of corridors, specialised equipment laboratories and meeting rooms.

--- Insert Figure 1 about here ---

During the second observation that took place in November 2010 (three months after the relocation) the same 26 industrial scientist were observed again over 30 days. To ensure comparability, the second observation took place on the same working days as in the first measurement period, and was conducted by the same observers using the same observations protocols.

In the new building, the 26 industrial scientists were co-located with other experts from several disease areas, on the first two floors. Each floor has an multi-space environment with an integrated laboratory, i.e. an open space with only a few individual laboratories located in enclosed rooms for reasons of safety or noise. The central wet and sterile laboratory zone, which has no dividing walls or pillars, is fully integrated in the office area. Hygiene in general is secured by airflows that impede contaminated air to flow from lab to desk zone. Employees have to wear lab coats and protective glasses in the lab zone. Lighting and atmosphere had changed due to the new, modern, full-glazed building, and scientists were generally happy with the new building. However, equipment and facilities have basically stayed the same as before the move. Regarding floor and room space, scientists had relatively more desk space and less bench space in their cellular offices whereas with the new open environment individual bench space increased (about 30% more than before) and desk space decreased (about 30% less than before).

--- Insert Figure 2 about here ---

The observation protocol recorded the number and duration of FtF communication events, number of people involved in the conversation, its location and the hierarchical relationships among conversing partners. The duration of communication were measured with the help of a stopwatch. After each observation, meetings of upwards of an hour were held to compare data and clean it whenever double-observations had occurred. We recorded a total of 3,172 communication events in the old and new buildings, during 380.5 hours of observation.

--- Insert Table 1 about here ---

In the third measurement period, we built on the results of the observations in the the first two periods. These had highlighted the changes in communication patterns particularly for the research associates, the movement of conversation activity from bench to desk. Notes from observations as well as interviews suggested the importance of knowledge sharing and of observing others working with equipment. In order to understand these trends better, we decided to observe all 46 industrial scientists that were located on the first floor of the new building, offering more scope to observe multidisciplinary interactions. Additionally, those 26 scientists who have been observed in the first two measurement periods on two floors partly had left the company or were promoted to other expert groups after two years.

The third observation was conducted on eight days during November and December 2012 by different observers who had been instructed by those involved in the first two observation periods, and were familiar with the reports, outcomes and data selection related to 2010. 20

hours of pilot observations aimed first at improving and expanding the 2010 observation protocol and second to allow the observers to be accepted as ‘part of the furniture’ in the building.

In the third observation period the focus of the observations changed in order to provide deeper insights on the themes emerged from the first part of the study. Recording duration and other characteristics of interactions is demanding on the observer and would not allow sufficient time and attention to focus on other aspects of the exchange. In the third observation period we therefore moved to a more in-depth observation of interactions rather than an attempt to gather information on all the interactions taking place in a given moment, allowing to collect data on (1) the type of conversation (a) science and technical advice, (b) work coordination (e.g., schedules for delivery of results or use of equipment), (c) social, non-work related; and (2) location (e.g., desk, bench, corridors, etc), interdisciplinarity.

Qualitative observations. In the first, second and third observation period, an additional observation sheet allowed daily qualitative descriptions of what we had observed to augment our measurements. These notes included references to typical operational procedures or behaviours. The data collected from the observations, including field notes with detailed descriptions of contexts, were transcribed and coded for analysis.

Interviews. In the first two phases of the study, we interviewed the same 20 scientific staff, of which 10 were also part of the group of those 26 that we observed, the others came from other floors of the building. In the third phase of the study, we reinterviewed 9 of the original 20 scientists, and 4 others, which allowed a good representation of the first floor occupants. The interviews lasted between 45 and 60 minutes.

--- Insert Table 2 about here ---

The semi-structured interviews included open questions about the influence of the new architecture, furniture and seating arrangements on communication behaviour, working procedures, new ideas and the general atmosphere on the floor. All interviews were conducted by two of the university research team; one conducted the interview, while the other took notes and observed (Eisenhardt, 1989). As interviewees expressed their feelings and sometimes shared confidential information, they were not audio recorded in order to let them speak freely. However, interview notes were compared and discussed after the interview and together with the observation notes transcribed and coded in tables in order to find common patterns that led to the following results. Interviews and observations contribute to explain the mechanisms behind our quantitative findings, so codes are partly emergent from the interview themselves, partly driven by the quantitative findings, and partly inspired by existing literature.

Results

The way in which the scientific staff conduct their work is broadly consistent with previous descriptions of scientists' work. In the cell-based setting, we observed people regularly moving between the laboratory bench and their office desk to document and analyse results of their experiments. Visualisations also played an important role, with discussions and interpretation taking place around data from experiments. A scientist explained: *'I had a meeting yesterday [in the meeting room]. He could see my desktop. We spent an hour and half and I was showing him all these different things on my desktop. That made it much easier'.*

The workplace culture had stressed the importance of interaction and informal communication long before the new building became available, and was perceived as enabling. An associate remarked: *'It's about your own curiosity. If you ask, you can be sure to get information.'* While these aspects as well as the core equipment were constant before and after the relocation, the move to the new environment caused significant changes in with whom, where, and about what scientists communicated.

Table 3 reports descriptive statistics for the communication data gathered during our quantitative observations in the cell-based workspace (first observation phase) and in the multi-space environment three months after the move (second observation phase). Since changes in communication patterns affected especially research associates, data on frequency of communication and average time spent in FtF conversations at a bench refer only to them. Data on duration of communication events is skewed, with a very high number of short communication events and few longer conversations. Logarithms of duration (in seconds) were used to obtain a normal distribution. Since the distribution variances differ, we use the Welch test to assess whether differences between means before and after relocation are significant.

--- Insert Table 3 about here ---

The table shows that scientists spend more time in communication activities in the open environment but in shorter communication events, confirming the findings of previous studies for managers (Boutellier et al., 2008b). We have organised the discussion of the other changes in three major areas: changes in communication in terms of (1) hierarchical levels and disciplines (i.e., research groups), (2) location (bench compared to desk zones); and, (3) effects on awareness of expertise location.

Changes in communication: hierarchical levels and multidisciplinarity

Table 3 shows that the move to the new multi-space environment increased the share of communication events at the same hierarchical level across reporting lines (groups) from 43% to 55% of all observed communication events. The remaining communications include communications among individuals that were at different hierarchical levels *and* in different reporting lines (groups); or communications with external visitors. The share of communication events along the hierarchy within a group decreased from 22% to 11%. Both results are significant at $p = 0.001$.

Our qualitative results show that this shift in communication from 'along' to 'across' the hierarchy reflects significant changes in how research associates communicate and work. The multi-space environment allowed them much more FtF contacts across different lab units. Both management and research associates recognised the changes and a unit head reported: *'The changes for the associates were probably the largest although they haven't really realised it. They are much more in contact with others...'*. In the old building with the cell-based structure things were different. An associate said: *'Our supervisor was the only contact in the old environment'*. This increase in communication at the lower hierarchical level reflects the empowerment of associates in the day-to-day handling of experiments. For instance, a research associate from the chemistry unit told us: *'I used to synthesize molecules and ship them [to molecular biologists] without reflecting much on the future use. Today, I directly talk to the associate who is testing my substances. We deliberate upon the little details without involving the scientists'*. This suggests that the new workspace facilitated "communication for coordination" (Allen, 2007) among associates.

Two years after the move, the reduction in the role of hierarchy and the increase of informal FtF communication between associates are still perceived as an important result of the move to a multi-space environment. A unit head remarked on the effects of the improvement in coordination that resulted from these changes: *'Timely response was not possible in the old environment. ... Hierarchy has flattened significantly.'*

Changes of communication: bench vs. desk

Rather unexpectedly, the increased communication among associates is not matched by an increase in communication at the bench (see Table 3), where associates spend a significant part of their time. In fact, three months after the relocation, the share of FtF communication events at the bench *decreased* from 44% to 36%; the median duration of an FtF event at the bench decreased from 47 to 38 seconds; and the mean values decreased from 151 to 132 seconds, although this last difference is not statistically significant. The frequency of communication events among associates at the bench decreased from 2.3 to 1.5 events per person per hour. Research associates on average spent 196 seconds (3 minutes) per hour in FtF conversation at the bench in the new laboratory environment, versus 353 seconds (6 minutes) per hour in the old laboratory locations. A research associate observed: '*The [new] lab is surprisingly quiet'*.

The data in Table 3 show that there is a shift of communication activity away from the bench to the desk. Our interviews and observations show that this is due to two main reasons. First, in the new setting, deskwork and bench-work are clearly distinct because desks and benches are located in different areas. This spatial separation between the two activities is emphasised, both physically and symbolically, by the need to wear protective clothing when entering the lab area. In addition, the computers and visual representations needed to discuss the results of the experiments are available at the desk, not at the bench. Our interviews show that this contributed to communication moving away from the bench and to the desks. For instance, one scientist told us: *'A proper scientific discussion away from our desks is pointless because that is away from where our data is'*.

Second, the decrease in conversation at the bench also resulted from the conscious effort of associates to avoid disrupting other people's work. Laboratory work consists of both activities that require precision and cognitive focus and for which distractions or interruptions might destroy the work of several hours; and of activities that are relatively simple, repetitive and less delicate, which suffer less from distractions. In the old cellular labs, there would often only be a couple of research associates working at the same time in each lab, and they could easily monitor each other's work and manage conversations and interruptions. This meant that, in the periods when work was less demanding, conversations in the old setting were often social in nature, interspersed with periods of high concentration and silence when the work required it.

In the new setting, the larger number of associates sharing the new laboratory space means that, at any moment, it is likely that somebody is engaged in a task that requires concentration while at the same time it is more difficult to know whether each associate that could be disturbed is carrying out delicate work, which had the effect of deterring conversation. An associate told us: *'We talk more in the desk zone because our lab work often does not allow us to chat at the same time, whereas processes in the desk zone can be put on hold'*. This combined with lower density in the lab, one associate remarked: *'I had more [social] chats at my lab bench before, this is hardly possible here because we are widely distributed'*.

Two years later, it was rare to observe people talking while working at the lab benches. Data from the third phase of our study confirm that indeed there are more conversations carried out at the associates desks' than at the bench (38% and 11% respectively), and that social conversations (i.e. non-work related interactions) account for only some 12% of all conversations observed in the desks and laboratory areas.

Changes in communication: Locating expertise in multi-space integrated laboratories

The move to the new environment appears to have brought about an increased awareness of the distribution of expertise among scientific staff. This was remarked upon particularly for the research associates in the second phase of the study. For example, a scientist told us: *'Their [the research associates'] visibility and the visibility of their work has strongly increased. We are now much more aware of the three 'Ps': people, projects, and procedures. That is what matters: Who is working on which projects and the methods'*.

In the open laboratory, communication across the hierarchical lines does not only help coordination as discussed before, but also makes it easier for research associates to become familiar with the tasks and expertise of co-workers and to identify the right person to consult. Both scientists and research associates actively consult co-workers: *'I have now many more contacts to people with other expertise'*. The new open multi-space setting helped associates expanding their knowledge by increasing their awareness of what other research associates were doing. An associate said: '*My colleagues then show me their methods and we mutually assist each other in our work'*.

The ability to overhear conversations was important. A scientist reported: *'Definitely overhearing happens very often. Especially when people are talking about approaches similar to your own ones. You can talk to those colleagues later'*. In addition to making people more visible and audible, the new setting has increased the visibility of the materials being worked on and with (e.g. chemicals, reagents, media cultures). The laboratory equipment, the machines, tests and assays, are subject to rapid technological change, requiring associates to keep up to date and understand how to work with them. Conversations are often triggered by an associate seeing a novel, unusual, or unfamiliar technique or piece of equipment being exploited. One research associate explained: *'You get by somebody and say "you are doing this kind of experiment" and he will tell you 'this is doing this and this is doing this'. It has become the main source how I get information'*. In contrast, a unit head remarked: *'It [the open multi-space] is not my main source of information. This would be rather our project meetings.'* Given the unit heads' main responsibilities (i.e. giving directions, coordinating or looking at the big picture), formal meetings remain crucial for them.

The effectiveness of objects in mediating development of maps of expertise varies across the hierarchy as seen above, but also disciplines. In our setting, people remarked that: *'Yes, equipment and screens tell me quickly what people are dealing with. [This is] probably easier in chemistry than in biology'*, and *'Seeing somebody pipetting something does not tell you much'*.

Interviewees, particularly at research associate level, were often enthusiastic about the opportunities that the new environment offered to expand their own personal network and expertise. In the third part of the study, this effect seems to have somewhat diminished for research associates. For instance, one associate remarked that the importance of the visibility of equipment for developing expertise maps has diminished over time because when they moved in, there was a lot of new and unfamiliar equipment that other groups were using, and this often started conversations. This suggests that, as time passes from the relocation, familiarity with material and equipment has increased and the visibility of people seems to have become more important.

In addition, some associates operated in a small disciplinary group in the building, with most of their disciplinary colleagues operating elsewhere. This seems to pose some challenges in terms of maintaining and developing expertise in their own discipline. One research associate remarked: '*There are days when I hardly speak with any colleague from my own discipline. That is not good for me.*'

In order to better compare the results of each of the three measurement periods qualitatively, we have summarised them in the following table.

--- Insert Table 4 about here ---

Discussion

Our study sheds light on some under-researched effects of open space working environments on communication patterns in organisations, and specifically in R&D and knowledge intensive settings.

First, our study provides evidence on the impact of open working environments on communication along and across the hierarchy. Previous research, which has compared reactions to the move between managerial/professional and clerical employees in organisations, has shown that managers/professionals are usually (but not always) less satisfied than clerical employees with the move to open offices (Davis et al., 2011). Older employees (which are also on average higher up in the hierarchy) are also less satisfied then younger ones (McElroy &

Morrow, 2010). Explanations for why this is so point to an heightened need for privacy in managerial/professional work (e.g., performance reviews, client conferences), the importance of offices as sign of status, or the higher cognitive demands of managerial/professional as opposed to clerical work, which make interruptions particularly counterproductive (Davis et al., 2011; Elsbach & Pratt, 2007).

By combining our quantitative observations with interviews and qualitative observations, we are able to show that, in a knowledge intensive setting, communication changes from within the hierarchical chain to across the hierarchical chain in particular for junior professionals, who engage in more communication activity with their peers situated in other groups. This increased communication is aimed primarily at facilitating coordination of activities, as well as improving knowledge of current technical developments (two of the three categories of communication identified by Allen (2007)).

This shift in communication from within to across the hierarchy was a somewhat unexpected result. The flattening out of communication, which has been shown to be beneficial to new product development in mass manufacturing contexts (e.g. Juran, 1988; Womack & Jones, 2003), has been identified in connection with managerial interventions that flatten the organisational structure by reducing the number of hierarchical levels and empowering those at the operational end. Here, the spatial arrangement of work had an effect above and beyond other forms of managerial intervention.

Zalesny and Farace's (1987) study of a relocation of a government agency from traditional to open plan offices showed a significant increase in information requests received by clerical staff. Our study shows that this trend holds for junior knowledge workers as well, and expands these quantitative findings with a qualitative investigation that clarifies the reasons for these changes, showing that junior knowledge workers are more efficient in coordinating interdisciplinary tasks. In addition, research associates appear to benefit particularly from the wider possibilities to learn about what others do through visibility of experimental equipment, screens, people and through overhearing.

Balancing the gain in understanding who knows what, is the risk that junior knowledge workers might lose contact with colleagues in their own discipline. Therefore, maintaining knowledge about technical developments in their own fields might suffer unless other managerial actions are taken to compensate. These might include ensuring a minimum critical mass for each discipline, junior staff rotation every few months to locations where such mass exists, and creating expert communities.

Our study confirms the importance of visual and aural accessibility in open plan settings. The visibility of people, as discussed above, provides clues about their availability to be engaged in conversation (Backhouse & Drew, 1992) and might help newcomers to integrate into an organisation and to 'learn by observation', by watching and overhearing others (Becker et al., 1995; Fried et al., 2001). Thus, accessibility of key actors (e.g. those who are experienced or those with many ideas) becomes more important than increases in pure physical proximity to one's co-workers (Coenen et al., 2004; Dolfsma & Eijk, 2015).

Our study also contributes to a growing body of research that emphasises the importance of physical objects, beyond visual and aural accessibility of people (e.g., Elsbach & Bechky, 2007; Heerwagen et al. 2004). The visibility of physical objects through which work is accomplished has two effects. First, as discussed above, they contribute to increasing the awareness of expertise location. The literature that looks at this issue has typically examined IT systems (e.g., Criscuolo et al. 2007) or at the characteristics of "transactive memory systems" (i.e., maps of who knows what that people develops by working together in groups) (Lewis and Herndon 2011; Ren and Argote 2011; Wegner 1987). There has been little examination of how the design of workspace and the visibility of materials might help in the process of creating and updating a transactive memory system, and our study suggests that workspace characteristics are likely to be central for further research.

Second, objects and visual displays of information can support coordination of activities – as people can see in which work others are engaging and gauge the progress of tasks (Hughes et al., 1996), as well as supporting an understanding of the overall work (Becker & Sims, 2001; Hargadon & Sutton, 1997; Lahlou, 1999). Coordination through visibility of objects in our setting appears to be related primarily to regulating interruptions – a critical issue in open workspaces (Perlow 1999, Sundstrom et al. 1982, Kaarlela-Tuomaala et al. 2009). By being able to see what artefacts others are manipulating, the individuals in our setting were able to infer whether the work required concentration or the researcher could be interrupted.

Finally, visual representations of information can be critical to create a shared situation awareness (Artman, 2000) that is essential to carry out complex, unpredictable tasks. Our case suggests that the debate on "workspace awareness" (e.g. Heerwagen 2004) should be expanded to look at effects on knowledge flows.

Our study looks at the effects of a move to open space over a much longer period of time than is usual in this kind of investigation. Our results suggest that the effects of a move to open space tend to surge soon after the move and then settle down over time, both in terms of benefits and in terms of drawbacks. In terms of benefits, some of the effects of the ability to locate knowledge and develop a map of expertise appear to decrease somewhat over time. In terms of drawbacks, the disruptive effects of interruptions appear to have also diminished over time, as people developed mechanisms, including an etiquette, to cope with them – in particular the ability to read cues that modulate interaction (Allen & Gerstberger, 1973; Backhouse & Drew, 1992).

However, distractions and interruptions continue to typify open workspaces and should be taken seriously depending on the type of work tasks (Kaarlela-Tuomaala et al., 2009). The literature mostly considers them a phenomenon whose effects can be reduced by working at home or in another area of the workspace. However, recent work on the effect of contemporary communication technologies shows that people develop mechanisms to manage interruptions until they become an integral and natural part of working (Wajcman & Rose, 2011). In our study, we found that although there were multiple spaces, people tended not to move from their desks and tended to adapt over time to the new open working environment. While perceiving intelligible conversations of colleagues could be uncomfortable (Pierrette et al., 2015), aural accessibility (i.e. hearing what colleagues talked about) also allowed people to develop a more complete map of the location of the expertise and capabilities available in the organisation, and at least some of the scientists valued this opportunity.

Finally, we observed a shift in the location of discussions and the content of conversations after the relocation into the open multi-space offices with an integrated laboratory, a kind of workspace that has been investigated only partially (Coradi et al. 2015; Zoller & Boutellier 2013). The specificities of the integrated lab (see Figure 2) - the distance between individual bench and desk is greater, but both lab and office areas offer high visibility – made scientists move their discussions from bench to desk. In our interviews and qualitative observations, we found two reasons that have been mentioned above: First, precise lab work needs concentration and scientists did not want to disturb their colleagues. Second, the discussions moved to the desk, because this is the place where their data are. These findings are supported by the quantitative data from the first two observation periods.

Regarding change in the content of conversation, interviews and qualitative observations in the first phases of our study suggest that social conversation decreased at the desk and bench after moving to the new workspace – although there are indications that social conversation might have migrated to the areas of the building dedicated to social encounters. The reduced length of conversations in the new setting in phase two of the study, as well as the very limited amount of social conversation observed in the third phase appear to support this observation. However, among our results, this is the one that is more likely to be influenced by "observer effects" (see below for a fuller discussion), as social conversation might be more likely than work related conversation to be cut short in the presence of an observer – although the similarly stifling effects of lack or privacy in the open spaces have been often remarked upon (e.g., Davis et al. 2011).

Scientists in our setting did not seem to miss their former social conversations, partly because they could still take place in other spaces in the building. However, a decrease in social conversation might be connected to findings that open space arrangements increase the perception of social liabilities (such as uncooperative co-worker behaviour and lack of trust) and decrease workplace friendship (Morrison & Macky, 2017). Further research on exploring the changes in the amount and location of social conversation and their effects is therefore warranted.

Limitations

Our results are achieved within a specific method - a mixed method case study based on observations, which allows depth of analysis but has a number of limitations. We did our best to limit observer effects by conducting preliminary observations in the same conditions as when data were collected – in this way ensuring that observers were part of the office landscape and as unobtrusive as possible by the time data collection begun. Although we cannot exclude observer effects, it is reasonable to assume that these were present both before and after the relocation – and as our results are concerned with changes from one workspace to another, our main results should not be significantly affected by them.

While we benefited from key factors remaining the same before and after the relocation (specifically, the company's emphasis on informal communication and most of the scientific equipment), the move implied some changes. The work environment was newer and nicer, and this might have contributed to the surge in interactions after the move, as people were happy with the new environment. Similarly, the new building made possible to carry out new activities, such as weekly seminars, which might have contributed to raising the level of awareness of where knowledge resides. Despite this being a possibility, our interviews and observation data point clearly to the important role of visibility of people and equipment, as well as aural accessibility, in supporting the creation of better expertise maps.

We studied the effect of moving from enclosed to open workspaces on pharmaceutical scientists in a single company, so that it is difficult to assess the extent to which they can be generalised to other types of knowledge workers and other types of organisations. The combination of desk and bench work that characterises knowledge work in these settings is peculiar, but at the same time likely to become more relevant in the economy as advanced design and production techniques are radically changing manufacturing in a way that make it resemble lab work (The Economist, 2017).

Also, in terms of organisation, our case study company had a culture and specific managerial actions that promoted unplanned interaction. The effects on communication of more open workspaces in a setting where control rather than unplanned collaboration is emphasised might be different.

Finally, the longitudinal nature of our study is a strength, but also poses some limitations as conditions in the company changed over time. Specifically, in the third phase we could not observe the same set of scientists as in the first two phases, due to people having promoted or having left in the meantime.

Further limitations derive from the focus of our study, in which we have looked primarily at the effects of more open work environments on communication along and across hierarchical chains, location of communication and the ability to locate expertise. We have not examined the effects that open work environment can have on the ability of scientists to carry out the concentrated and cognitively complex work that is central to their activities. Most studies show that open work spaces interfere with cognitively complex work (Elsbach & Pratt, 2007; Davis et al. 2011), and indeed we have indication that this was to some extent the case in this setting. Whether the positive effects of serendipitous conversation and the ability to locate expertise outweigh the negative effects on concentrated work is an important question that we do not tackle but that certainly demands further investigation.

This leads to the last and perhaps most important limitation of our study, which links changes in workspace to changes in communication behaviour. While there is ample literature arguing that informal communication is important in improving the performance of scientists (e.g., Perry-Smith 2006; Rothwell & Robertson 1973; Tushman & Katz 1980), our setting did not allow us to construct reliable measures of outcomes. Scientists in our sample were employed in industry and so published little – and it was therefore not possible to observe changes in publication behaviour (e.g., number of paper, or number of different disciplines involved). Given the length of the new drug development process, and the number of possible other intervening factors, it was not possible to ascertain the effect of changes on the success in developing new drugs, or moving to the following stages in the development process.

Conclusions

By investigating changes in who communicates and what is discussed rather than just how much communication is involved, our study provides a more nuanced view of the effects of moving to a multi-space environment with an integrated laboratory. We found that the new workspace has increased communication across hierarchical chains – but has done so particularly at the lower levels in the hierarchy by enabling junior researchers to bypass reporting lines and providing them with opportunities to develop expertise maps across disciplines.

By focusing on the knowledge flows within an organisation, we contribute to move beyond the debate on whether open spaces increase conversations by increasing propinquity among co-workers, or decrease conversations by reducing privacy (Fayard and Weeks, 2007). Changes in what people talk about when they meet should also be considered in discussing the advantages and disadvantage of open working environments. Overall, our findings suggest that the organisation of workspace remains an important managerial lever to foster interdisciplinary communication in R&D.

Acknowledgements

The authors thank S.A., N.S., C.H., C.E., T.H., J.W. and F.N. for their help with data acquisition, and the case study company for making this research possible. Minority funding by the case study company is gratefully acknowledged. The authors are solely responsible for the design, conduct, and analysis of the study, and the conclusions that are drawn.

References

Allen, T. J. (1970) Communication networks in R&D laboratories. *R&D Management*, **1**, 14-21.

Allen, T. J. (2007) Architecture and communication among product development engineers. *California Management Review*, **49**, 23-41.

Allen, T. J. and Gerstberger, P. G. (1973) A field experiment to improve communications in a product engineering department: The nonterritorial office. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, **15**, 487-498.

Allen, T., and Henn, G. (2007) The organization and architecture of innovation. Routledge.

Andereggen, S., Zoller, F. A. and Boutellier, R. (2013) Sharing research equipment to bridge intraorganizational boundaries - The cases of Novartis and ETH Zurich. *Research-Technology Management*, **56**.

Artman, H. (2000) Team situation assessment and information distribution. *Ergonomics,* **43**, 1111-1128.

Backhouse, A. and Drew, P. (1992) The design implications of social interaction in a workplace setting. *Environment and Planning B*, **19**, 573-573.

Becker, F. (2007) Organizational ecology and knowledge networks. *California Management Review*, **49**, 42-62.

Becker, F., Quinn, K. L. and Tennessen, C. M. (1995) *The ecology of collaborative work*: Cornell University International Workplace Studies Program, New York State College of Human Ecology.

Becker, F. and Sims, W. (2001) Offices that work: Balancing communication, flexibility, and cost. *International Workplace Studies Program*, 77.

Ben-Menahem, S. M., von Krogh, G., Erden, Z., and Schneider, A. (2016) Coordinating knowledge creation in multidisciplinary teams: Evidence from early-stage drug discovery. *Academy of Management Journal*, **59**, 1308-1338.

Boje, A. (1971) *Open-plan offices*. London: Random House Business.

Boutellier, R., Gassmann, O. and Von Zedtwitz, M. (2008a) *Managing global innovation: uncovering the secrets of future competitiveness*: Springer Science & Business Media.

Boutellier, R., Ullman, F., Schreiber, J. and Naef, R. (2008b) Impact of office layout on communication in a science-driven business. *R&D Management*, **38**, 372-391.
Chan, J. K., Beckman, S. L., and Lawrence, P. G. (2007) Workplace design: A new managerial imperative. *California Management Review*, **49**, 6-22.
Choi, S.Y., Lee, H., and Yoo, Y. (2010) The impact of information technology and transactive memory systems on knowledge sharing, application, and team performance: A field study. *MIS Quarterly*, **34**, 855-870.
Coenen, L., Moodysson, J. and Asheim, B. T. (2004) Nodes, networks and proximities: On the knowledge dynamics of the Medicon Valley biotech cluster. *European Planning Studies*, **12**, 1003-1018.
Coradi, A., Heinzen, M. and Boutellier, R. (2015) A longitudinal study of workspace design for knowledge exploration and exploitation in the research and development process. *Creativity and Innovation Management*, **24**, 55-71.
Criscuolo, P., Salter, A., & Sheehan, T. (2007). Making knowledge visible: Using expert yellow pages to map capabilities in professional services firms. *Research Policy*, **36**, 1603-1619.
Davenport, T. H., Thomas, R. J. and Cantrell, S. (2002) The mysterious art and science of knowledge-worker performance. *MIT Sloan Management Review*, **44**, 23-30.
Davis, M. C., Leach, D. J. and Clegg, C. W. (2011) The physical environment of the office: Contemporary and emerging issues. In: Hodgkinson, G. P. Ford, J. K, eds. *International Review of Industrial and Organizational Psychology*. Chichester, UK: Wiley, 193 - 235.
Dolfsma, W. and Eijk, R. (2015) Distances in Organizations: Innovation in an R&D Lab. *British Journal of Management*.
Dougherty, D. and Dunne, D. D. (2012) Digital Science and Knowledge Boundaries in Complex Innovation. *Organization Science*, **23**, 1467-1484.
Duffy, F. and Powell, K. (1997) *The new office*. London: Conran Octopus.
Edmondson, A.C. and McManus, S.E. (2007) Methodological fit in management field research. *Academy of Management Review*, **32**,1155-1179.
Edwards, A. M., Isserlin, R., Bader, G. D., Frye, S. V., Willson, T. M. and Yu, F. H. (2011) Too many roads not taken. *Nature*, **470**, 163-165.
Eisenhardt, K.M. (1989) Building theories from case study research. *Academy of Management Review*, **14**, 532-550.
Elsbach, K. D. and Bechky, B. A. (2007) It's more than a desk: Working smarter through leveraged office design. *California Management Review*, **49**, 80-101.
Elsbach, K. D. and Pratt, M. G. (2007) The physical environment in organizations. *Academy of Management Annals*, **1**, 181-224.
Fayard, A.L. and Weeks, J. (2007) Photocopiers and water-coolers: The affordances of informal interaction. *Organization Studies* **28**, 605-634.
Fried, Y., Slowik, L. H., Ben-David, H. A. and Tiegs, R. B. (2001) Exploring the relationship between workspace density and employee attitudinal reactions: An integrative model. *Journal of Occupational and Organizational Psychology*, **74**, 359-372.
Granovetter, M. S. (1973) The strength of weak ties. *American Journal of Sociology*, **78**, 1360-1380.
Hargadon, A. and Sutton, R. I. (1997) Technology brokering and innovation in a product development firm. *Administrative Science Quarterly*, **42**, 716-749.
Hatch, M. J. (1987) Physical barriers, task characteristics, and interaction activity in research and development firms. *Administrative Science Quarterly*, **32**, 387-399.
Heerwagen, J.H., Kampschroer, K., Powell, K.M., and Loftness, V. (2004) Collaborative knowledge work environments. *Building Research & Information*, **32**(6), 510-528.
Hughes, B. and Wareham, J. (2010) Knowledge arbitrage in global pharma: a synthetic view of absorptive capacity and open innovation. *R&D Management*, **40**, 324-343.

Hughes, J., King, V., Mariani, J., Rodden, T. and Twidale, M. (1996) Paperwork and its lessons for database systems: An initial assessment. In: Shapiro, D., Tauber, M. J. and Traunmüller, R., eds. *The Design of Computer Supported Cooperative Work and Groupware Systems*. Amsterdam: North-Holland, 43-66.
IMAP. (2011) Pharmaceuticals & Biotech Industry Global Report.
Juran, J. M. (1988) *Juran on planning for quality*. New York: Free Press.
Kaarlela-Tuomaala, A., Helenius, R., Keskinen, E., & Hongisto, V. (2009) Effects of acoustic environment on work in private office rooms and open-plan offices–longitudinal study during relocation. *Ergonomics*, **52**, 1423-1444.
Knorr Cetina, K. D. (1999) *Epistemic cultures. How the sciences make knowledge*. Cambridge, MA: Harvard University Press.
Kraut, R. E., Egido, C. E. and Galegher, J. E. (1990) Patterns of Contact and Communication in Scientific Resarch Collaboration. In: Galegher, J. E., Kraut, R. E. and Egido, C. E., eds. *Intellectual teamwork: Social and technological foundations of cooperative work*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc, 149-171.
Lahlou, S. (1999) Observing cognitive work in offices. *Cooperative Buildings. Integrating Information, Organizations, and Architecture*, 150-163.
Latour, B. (1987) *Science in action: How to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.
Latour, B. and Woolgar, S. (1986) *Laboratory life: The construction of scientific facts*: Princeton University Press.
Lewis, K. and Herndon, B. (2011) Transactive memory systems: Current issues and future research directions. *Organization Science* **22**: 1254-1265.
Merz, M. and Biniok, P. (2010) How technological platforms reconfigure science-industry relations: The case of micro-and nanotechnology. *Minerva*, **48**, 105-124.
McElroy, J. C. and Morrow, P. C. (2010) Employee reactions to office redesign: A naturally occurring quasi-field experiment in a multi-generational setting. *Human Relations*, **63**, 609 – 639.
Morrison, R. L., & Macky, K. A. (2017) The demands and resources arising from shared office spaces. *Applied Ergonomics*, **60**, 103-115.
Moultrie, J., Nilsson, M., Dissel, M., Haner, U. E., Janssen, S. and Van der Lugt, R. (2007) Innovation spaces: Towards a framework for understanding the role of the physical environment in innovation. *Creativity and Innovation Management*, **16**, 53-65.
Nightingale, P. (2000) Economies of scale in experimentation: knowledge and technology in pharmaceutical R&D. *Industrial and Corporate Change*, **9**, 315-359.
Orsenigo, L., Pamolli, F. and Riccaboni, M. (2001) Technological change and network dynamics - Lessons from the farmaceutical industry. *Research Policy*, **30**, 485-508.
Perlow, L. A. (1999) The time famine: Toward a sociology of work time. Administrative science quarterly, **44**, 57-81.
Perks, H., and Roberts, D. (2013) A review of longitudinal research in the product innovation field, with discussion of utility and conduct of sequence analysis. Journal of Product Innovation Management, **30**, 1099-1111.
Perrow, C. (1986) Complex organizations: A critical essay.
Perry-Smith, J. E. (2006) Social yet creative: The role of social relationships in facilitating individual creativity. *Academy of Management Journal*, **49**, 85-101.
Pettigrew, A. M. (1990) Longitudinal field research on change: Theory and practice. *Organization Science*, **1**, 267-292.
Pierrette, M., Parizet, E., Chevret, P. and Chatillon, J. (2015) Noise effect on comfort in open-space offices: Development of an assessment questionnaire. *Ergonomics*, **58**, 96-106.

Pisano, G. P. (2006) *Science business: the promise, the reality, and the future of biotech*. Boston: Harvard Business School Press.
Rashid, M., Kampschroer, K., Wineman, J. and Zimring, C. (2006) Spatial layout and face-to-face interaction in offices - a study of the mechanisms of spatial effects on face-to-face interaction. *Environment and Planning B: Planning and Design*, **33**, 825-844.
Ren, Y. Q. and Argote, L. (2011) Transactive memory systems 1985-2010: An integrative framework of key dimensions, antecedents, and consequences. *Academy of Management Annals*, **5**, 189-229.
Rothwell, R. and Robertson, A. B. (1973) The role of communications in technological innovation. *Research Policy*, **2**, 204-225.
Sams-Dodd, F. (2005) Target-based drug discovery: is something wrong? *Drug Discovery Today*, **10**, 139-147.
Stryker, J. B., Santoro, M. D. and Farris, G. F. (2012) Creating Collaboration Opportunity: Designing the Physical Workplace to Promote High-Tech Team Communication. *IEEE Transactions on Engineering Management*, **59**, 609-620.
Sundstrom, E., Herbert, R. K. and Brown, D. W. (1982) Privacy and communication in an open-plan office: A case study. Environment and Behavior, **14**, 379-392.
Sundstrom, E., Town, J. P., Rice, R. W., Osborn, D. P. and Brill, M. (1994) Office noise, satisfaction, and performance. *Environment and Behavior*, **26**, 195.
The Economist (2017) The don't make 'em like that any more. 14th January, print edition.
Toker, U. and Gray, D. O. (2008) Innovation spaces: Workspace planning and innovation in US university research centers. *Research Policy*, **37**, 309-329.
Tushman, M. L. and Katz, R. (1980) External Communication and Project Performance - An Investigation into the Role of Gatekeepers. *Management Science*, **26**, 1071-1085.
Van den Bulte, C. and Moenaert, R. K. (1998) The effects of R&D team co-location on communication patterns among R&D, marketing, and manufacturing. *Management Science*, 1-18.
Wajcman, J. and Rose, E. (2011) Constant connectivity: Rethinking interruptions at work. *Organization Studies*, **32**, 941-961.
Watch, D. (2012) Trends in lab design: National Institute of Building Sciences.
Wegner, D.M. (1987) Transactive memory: a contemporary analysis of the group mind. In: Mullen, B. and Goethals, G.R. eds. *Theories of Group Behavior*, New York: Springer, 185-208
Williams, C. and Lee, S. H. (2009) Exploring the internal and external venturing of large R&D-intensive firms. *R&D Management*, **39**, 231-246.
Wineman, J. D. (1986) *Behavioral issues in office design*: Van Nostrand Reinhold New York, NY.
Wohlers, C., & Hertel, G. (2016) Choosing where to work at work–towards a theoretical model of benefits and risks of activity-based flexible offices. *Ergonomics*, 1-20.
Womack, J. P. and Jones, D. T. (2003) *Lean thinking: banish waste and create wealth in your corporation*. New York: Free Press.
Zalesny, M. D. and Farace, R. V. (1987) Traditional versus open offices: A comparison of sociotechnical, social relations, and symbolic meaning perspectives. *Academy of Management Journal*, **30**, 240-259.
Zoller, F. A. and Boutellier, R. (2013) Design principles for innovative workspaces to increase efficiency in pharmaceutical R&D - Lessons learned from the Novartis Campus. *Drug Discovery Today*, **18**, 318-322..

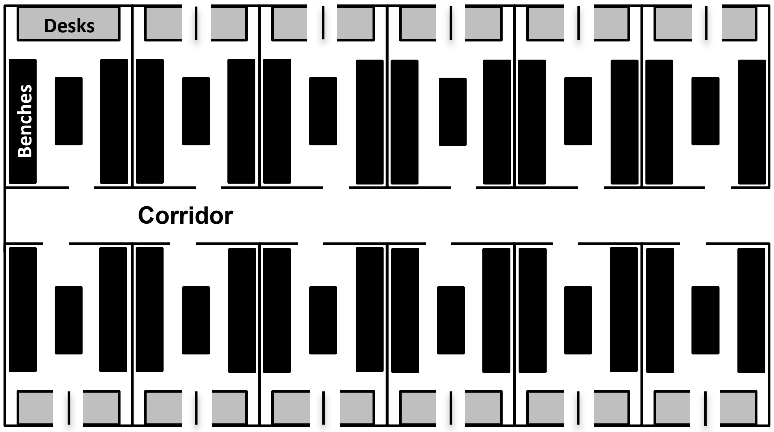

Figure 1. Schematic representation of cell-based office and laboratory environment

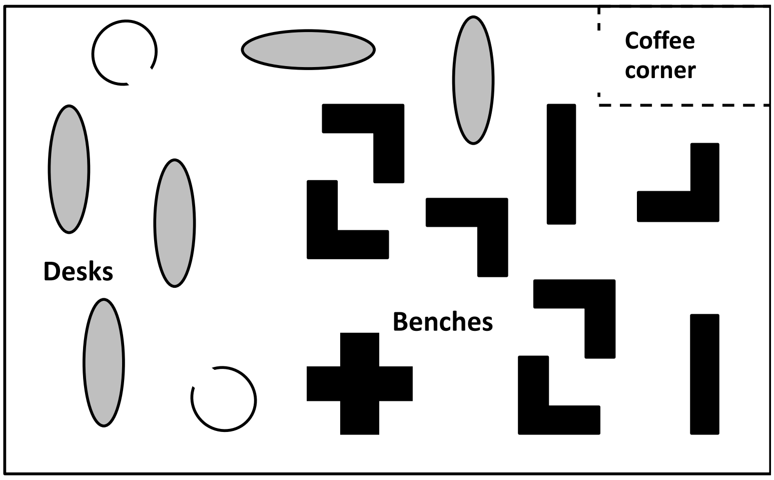

Figure 2. Schematic representation of one floor of the new open multi-space environment with an integrated laboratory

	Person-hours observed	Recorded no. of communication events
1st phase	147	984
2nd phase	233.5	2,188
3rd phase*	30	100
Total	410.5	3,272

*The 3rd observation phase is not included in the quantitative communication assessment.

Table 1. Person hours observed and recorded number of communication events

First and second phase (2010)	**Discipline**	8 cell biology	3 molecular biology	4 disease areas	3 chemistry
	Hierarchical level	2 unit heads	9 scientists		9 research associates
Third phase (2012/13)	**Discipline**	3 cell biology	7 molecular biology	-	3 chemistry
	Hierarchical level	-	4 scientists		9 research associates

Table 2. Overview of the employees interviewed before and after the move

		Cellular environment	Open multi-space environment
% FtF communication events on same hierarchical level		42.85%	54.74%‡
% FtF conversations events within reporting line		21.96%	10.58%‡
% FtF events at bench in laboratory		43.99%	35.87%‡
% FtF communication time at bench[b]		39.34%	35.28%
Median duration of an event [s]		46.92	38.31
Average duration of an event [s]	Bench	151.1	132.4
	Overall	125.7	137.8
Frequency of communication [events/person/h]^	Bench[a]	2.337	1.484**
	Desk	1.629	2.786***
	Overall	4.165	4.519
Average time spent in FtF conversations [min/h][b]	Bench[a]	5.885	3.274
	Overall	8.722	10.378
No. of participants in FtF events	Bench	2.096	2. 230***
	Overall	2.124	2.179**

[a]numbers of associates
[b]deduced from duration and frequency

**difference significant at the 0.01 confidence interval (Welch-test)
***difference significant at the 0.001 confidence interval (Welch-test)
^ paired samples test

Table 3. The move into an open space caused changes in the characteristics of face-to-face communication.

FOCUS AND RESULTS	1st observation period – Cellular labs May 2010	2nd observation period – open multi-space labs November 2010	3rd observation period – open multi-space labs November 2012 – January 2013
Observation location	3 buildings 26 scientists	2 floors 26 scientists	1 floor 46 scientists
Observation protocol	Number, duration, n of people involved, hierarchical level of participants, location in a total of 3,172 conversations.		Type of conversation (science and technical advice, coordination, social) and location, interdisciplinarity in a total of 100 conversations.
Changes in communication: hierarchical levels and multidisciplinarity	• 43% of all FtF-communication events on same hierarchical level. • Research associates talk with their supervisor and their colleagues in the lab unit (discipline).	• Increase to 55% of all FtF-communication events on same hierarchical level. • Mainly research associates talk more with each other across different lab units (disciplines). • Empowerment of the lower hierarchical level. • Joint problem solving and coordination among research associates.	• Lateral communication (among peers across hierarchical lines) has become more institutionalized. • Informal FtF-contacts are still strong on lower hierarchy level and across disciplines.
Changes in communication: bench vs. desk	• Share of FtF-communication at bench 44%. • Median duration of an FtF-event at bench is 47s. • Frequency of communication events: 2.337 events per person per hour. • Research associates spend on average 6min per hour at the bench. • Few research associates in one closed room monitor each other's work and manage their conversations and interruptions. • Social conversations take place when work is less demanding.	• Decrease of FtF-communication at the bench to 36%. • Decrease of median duration of an FtF -event at bench to 38s. • Decrease of frequency of FtF -event to 1.484 per person per hour. • Decrease of time spent at bench of research associates: on average 3min per hour. • The lab is quiet. • Communication activity moves from bench to desk. • Discussion at desk where the data is. • No discussion at bench to avoid disrupting people during precise lab work.	• Rarely discussion at lab benches. • Data confirm that FtF-events moved from bench to desk area. • Rarely social conversation in open desk and bench area compared to work-related interactions. • Interaction has professionalized, with better-developed informal rules to manage interaction.
Changes in communication: Expertise allocation in multi-space integrated laboratories	• Communication within the group and along the hierarchy and formal project meetings are main source of information.	• General changes in conversation patterns (see above), but no explicit comments to expertise allocation. • General visibility of research associates and more interdisciplinary communication on one hierarchical level support expertise allocation. • New, unfamiliar equipment of new colleagues started conversations and thus, first impression about others expertise.	• Explicit comments about ability to locate expertise • Deeper awareness about people, projects and procedures. • Visibility and overhearing of colleagues support awareness of others expertise. • Equipment and materials worked on are more familiar. Therefore, visibility of people supports expertise allocation more than objects. • Changes for research associates less prominent in terms of access to expertise less prominent, drawbacks highlighted in terms of neglect of own discipline.

Table 4. Summary of results and comparison of the three observation periods