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OVERVIEW: Multinational, technology-intensive companies routinely use globally distributed R&D teams, but COVID-19 represented an additional challenge. Lockdowns and home-office working severely limit human interaction and can impact the communication, social interaction, and knowledge sharing critical to successful R&D. Our study investigated how COVID-19 affected R&D processes at three global companies, using a project complexity perspective. Although R&D managers responsible for global projects are accustomed to the challenges of managing communications, the fact that teams were forced into home-office working made new product development more difficult in several ways. Ensuring that technical details are understood by all members of dispersed teams is crucial. Of particular note, and central to our findings, is the emphasis that R&D managers placed on maintaining a high level of social interaction in their teams, and special efforts were needed to keep interactions at a sufficient level to foster the generation and transfer of tacit knowledge. The findings have strong implications for the way that R&D project management is likely to be conducted in a post-COVID-19 world, and we demonstrate how the complexity framework we used can benefit managers in navigating this and other challenges.

KEYWORDS: COVID-19, NPD team, Social interaction, Tacit knowledge, Complexity

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Innovation is essential not only in stable business environments but also in times of crisis (Głodziński and Marciniak 2016; McCausland 2020) to ensure that companies can take advantage of improved conditions once the difficulties pass (Prabhu 2010). Volatile business environments can lead to a focus on damage limitation, operations, and cost control, and thus overwhelm a firm's ability to innovate. The evidence from research is mixed, showing firms reducing (Archibugi and Filippetti 2011; Brenčič, Pfajfar, and Rašković 2012; Archibugi, Filippetti, and Frenz 2013), maintaining, or even increasing, their innovation efforts (Cincera et al. 2012) during a crisis. With respect to the COVID-19 pandemic, the evidence is similarly mixed, reflecting either a slowdown in innovation investments (Bar Am et al. 2020) or concrete plans to continue innovating (Rainmaker 2020).

Although more innovative firms are more likely to survive a crisis (Cefis, Bartoloni, and Bonati 2020), crises impose significant constraints on a firm's innovation processes and activities; existing procedures become destabilized. Companies need to find new ways of working (Dynes and Aguirre 1979; Pearson and Clair 1998), but there is insufficient research on how individual organizations continue to innovate during a crisis.

Similarly, there is only sparse research on R&D management at the project level during crisis situations, and COVID-19 has created new challenges and difficulties. The very nature of R&D presents a series of socio-technical, cultural, and coordination challenges. For co-located teams, these challenges are somewhat easier because their physical proximity facilitates familiarity among team members (Wilson and Doz 2012) and direct communications. For distributed teams, the challenges are greater (Chiesa 1996) because R&D projects are complex and rely on the generation of new knowledge (Goffin and Koners 2011). The rapid rise of globally distributed R&D teams (Gerybadze and Reger 1999; Von Zedtwitz and Gassmann 2002; Jaruzelski, Schwartz, and Staack 2015; Farrington 2020; Papanastassiou, Pearce, and Zanfei 2020) has meant approximately one-third of new product development (NPD) teams use distributed working (Markham and Lee 2013). Global distributed teams are "a single, coordinated product development operation that includes distributed teams in more than one country" (Eppinger and Chitkara 2006, p. 23), enabling the use of both the parent company assets and the advantages of the host countries (Moncada-Paternò-Castello, Voigt, and Vivarelli 2011).

COVID-19 brought additional disruptions: lockdowns, home-office working, social-distancing, and self-isolation severely limiting interaction and negatively impacting the communication and knowledge sharing so critical to successful R&D. The global R&D management challenge has intensified as local units of international teams themselves became physically dispersed by home-office working.

In 2020, we interviewed R&D managers to investigate how COVID-19 had affected global R&D processes and teams. Our respondents came from three global companies in the automotive components, medical devices, and metal component industries, purposively selected. Maylor and Turner's (2017) complexity framework facilitated our analysis, and respondents validated the findings derived via this framework in a follow-up study in 2021. Our findings show that managers not only implemented technical solutions to keep communication flowing, but they took steps to generate a high intensity of social interaction within teams, which proved vital to keep connections at a sufficient level to foster the generation and transfer of tacit knowledge. We suggest the idea of "tacit knowledge half-life" to indicate the requirement to maintain this potentially fragile aspect of global teamwork, which is so critical to product development, and highlight that continuing to nurture social capital is vital in making this kind of dislocated, distributed work effective. These ideas have strong implications for the way that R&D project management is likely to be conducted in a post–COVID-19 world. We further demonstrate the utility of the Maylor and Turner (2017) framework as a validated, practical tool for ongoing managerial problem-solving in the NPD context, and as a method to reflect and learn from completed work.

Literature Review

Our literature review covers the following topics: knowledge management in global R&D teams; ICT usage in global R&D; social and cultural factors in global R&D; and COVID-19's impact on global R&D.

Knowledge Management in Global R&D Teams

Global R&D teams are not a new phenomenon (Boutellier et al. 1998), and many companies use them successfully (de Brentani, Kleinschmidt, and Salomo 2010; Papanastassiou, Pearce, and Zanfei 2020). Effective communication within and between teams is critical to the NPD process because NPD is a knowledge-intensive activity (Johannessen, Olaisen, and Olsen 1997; Mehra and Dhawan 2003), and project managers must specify "which information different teams will need from each other at particular stages of the project" (Sosa, Eppinger, and Rowles 2007, p. 134).

In R&D projects, teams must share both explicit, codified knowledge and, *tacit knowledge*—that is, knowledge that is extremely difficult to articulate, share, and document (Nonaka and Takeuchi 1995; Hull, Coombs, and Peltu 2000; Soderlund 2002; Goffin and Koners 2011). Projects conducted at a single location benefit from the constant interaction between team members, as this interaction facilitates the exchange of tacit knowledge (Wilson and Doz 2012). By contrast, the challenge in global teams is to transfer embedded knowledge from the main R&D facility (Moncada-Paternò-Castello, Voigt, and Vivarelli 2011) to other R&D locations and vice-versa, particularly in cases where other locations have teams with stronger technological capabilities than the main R&D facility (Song and Shin 2008). Furthermore, the success of global teams stems from the availability of a range of specialists with specific technical knowledge in host countries, unavailable in the home

location (Sole and Edmondson 2002). Global teams can leverage "a diverse but unique combination of talents and knowledge-based resources, thereby enhancing the firm's ability … in international markets" (Salomo, Keinschmidt, and de Brentani 2010, p. 955). Another advantage is that global teams can be close to markets, allowing them to have specific local market knowledge, which allows more appropriate products to be developed (Salomo, Keinschmidt, and de Brentani 2010) and more customer-oriented (Comstock 2013).

Sharing knowledge is fundamental to global R&D (Papanastassiou, Pearce, and Zanfei 2020), but it presents many challenges (Von Zedtwitz 2020), including the geographic and time zone separation of teams, and differences in culture, work ethics, and communications (Boutellier et al. 1998). Global teams' ability to access knowledge from different locations brings with it "a curse (a source of communication difficulty) for dispersed teams" (Sole and Edmondson 2002, p. 17). Lewis (1998) identified the problem of achieving a common, consistent understanding of complex projects. The more dispersed a team is, the more challenging the constraint becomes, and so "companies need to identify the optimal level of R&D dispersion that allows them to minimize the cognitive, transaction, and organizational costs of technology acquisition" (Ardito et al. 2018, p. 174).

ICT Usage in Global R&D

Global teams working at multiple locations need optimal communications, which has led to the intensive use of information and communication technology (ICT) to support the creation, capture, and sharing of knowledge (Forman and Zeebroeck 2012). Hauptman and Hirji (1999, p. 179) found "information technology [can help] overcome the negative effect of geographic distance and time-difference in cross-national teams." Similarly, Zhao et al. (2019) demonstrated how information technology can be leveraged to build organizational agility within global teams. Many studies of ICT have focused on the transfer of information (explicit knowledge), but researchers have found that when ICT focuses heavily on explicit knowledge, knowledge management is not effective (Braganza and Möllenkramer 2002).

ICT tools include videoconferencing, social media, shared CAD systems, and the like. For example, to support the creation and transfer of tacit knowledge, so-called *boundary objects* such as virtual white boards and chat functions can be useful. These boundary objects in virtual communities "impact the relationship between people and technology … [and] facilitate knowledge sharing among differing social domains" (Marheineke, Habicht, and Möslein 2016, p. 1086). Managers need to consider carefully how and in what ways ICT supports collective or individual processes (Montoya et al. 2009) and remain alert to the human dimension.

ICT can support knowledge management (Howells 1995; Marion, Barczak, and Hultink 2014), but it cannot mimic the richness of face-to-face social interaction so beneficial to global R&D. Communications using ICT can also lead to misunderstandings (Wilson and Doz 2012), so, to be effective, the technology needs to be complemented by suitable organizational and human resource practices (Boutellier et al. 1998).

Social and Cultural Factors in Global R&D

Beyond ICT use, social interactions influence a team's ability to be successful in NPD (Muethel, Siebdrat, and Hoegl 2012). Grant (1996) argued that stable and good social relationships positively impact the work of global teams and, similarly, Baxter, Goffin, and Szwejczewski (2013) observed that, for globally distributed projects, these factors are essential if knowledge sharing is to take place. Based on a single case study, "management can encourage the formation of V-CoP [virtual communities of practice] if, along with the creation of virtual project teams they promote informal interaction between the team members, encourage commitment, and put together 'the right mix of people'" (Marabelli et al. 2013, p. 310), an observation supported by Lee-Kelley and Turner (2017). Athreye, Batsakis, and Singh (2016) declared social interaction as the only way for the tacit and context-dependent nature of the technological knowledge required for new product development to be channeled between sites.

Researchers have studied how the global distributions of teams impact NPD. Stark and Bierly III (2009) found that the more distributed teams become, the more deleterious is the effect of conflict as relationships become harder to rebuild and resolve. This finding has important implications for management. Stark and Bierly III (2009) suggest conflict resolution strategies are needed when teams are highly dispersed along with a suitable mix of virtual and face-to-face interactions.

Cultural factors can impact social factors (Slade 2020). Both national and local cultures play a role in NPD communications, and the possibility of integrating different skills, experiences, and knowledge bases (Salomo, Keinschmidt, and de Brentani 2010) is one opportunity that makes global R&D attractive for innovative firms. A positive organizational culture that stimulates engagement, allows people to take risks in a safe environment, encourages learning, and stimulates independent thinking is essential for innovation (Rao and Weintraub 2013; Hill et al. 2014).

COVID-19's Impact on Global R&D

With its emphasis on generating new knowledge, face-to-face interactions to support tacit knowledge transfer, internal and external collaborations, cultural tolerance and conducive climates, contemporary R&D proves to be a very human, social, activity (Anderson and West 1998; Leonard-Barton 1998; Markham and Lee 2013; Dutton, Turner, and Lee-Kelley 2014; Marion, Barczak, and Hultink 2014; Nambisan et al. 2017). COVID-19 has compounded the challenge, as home-office working became necessary for previously co-located teams, working as part of global networks. The pandemic has made the face-to-face interaction, communication,

> The pandemic has made the face-to-face interaction, communication, and knowledge sharing critical for the transfer of knowledge tangibly more difficult.

and knowledge sharing critical for the transfer of knowledge tangibly more difficult. Knowledge sharing and learning can be successful in globally dispersed NPD projects (Sole and Edmondson 2002), but the topic requires further research.

Methodology

To investigate the impact of COVID-19, we asked three questions: 1) What effect has COVID-19 had on global R&D processes?; 2) How are managers and teams responding?; and 3) What activities are global R&D teams carrying out to manage knowledge sharing? Previous studies of global R&D have used surveys (Bierly, Stark, and Kessler 2009) or case studies (Braganza and Möllenkramer 2002; Gassmann and Von Zedtwitz 2003). Due to the transient nature of the response to COVID-19 and the need for unintrusive data gathering from time-pressed R&D managers, we opted for online semi-structured interviews. We designed the interviews to be 30 minutes long and focused on five topics, with two questions for each topic.

The main focus was on the project level. Most of the interviewees are experienced project leaders and R&D or business managers able to give perspectives across multiple projects. Purposive sampling from the research team's existing relationships allowed fast access to three global companies in the automotive components, medical devices, and precision-formed components industries. The companies are referred to as AutoComponentsCo (AC), MedDeviceCo (MD), and PrecisionCo (PC), to preserve anonymity and confidentiality.

At each company we interviewed 10 experienced NPD professionals (Table 1). We completed over 20 hours of interviews during four weeks (June–July 2020). Interviews were recorded and transcribed, although some respondents opted for no recording and, in those cases, interviewers made extensive notes. We had follow-up conversations in the spring of 2021 to understand how the organizations were faring and to determine the suitability of the complexity assessment approach. The typical projects run by the firms

TABLE 1. Data sample

#	Company	Company Characteristics (somewhat disguised)	Managers Interviewed	Interviewees' Locations
1	*AutoComponentsCo* [Respondents AC$_x$]	Automotive supplier designing and manufacturing complex components and systems Approximate turnover: $10B to $20B 50,000–100,000 employees	R&D Manager (AC1) R&D Manager (AC2) Project Leader (AC3) Project Leader (AC4) Project Leader (AC5) Project Leader (AC6) Project Leader (AC7) PM Manager (AC8) PM Director (AC9) BU Manager (AC10)	China, Czech Republic, India, Italy, and US
2	*MedDeviceCo* [MD$_x$]	Medical Device supplier designing and manufacturing implants and instruments Approximate turnover: $10B to $20B 10,000–20,000 employees	R&D Manager (MD1) R&D Manager (MD2) Project Leader (MD3) R&D Manager (MD4) Director R&D (MD5) Project Leader (MD6) Project Leader (MD7) R&D Manager (MD8) Project Leader (MD9) Project Manager (MD10)	Switzerland, UK, and US
3	*PrecisionCo* [PC$_x$]	Producer of precision formed components Approximate turnover: $500M to $1B 1,000–5,000 employees	New Business Development Director (PC1) Project Manager (PC2) R&D Manager (PC3) Project Manager (PC4) Project Manager (PC5) R&D Manager (PC6) Innovation Manager (PC7) Technical Director (PC8) Innovation Manager (PC9) Innovation Director (PC10)	UK, Spain, and Germany

studied are NPD/NPI (new product introduction), with a 24 to 60 months' timescale, each involving 5 to 25 full-time employees, from 2 to 6 national cultures and based in 2 to 5 different geographical locations.

We sought to understand the multiple factors in managing R&D projects by applying the *project complexity* perspective (Baccarini 1996; Dvir et al. 1998; Pich, Loch, and De Meyer 2002; Jaafari 2003; Xia and Lee 2005; Geraldi, Maylor, and Williams 2011). We drew on work that emphasizes the managers' "lived experience" (Williams 2005; Cicmil et al. 2009), allowing us to investigate the realities they faced during the pandemic.

We applied the Maylor and Turner (2017) complexity framework (based on Maylor, Turner, and Murray-Webster 2013) for three reasons: it is an established and validated framework; it has been used to investigate complexity in various scenarios; and it focuses on three different characteristics of complexity, which appeared useful in investigating global teams. *Structural Complexity* increases with the number of people involved, financial scale, scope, number of interdependencies, and the pace of the work. *Socio-political Complexity* represents the challenge from people, politics, and the range of stakeholders that have influence. *Emergent Complexity* is a function of novelty, and a lack of clarity about a project's vision and how the future will unfold. These dimensions highlight that R&D complexity involves more than technical (structural) challenges; it encompasses subtler social factors that are so vital (perhaps even the most important) in ensuring a successful outcome. Maylor and Turner (2017) proposed that typical responses fit into three categories: a *planning and control* approach (for example, established project management tools and techniques), *relationship development* with key stakeholders, and *flexibility* (that is, deviations from normal processes). Combining the complexities and responses gives a 3x3 analysis framework (Turner, Aitken, and Bozarth 2018). Although the complexity framework has not, to our knowledge, been used in such an R&D context before, it enabled coding and classification of typically "messy" project data (Ackoff 1979) and enabled us to identify complexities and responses. Our approach is also in line with current work that uses this framework in analyzing COVID disruption (Boehme et al. 2021).

Results

Managers of R&D teams during lockdown encountered a range of complexity challenges requiring a variety of responses (Table 2). Just over half of the complexities coded in the data were structural, including issues such as planning effective communication and ensuring tasks were completed effectively. One-third were socio-political complexities associated with the interpersonal aspects of managing NPD teams. Project leaders tried hard to make sure that their personnel had the necessary support, but they were also aware that the lack of face-to-face contact inhibited the previously accepted ways of operating and knowledge sharing. Interestingly, all respondents highlighted structural challenges, and 26 of the 30 respondents brought up socio-political complexities. Finally, emergent complexity represented one tenth of the

> **The respondents acknowledged the lack of "fortuitous" knowledge sharing, so managers implemented meetings and social events in the hope of "planned serendipity."**

complexities, and these focused on recognizing future uncertainties and attempting to mitigate them. The respondents acknowledged the lack of "fortuitous" knowledge sharing, so managers implemented meetings and social events in the hope of "planned serendipity" (a term used by one of the respondents). The interviewees could not fully quantify the benefits that they anticipated would come from these interactions, but they viewed such events as valuable in cementing interpersonal relationships and stimulating practical discussions that aid complex product development. The respondents also acknowledged the importance of relationship building, especially with new customers and staff, and the idea of supporting staff in their search for novel solutions.

Over half of the complexity challenge responses coded in the data related to "planning and control" solutions, and all 30 respondents mentioned these challenges. One-third of the coded responses were "relationship development," emphasizing again the vital social aspect inherent in R&D: 27 of the 30 respondents gave responses related to relationship development. Respondents viewed teambuilding and reinforcing existing relationships as essential to enable the complex knowledge to be shared and judgments made in the fluid R&D environment. Flexibility responses accounted for the rest of the responses, with staff adapting rapidly and, seemingly, effectively. Although some of the results were as the researchers expected—that is, structural complexities addressed by planning and control solutions—the analysis of the data showed that all three complexities (structural, socio-political, emergent) could be tackled with each of the response types (planning and control, relationship development, flexibility)—that is, offering nine permutations. The

TABLE 2. Summary of coding data

	Respondents (#)	Total References (%)
Complexity challenge		
Structural	30 (100%)	103 (55%)
Socio-Political	26 (87%)	63 (34%)
Emergent	10 (33%)	20 (11%)
Challenge response		
Planning and Control	30 (100%)	93 (51%)
Relationship-building	27 (90%)	63 (35%)
Flexibility	14 (47%)	26 (14%)

prevalence of the "non-obvious" solution types highlights the usefulness of the framework in uncovering ways forward when faced with these challenges.

Structural Complexities and Responses

Respondents from the three organizations voiced similar issues and experiences. From a structural perspective, the rapid lockdown transition meant that the initial effort entailed ensuring that staff could function from home effectively. Videoconferencing tools (some preexisting, some new) caused a major shift in how staff interacted. Immediate concerns included straightforward practical issues such as the availability of laptops, Internet bandwidth, and familiarity with the tools. Once NPD project managers had overcome the practical difficulties, more subtle and challenging issues arose, such as ways of communicating effectively in this new situation.

Managers tended to have more meetings, whereas many engineering staff had fewer meetings and more uninterrupted work (for which some were thankful). Teams became aware of colleagues' personal issues such as childcare, but these domestic realities did not appear to cause disruption. The predominant perception amongst respondents was that younger staff adopted this new way of working more favorably than senior staff, though they were less likely to have a home office. Respondents also noted that since almost everybody was now working remotely, the distinction between each manager's co-located "home" team and team members in other locations diminished, thereby seemingly reducing the effect of "distance."

A common theme was the increased number of shorter-duration meetings. Online meetings enabled information transfer, but most respondents highlighted their limitations. For example, the multiple communication options (video calls, phone calls, instant messaging, email) necessitated an understanding of the hierarchy of urgency. As one MD manager noted, "If it's urgent, call me. If it's not urgent, instant message me, and if it's super-not-urgent, email me." (MD3).

Respondents expressed concern that project teams did not fully understand project-related technical issues (and not the ICT tools mentioned). This uncertainty made discussions longer and required more rigor in email follow-ups (meeting minutes) to ensure that all points were clear. Ensuring the necessary clarity was harder across national cultures, and respondents expressed doubts about whether each side understood the details, thereby leading to increased time spent establishing a consistent and agreed upon understanding. Some managers thought that their written communication had improved as a result. Some respondents indicated that the lack of boundary objects in discussions (whiteboard, laptop, coffee machine) made knowledge sharing harder. One manager said, "You can get away with that not being quite as clear when you're all together" (MD5).

A major challenge for most interviewees was that lack of social interaction meant serendipitous knowledge sharing no longer took place. One manager said, "In the office you are accidentally exposed to information that may be useful"

(AC2). To overcome this, managers deliberately scheduled meetings both for project teams and also for project-to-project knowledge sharing, to implement a mechanism for communication that would no longer occur naturally. Meeting behavior, though, varied between organizations. AC staff generally did not use the cameras on calls, relying only on voice. Others emphasized how important visual communication was. In some instances, there was a significant improvement in meetings, as previously the offsite/offshore members who would dial in voice-only could get neglected or overlooked in meetings. An increased equality was noted if everyone was on the video call, regardless of location, and respondents indicated that they perceived it increased tacit knowledge sharing in particular.

We determined that structural complexities can be addressed through the three response types: planning and control (use of tools), relationship building (setting up regular virtual meetings), and flexibility (changing working patterns to accommodate others' needs).

Socio-Political Complexities and Responses

Social aspects were a major theme. According to one manager, "the spontaneous conversations in the kitchen at work are not taking place anymore" (PC2). Managers scheduled extra one-to-one meetings with their direct reports to offer support and "check in" with no particular agenda, In addition, cohesion could be bolstered by informal social events such as coffee meetings, Zoom quizzes, virtual treasure hunts, book clubs, Friday drinks, cooking events, fancy-dress themes, and "people are posting three pictures from their home and then the rest of the colleagues guess whose house that is" (MD1).

A point that came up regularly was that preexisting relationships with colleagues could continue with few problems, but new relationships were hard to forge online. One respondent said, "With some colleagues that sit next to me in the office, when I speak they already know what I mean. With new hires, it's more difficult. I have to make everything very clear, explain the main objectives, the action items and put everything in writing" (AC9).

For team management, trust developed pre-lockdown extended to working from home. One interviewee said, "We encourage our colleagues to produce good quality work rather than quantity. I trust my team completely even if everybody is working from home" (PC7). The importance of delivering the work, rather than putting in the hours, means, one manager said, "[the] stigma around not being in the office at eight o'clock and leaving before five o'clock, or whatever, is completely gone" (MD5).

Responses to socio-political complexities could also be mapped to the three forms. Planning solutions included the regular one-to-ones to ensure communication and support; relationship-building was strongly evident, encompassing the focus from respondents on stimulating regular social interaction; and flexibility included supporting colleagues' unavailability (for example, due to childcare issues) and working around that.

Emergent Complexities and Responses

Customer input in NPD was now harder to obtain. Similarly, developing new business relationships without in-person meetings was a significant challenge. One manager stated, "Many aspects of communication cannot be captured properly especially 'non-said information' like fear, pressure, concerns, and emotional aspects. This is dramatic … when it comes to establishing new business relationships" (PC1). Given the wholesale change, virtually overnight, in how people worked, the overwhelming perception was that the disruption was not affecting project delivery significantly, and everyone was stepping up.

The three companies took some major steps that might never have occurred pre-COVID-19. MD's NPD required prototype testing together with surgical teams. Usually this major milestone entails NPD teams flying around the world to directly observe simulated surgery. Instead, since the start of the pandemic, the company has sent prototypes to their customers so that the simulated surgery sessions could be conducted in the customer's home country with the NPD team observing them online, which has saved time and costs.

Overall, respondents indicated that the experience of remote working was successful. Despite the rapid transition, respondents found that knowledge sharing did continue, albeit differently, with projects generally progressing according to the original plans. Uncertainty remained as to how "normality" would resume, and what it would look like. Respondents acknowledged that returning fully to pre–COVID-19 conditions was unlikely and many aspects of remote working had been validated. At the time of initial interviews (summer 2020), the plans for returning to "normal working" were unclear, but the need to address the social aspect of NPD teamworking was front of mind.

Responses to emergent complexities came in three forms. Planning and control included actively seeking meetings with other groups to keep "in the loop" and ensure sharing of current issues and knowledge. Relationship development

> **Given the wholesale change in how people worked, the overwhelming perception was that the disruption was not affecting project delivery significantly, and everyone was stepping up.**

included supporting staff by updating them regularly on the current and evolving situation (for example, on the "return to work" expectations). Finally, respondents reported on the flexibility involved in finding practical, context-dependent solutions for sharing detailed technical information with others.

We identified a wide range of practical managerial responses to the pandemic (Table 3). Mapping these to the Maylor and Turner (2017) framework highlighted the variety of solutions implemented, as all nine of the options were populated. This variety of practical options reinforces the challenge of R&D, in that "template" answers are unlikely to be sufficient. It also underlines the importance of the critical "social" aspects despite the inherently technical nature of the contexts.

Discussion

We sought to investigate how global R&D teams responded to the COVID-19 pandemic and its impact on knowledge sharing. Certain aspects, such as the rapid shift to a reliance on electronic communication was unsurprising, especially as it was evident in other sectors worldwide. Similarly, our

TABLE 3. Examples of managerial complexities and responses during the pandemic

		Complexity		
		Structural	**Socio-political**	**Emergent**
		Increases with the number of people involved, financial scale, scope, number of interdependencies, and the pace of the work	Represents the challenge from people, politics, and the range of stakeholders that have influence	A function of novelty, and a lack of clarity about project's vision and how the future will unfold
Response	*Planning and Control*	Use of tools (for example, technology); coordination	Regular one-to-ones to ensure communication and support	Actively seeking meetings with other groups to keep "in the loop" and ensure sharing of current issues and knowledge
	Relationship Development	Setting up regular virtual meetings	Focus on stimulating regular social interaction	Support staff by updating them regularly on the current and evolving situation (for example, on the "return to work" expectations)
	Flexibility	Changing working patterns to accommodate others' needs	Support colleagues' unavailability (for example, due to childcare issues) and working around that	Finding practical, context-dependent, solutions for sharing detailed technical information with others

> Technology can help maintain preexisting work relationships that support the sharing of tacit knowledge, yet these social bonds are unlikely to remain effective indefinitely.

finding that ICT plays a key role in supporting R&D activities confirms previous research (Boutellier et al. 1998). R&D teams rapidly overcame initial practical problems with equipment availability and connectivity and respondents reported that projects continued relatively smoothly. The relatively seamless transition from pre-pandemic working to pandemic working is testament to the utility of the ICT tools used in support of existing relationships.

Our novel findings are connected to knowledge management challenges, which all three companies clearly identified as important. Managers discussed how the explicit and tacit knowledge-sharing mechanisms (Nonaka and Takeuchi 1995; Goffin and Koners 2011) changed in the pandemic working environment. Explicit knowledge, which is generally understood as easy to share, now proved to be a challenge. Ensuring that technical details were correctly shared and understood required additional, clearer documentation of meetings. One observable benefit was that the companies achieved a "level playing field" between the main R&D facility and other locations, since everyone was in the same situation on video calls. Attempting to share tacit knowledge proved even more challenging than before COVID-19—it required different thinking to account for the lack of informal, serendipitous interaction and knowledge sharing that occurs in a direct, shared physical environment. Managers tried to stimulate informal social interaction in the virtual space and highlighted consistently how important pre-COVID relationships and culture were in supporting working remotely. While it proved relatively straightforward for staff who had already established relationships that built trust to continue to work together, it was difficult to build new internal and external relationships without face-to-face contact.

The lens of complexity (Maylor and Turner 2017) was instructive and revealed a different perspective on the response to the pandemic. Structural complexities, representing primarily technical and coordination challenges, accounted for just over half the challenges coded. Given the nature of the work and the new situation, we initially expected that this figure would be higher. Socio-political (people) issues accounted for over one-third of the challenges, representing mainly the difficulty of maintaining relationships under these new conditions. Interestingly, emergent complexities, representing uncertainty about the

future, was only one tenth. Our results indicate that the managers were, understandably, focused primarily on the immediate project requirements, and the evidence suggests that despite upheaval of the ways of working, the managers' focus on safeguarding key project activities from delays was successful in the case organizations. A planning approach (half) and relational mechanisms (one-third) dominated the responses, showing that the more mechanistic "engineering" and "project management" functions need the significant support of the social and interpersonal factors that help to make the projects work in practice and enable practical and effective knowledge transfer.

What does this mean for practitioners and researchers? Managing global R&D involves structure, ICT, and good project management practices; however, these elements could be considered as "necessary but not sufficient." In addition, the social capital of the global project team, with other teams, and a range of stakeholders, is crucial. The evidence from this study shows that the social relationships can survive the major disruption of lockdown, allowing projects to continue despite the dramatic change. Working from home can be effective, but it is more difficult. Specific efforts need to be taken to maintain relationships, and ICT can enable working with limited disruption and even offer new, efficient ways of collaborating. Some issues, such as mechanical engineers being prevented from accessing important hardware in the offices, were harder to overcome.

Management skills are needed to keep relationships going. Managers need to ensure that explicit knowledge continues to be shared and understood, and to reinforce informal interactions. Through the COVID-19 crisis, some of these previously less-visible social factors became more evident and overt. Viewing the issues through the complexity lens makes "people" aspects more distinguishable, which brings to the fore the idea that social factors are inherent to R&D, even if they appear less prominent than more formal processes (Dutton, Turner, and Lee-Kelley 2014). Managing social complexity (Maylor and Turner 2017) is a skill that managers need to hone for working with dispersed teams.

The data suggest organizations can work remotely, at least in the short-term, because of already established relationships and knowledge sharing. Technology can help maintain preexisting work relationships that support the sharing of tacit knowledge, yet these social bonds are unlikely to remain effective indefinitely. We posit the idea of "tacit knowledge half-life"—that is, the ability of teams to share tacit knowledge will decay over time if participants remain predominantly dispersed. Building new relationships with staff, suppliers, or customers without face-to-face interaction is difficult. As the underlying intangible assets begin to decay, there could be a decline in the momentum of existing and new projects. Managers must use their judgment as to how best to support their staff and projects. In this uncharted territory, the maps used previously (for example, processes, standards, and best practices) do not accurately reflect the new terrain of managing social interaction to stimulate serendipitous exchange of tacit knowledge.

COVID-19 has had major impacts on R&D management. For managers, many of these problems are related not to structural (traditional) project management issues but to social interaction. Many of the complications of dispersed working will remain in the future but, as one respondent said, "Engineers like to solve problems … [so we will] make this work." (MD8)

Managerial Implications

Most technical organizations and staff are comfortable with *structural* challenges, but many of the most demanding project issues have their roots in social and "people" issues. In conducting our research, we asked managers in the case companies explicitly about the structural, socio-political, and emergent risks and issues that team members were worried about. A manager from MD said they scheduled "short and frequent" one-to-one meetings and used new technologies for better communication and cooperation. A manager from AC noted that, to cope with the difficulties of planning under uncertainty, they gave more attention to understanding employees' personal/family needs and worries, as well as supporting the use of flexible working solutions. The complexity framework enables structured (often informal) discussion about the kind of practical steps that would be most valuable. In uncertain times, this open discussion can be more beneficial than "standard" risk processes, which often miss socio-political and less-quantifiable concerns. We share additional examples of the problems and responses implemented by the spring of 2021 by the case organizations in support of their NPD (Table 4). It is not necessary (nor likely) that all nine boxes will be populated.

Our framework offers a valuable approach to practical problem-solving in managers' R&D functions. Managers can use it with their teams to identify solutions to the ongoing challenges they face in their R&D projects. For NPD managers, the framework can be beneficial in two distinct ways. First, in ongoing projects with difficulties, it facilitates a structured conversation, which can identify the particular problem. NPD managers can use the framework to identify the type of problem (structural, socio-political, or emergent) and potential solutions (planning and control, relationship development, or flexibility). Second, it can be valuable as a tool for reflection and learning, either during the project (such as at a gate review) or at its conclusion. Reviews often focus primarily on structural issues such as "How did we perform versus our targets?" and "What technical issues did we encounter?" By also explicitly considering the socio-political ("How well did we deal with the stakeholders and their concerns?") and emergent ("How effectively did we deal with change and the unexpected?"), managers and teams can gain a more rounded appreciation of a project's performance and how it may be improved in the future.

Within an R&D context it is important to capture the (often intangible) "social" aspects and tacit knowledge use that underlie performance, especially in distributed teams. Our experience indicates that this framework effectively brings these more "hidden" challenges to the surface, along with the more readily identifiable technical issues. By acknowledging the complex reality of the project, managers can gain insights that might otherwise not be identified, enabling practical solutions to be implemented in a timely fashion.

Study Limitations

The main limitation of our study is the restricted dataset, based on three companies. However, the data represent an

TABLE 4. 2021 review of complexity/responses with managers from case organizations

		Complexity		
		Structural	**Socio-political**	**Emergent**
Response	*Planning and Control*	Need for more frequent NPD team meetings to build and share knowledge. ⟶ Schedule meetings that can be attended in person or remotely.	Existing pre–COVID-19 personal relationships are insufficient. ⟶ Ensure short frequent one-to-ones and group meetings with staff to refresh social capital.	Traditional NPD knowledge channels are lost or limited. ⟶ Ensure tacit and explicit knowledge and learnings are shared with group, both formally and informally.
	Relationship Development	Enable direct reports to communicate in the group network to support the continuity of product development.	Challenge of "on-boarding" new starters. ⟶ Make time for all team members to meet the new staff and ensure regular conversations to make them part of the development team.	Difficulty of planning under uncertainty. ⟶ Managers should support discussions about concerns both in meetings and informally to allay members' worries.
	Flexibility	Ongoing challenge of coordination and sharing NPD information given uncertain availability of individual team members. ⟶ Managers should support and institutionalize flexible working according to personal circumstances.	Empathize with colleagues' personal situations, including family commitments, childcare, and working hours.	Scan new technology opportunities to aid communication and teamwork. This involves both the (relatively straightforward) IT aspects and the more difficult challenge of effective knowledge sharing.

important snapshot of R&D during the COVID-19 crisis. Future work may look at what happens over an extended period with teams working from home—does it remain effective? How much face-to-face meeting time is required to sustain effective relationships? From this we may gain insight into the implications for the home/office balance in R&D projects. Many of the findings are applicable to co-located but not dispersed teams.

Conclusion

We looked at how three global organizations responded to the impact of the COVID-19 pandemic on the management of R&D projects. When faced with this sudden and wholly unanticipated operational challenge, all three organizations managed to transition rapidly to new ways of working, with surprisingly little impact on their ongoing projects. R&D managers can take three main lessons from our study. ICT and project management are essential tools to enable global R&D teams to function in dispersed, homeworking situations. When used in isolation, these tools are not sufficient for the task of creating and sharing the amount of knowledge, which is central to R&D project work. Explicit and tacit knowledge created in typical projects needs to be communicated between team members. Informal social interaction within global R&D teams is pivotal. R&D managers took steps to stimulate social interaction; maintain relationships built on trust; focus on tacit knowledge; and ensure regular informal interactions. Respondents made significant efforts to support such activities, despite the challenge of the disruption. Our results demonstrate the advantage of considering the complexity of managing global teams in terms of structural, socio-political, and emergent issues. Managers can use the Maylor and Turner (2017) complexity framework to systematically analyze problems and to generate different solutions spanning planning and control, relationship development, and flexibility. Managers now have a new perspective on how to manage tacit knowledge and social interaction in global NPD project teams.

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