The impact of co-location on production knowledge transfer in collectivist and individualist cultures

Received 2 June 2022
Revised 27 December 2022
23 March 2023
19 April 2023
Accepted 19 April 2023

Pettis Kent
Loyola University Chicago, Chicago, Illinois, USA
Enno Siemsen
University of Wisconsin-Madison, Madison, Wisconsin, USA, and
Xiaofeng Shao
Shanghai Jiao Tong University, Shanghai, China

Abstract

Purpose – This paper enhances our understanding of how national culture impacts manufacturing performance (assembly speed, consistency between teams, etc.) during a production process move. The authors also investigate the efficacy of co-location as a strategy to enhance knowledge transfer from one organization to another.

Design/methodology/approach – To study the impact of national culture on production process moves, the authors develop and employ a team-based behavioral experiment within and between an individualist society (the United States) and a collectivist one (China). The authors also examine the impact of co-location on knowledge transfer effectiveness within and between these two unique cultures.

Findings – Interestingly, co-location has little impact on the performance of US recipient teams. Without co-location, Chinese recipient team performance lags significantly behind the US teams. However, firms can overcome these knowledge transfer challenges by co-locating source and recipient team members. These results suggest that firms should assess the national cultural context when considering co-location to manage their production move. There are contexts where co-location may be incredibly useful to facilitate an effective knowledge transfer (e.g. collectivist cultures like China) and contexts where this approach may not be as valuable (e.g. individualistic cultures such as the United States).

Originality/value – This research contributes to the academic literature in several ways. First, while past research demonstrates that national culture can be an essential barrier to information and knowledge sharing, this paper extends these findings showing that co-location may effectively overcome this barrier. After the authors offer and test the merits of co-location, they also establish the boundary conditions of this approach by showing that the effect of co-location on knowledge transfer is contingent on the cultural context. This contribution enhances our understanding of the relationship between national culture and knowledge sharing and has implications for managers developing approaches to transfer knowledge between cultures. Second, the authors develop and execute a novel cross-country experimental design. While cross-country experiments have been done before (e.g. Ozer *et al.* 2014, Kuwabara *et al.* 2007, etc.), it is still rare to see such experiments due to them being "technically difficult and costly" (Ozer *et al.* 2014, p. 2437). This research not only offer insights into how teams of people from individualist and collectivist societies send, receive and comprehend production knowledge. It also documents how these teams convert this knowledge into production results.

Keywords Cross-cultural, Production move, Knowledge transfer, Collectivism, Co-location

Paper type Research paper

The authors would like to thank the Carlson School of Management (University of Minnesota), Wisconsin School of Business (University of Wisconsin-Madison) and the Antai College of Economics and Management (Jiao Tong University) for their financial support of this project. A special thank you to the late Dr. Michael Houston, former Associate Dean of Carlson Global Initiatives at the Carlson School of Management, University of Minnesota.

0144-3577
DOI 10.1108/IJOPM-06-2022-0354

Firms often shift production within and between countries. Such a change in the location of a process is fraught with challenges, requiring the firm to ramp-up production at the new site. Firms can overcome this hurdle by thoughtfully managing the transfer of production knowledge associated with the move. One approach to do so is co-location – moving people from the source location to the destination to ensure that team members at the destination can benefit from learnings at the source. But the transfer of tacit knowledge inherent in such a co-location approach faces different challenges across various national cultures. We employ a team-based behavioral experiment to examine knowledge transfer effectiveness within and between an individualist society (the United States) and a collectivist one (China). We look at co-location and its impact on knowledge transfer within and between these two unique cultures. We can overcome knowledge transfer challenges for Chinese recipient teams by co-locating source and recipient team members. However, co-location has little impact on the performance of US recipient teams. These results suggest that firms should assess the national cultural context when considering co-location to manage their production move. Co-location may be incredibly useful to facilitate an effective knowledge transfer in some contexts (e.g. collectivist cultures like China). This approach may not be as helpful in other contexts (e.g. individualistic cultures like the United States).

1. Introduction

Customers, competitors and investors can pressure companies to move their production to different locations. This pressure often originates in management's intention to streamline production costs, expand or protect their current business footprint, or reduce lead times. Executives can focus on the post-move rewards, discounting the risk of moving their production processes to a new site. Yet, a production move is not trivial and demands managing several decisions in parallel, such as the new facility's location, whether to create a brownfield or greenfield site (Gaimon *et al.*, 2017) and whether to use existing or new equipment. Another challenging facet of orchestrating a move is managing the transfer of existing knowledge about the production process. Managing knowledge effectively within the firm is vital to maintaining operational efficiency and sustaining a competitive advantage (Dyer and Nobeoka, 2000; Grant, 1996; Kogut and Zander, 1992; Leoni *et al.*, 2022; Li *et al.*, 2012).

Our study focuses on intra-firm production process moves, where the same firm owns the source and recipient locations. While participants at these locations may cooperate to facilitate an effective knowledge transfer (Gray and Massimino, 2014; Hennart, 2009), process and product knowledge is often tribal – undocumented and not formalized in routines or technology, deeply embedded in frontline employees (Siemsen *et al.*, 2007; Tucker, 2007). Because the personnel employed at the source and recipient sites of the process move may differ, developing a strategy for the effective transfer of process knowledge is critical to an efficient ramp-up and overall post-move success (Letmathe and Rößler, 2019). Thus, companies invest significant time and energy to ensure that knowledge is transferred and retained successfully during a move. Practices adopted in the industry include, for example, creating standard operating procedures, structured codification (Kotlarsky *et al.*, 2014), the use of augmented reality devices (Wuttke *et al.*, 2022) or the "copy exactly" approach (McDonald, 1998). These practices create templates that allow firms to capture existing knowledge and then apply this knowledge to the new site to speed up the learning process during the production ramp-up. However, while firms may be patient about realizing post-move rewards, they will search for alternative solutions if these rewards fail to materialize (Edmonson *et al.*, 2003). Devising and executing an effective production knowledge transfer is, therefore, essential for the success of the overall production process move.

In this paper, we examine the use of *co-location* to effectively transfer production knowledge within and between unique national cultures, specifically the United States and China. One way of categorizing knowledge is to differentiate between tacit and explicit/codified knowledge (Nelson and Winter, 1982). Tacit knowledge is referred to as "know-how," while we conceptualize explicit/codified knowledge as "know what" (Edmonson *et al.*, 2003). While the distinction between tacit and explicit/codified knowledge suggests a dichotomy, tacit knowledge can become explicit/codified and vice versa (Edmonson *et al.*, 2003).

Co-location is "bringing together personnel from different departments into the same location" (Kahn and McDonough, 1997, p. 162). Firms often use co-location to transfer knowledge (e.g. Dyer and Nobeoka, 2000; Kotha and Srikanth, 2013). Importantly, this approach may not always be equally effective (Kahn and McDonough, 1997). The key idea we propose in our research is that co-location matters most in a context where tacit knowledge is seen as more valuable than explicit knowledge (Bhagat *et al.*, 2002). To test this idea, we introduce differences in national culture between source and recipient sites as a critical contextual variable. Specifically, we examine what role the cultural dimension of individualism/collectivism may play in driving knowledge transfer and performance differences post-transfer. Collectivist cultures like China may view tacit knowledge as more valuable than explicit knowledge. Individualist cultures like the United States may place a higher value on explicit vs. tacit knowledge (Bhagat *et al.*, 2002).

National cultural diversity is at the center of many of the world's production process moves: Toyota moving midsized pickup truck production from the United States to Mexico (CNBC.com January 17, 2020), Ford Motor moving the production of small cars from the United States to China (New York Times, June 20, 2017) or general electric (GE) moving turbine production from the United States to Europe and Asia (Wall Street Journal, September 15, 2015) are just a few examples of the inter-country production movement in our global economy that involve transferring knowledge between people with different national cultures. With the increase in globalization over the past three decades, coping with different cultures within the same firm is a daily reality at work.

Several academic studies provide evidence for extensive production process movements between the United States and China in both directions (Chen *et al.*, 2015; Cohen *et al.*, 2016; Sirkin *et al.*, 2014). Our objective is to understand if and how national culture impacts the effectiveness of a chosen approach for knowledge transfer (co-location) amid a production process move between two culturally very different countries. Specifically, we pursue the following research question: Is co-location an effective strategy to transfer knowledge regardless of the national culture context, or does its effectiveness depend on the national cultures involved? Since we are predominantly concerned with how quickly a firm can be productive after a move, we focus our laboratory experiment on assembly speed and assembly time variance as the dependent variables (see sections 2 and 3).

While production moves are complicated and multifaceted, at their core, they require the successful transfer and retention of knowledge and task comprehension. This setting lends itself well to a behavioral laboratory experiment. This method allows us to control who creates the knowledge and how it is transferred.

We contribute to the academic literature in several ways. While past research (e.g. Bhagat *et al.*, 2002; Özer *et al.*, 2014) demonstrates that national culture can be a barrier to information and knowledge sharing, we extend these findings by proposing that *co-location* may be an effective way to overcome this barrier. We also establish this approach's boundary conditions by showing that co-location's effect on knowledge transfer is contingent on the cultural context. This contribution enhances our understanding of the relationship between national culture and knowledge sharing from an academic standpoint and has implications for managers developing approaches to transfer knowledge between cultures.

We develop and execute a cross-country experimental design. We not only offer insights into how teams of people from individualist and collectivist societies send, receive and comprehend production knowledge. We also document how these teams convert this knowledge into production results. While cross-country experiments have been done before (e.g. Buchan and Croson, 2004; Kuwabara *et al.*, 2007; Özer *et al.*, 2014, etc.), it is still rare to see such experiments due to them being difficult and expensive (Özer *et al.*, 2014).

Section 2 reviews the relevant literature and develops hypotheses. Section 3 contains our research setting/methods. Section 4 consists of the analysis and results from our experiment, and Section 5 includes a discussion, managerial implications, limitations and future research.

2. Relevant literature and hypothesis development

2.1 Individualism, collectivism and national culture

Considering the global expansion of supply chains over the past few decades, the importance of studying the impact of national culture on business outcomes has increased among researchers. Examples of operations management (OM)-focused culture studies include Bockstedt *et al.* (2015), Flynn and Saladin (2006), and Özer *et al.*, 2014. Much cross-cultural management research is based on the early work of Geert Hofstede. Hofstede (1980) used data from a single organization (IBM) across seventy countries for his seminal work. He distinguished among several cultural dimensions: *individualism/collectivism*, *power distance*, *masculinity/femininity* and *uncertainty avoidance*. Over time, Hofstede added other dimensions, such as *long-term orientation* and *indulgence*.

An essential criticism of the Hofstede framework is that it focuses on cultural values, not cultural practices. Another important critique is that the data Hofstede based his assessments on is comparatively old; cultures have evolved since then. As a result, several studies have extended the work of Hofstede (Fatehi *et al.*, 2020). For example, Project GLOBE (Global Leadership and Organizational Behavior Effectiveness, House *et al.*, 2001) is a framework that focuses on values and practices. It is a multi-phase project in which 150 scientists and researchers worldwide examine the relationships within and between cultures. GLOBE establishes nine cultural dimensions: *uncertainty avoidance, power distance, society collectivism, group collectivism, gender egalitarianism, assertiveness, future orientation, performance orientation* and *humane orientation*.

Our study is only interested in one of these dimensions: individualism/collectivism. This dimension is present across cultural frameworks. The two countries we examine in our study, i.e. the United States and China, are seen as being on opposite ends of the individualism/collectivism scale (Özer *et al.*, 2014), with the United States being individualistic and China being collectivist (Hofstede, 1980; House *et al.*, 2001; Fatehi *et al.*, 2020). *Individualism* is a social pattern of loosely linked members who perceive themselves as largely independent of the collective. Motivation is based on people's preferences and needs, emphasizing rights and contracts. Conversely, *collectivism* is a social pattern of more tightly linked individuals who identify as belonging to one or more collectives (e.g. family, co-workers, in-groups and organizations). Motivation is based on norms and responsibilities imposed by these collectives.

The individualism/collectivism dimension is essential to understand how people from various cultures analyze social behavior and process information (Ardichvili *et al.*, 2006; Bhagat *et al.*, 2002; Erez and Earley, 1993; Hofstede, 1980; Triandis, 1989, 2001). People from individualist and collectivist societies have distinctly different ways of processing information and creating knowledge (Ardichvili *et al.*, 2006). Triandis (2001) argues that the individualism/collectivism dimension describes a fundamental cultural difference.

2.2 Cross-cultural challenges in production knowledge transfer

A successful process move requires effectively transferring production knowledge (Kent and Siemsen, 2018). The pace of the ramp-up after a move determines success: how quickly do manufacturing capabilities in a recipient location, such as speed, costs and quality, reach or exceed the prior levels at the source location? Any new process undergoes a learning curve, but where this learning curve starts at a recipient site and how quickly it unfolds is a function of how much knowledge was transferred during the move. Production knowledge transfer is already a challenge within a homogenous environment. Özkan-Seely *et al.* (2015, p. 177) argue that the expected benefits from knowledge transfer require patience due to "the difficulties in articulating and documenting knowledge as well as the challenges regarding its interpretation and application." Our research argues that this knowledge transfer becomes even more challenging in cross-cultural contexts. Note that in the context of our study, we effectively control for quality. The only manufacturing capability we examine is speed, i.e. the assembly time of a product. Reducing assembly time equates to improved efficiency and decreased cost (Edmonson *et al.*, 2003). This definition of performance is consistent with several seminal papers in the knowledge transfer literature stream (e.g. Darr *et al.*, 1995; Edmonson *et al.*, 2003; Epple *et al.*, 1991).

Previous research demonstrates the challenges of transferring knowledge between heterogeneous environments. For example, Winter and Szulanski (2001) show that firms adapt their service templates to a foreign environment in the context of global franchise expansion. Such adaptations can lead to new problems which can impede growth and profitability. More broadly, prior research documents the challenges of operating across distinct national cultures (Gupta and Gupta, 2019). Using Hofstede's cultural dimensions and the Malcolm Baldrige quality framework, Flynn and Saladin (2006) conclude that there "is not a universal model for performance excellence and that practices and approaches should be adapted to the local culture" (Flynn and Saladin, 2006, p. 599). Leveraging the GLOBE framework and performance data from 189 global plants, Naor *et al.* (2010) find that we can partially attribute manufacturing performance differences to these plants' national culture and organizational structure. Özer *et al.* (2014) demonstrate that sharing forecast information within a supply chain across cultures is challenging. They partially attribute these challenges to the Chinese culture and institutional environment, arguing that the Chinese collectivist orientation restricts trust and trustworthiness to one's narrow social network formed through family ties or long-term relationships. The authors advise that "companies that overlook the distinct cultural and market characteristics in China but simply replicate their US business models have encountered bitter failures in the Chinese market" (p. 2435). Without a doubt, we must carefully examine best practices in operations and supply chain management established in one cultural context concerning their applicability in other cultural contexts. Managing a process move and the relevant knowledge transfer across cultures is thus more challenging than managing it within.

Kedia and Bhagat (1988) examine technology transfer between cultures. Their research examines specifically how the dimension of individualism/collectivism impacts a cross-cultural transfer. They argue that individualistic cultures are more successful than collectivist ones regarding absorbing and diffusing imported technology. Bhagat *et al.* (2002) analyze cross-country knowledge transfer across several contextual variables, including forms of knowledge (human, social and structured), dimensions of knowledge (simple vs. complex, explicit vs. tacit, and independent vs. systemic) and cognitive styles (tolerance for ambiguity, signature skills and holistic vs. analytical modes of thinking). They argue that individualist cultures value explicit knowledge, which exists separately from the person conveying it, more than tacit knowledge. Collectivist cultures, in contrast, appreciate tacit over explicit knowledge since they see knowledge as inherently tied to a person. Thus, transferring knowledge from individualist cultures to collectivist ones may be particularly challenging since the people involved at source and recipient sites emphasize, value and view the related knowledge differently.

A consistent theme in these papers is that the challenges in selecting best practices or transferring knowledge in homogenous environments get exacerbated in heterogeneous environments, such as a production move between the United States and China. The added challenge originates from heterogenous cultural norms and values and language barriers. As a result, knowledge transfer from an individualist country (United States) to a collectivist one (China), or vice versa, will be more challenging than a transfer within such countries. The differences in how these cultures receive and process information will directly impact production assembly time post-transfer, compared to a similar transfer within individualist (or collectivist) countries. We, therefore, hypothesize the following:

H1. Transferring production knowledge between an individualist and a collectivist culture will lead to slower assembly time than a transfer between similar cultures.

2.3 Co-location and knowledge transfer

Globalization has led employees with different skill sets to co-work on projects in other geographical areas. This physical distance between people "decreases the probability that individuals meet by chance in hallways, at lunch, in front of closed elevators, or around the coffee machine. Distance decreases the chance of unplanned, serendipitous information transfer and problem clarification" (Van den Bult and Moenaert, 1998, p. S1-S2). As Kotha and Srikanth argue, " . . . in globally disaggregated projects, differences in language, culture and institutional diversity further exacerbate the coordination problems that arise due to geographic distance such as lack of frequent, rich situated interactions between interdependent agents" (Kotha and Srikanth, p. 7). To overcome these challenges, firms must encourage collaboration and communication between distal co-workers.

Epple *et al.* (1991) demonstrated that knowledge transfer requires human interaction. They studied data from a large North American truck plant that expanded from one shift to two using the same technology in both shifts. They found that the initial knowledge transfer, focused on "technology only," remained incomplete until first-shift workers spent time and shared their tacit knowledge with second-shift workers. Many companies still view *co-location*, or "bringing together personnel from different departments into the same location" (Kahn and McDonough, 1997, p. 162), as a powerful tactic to enhance knowledge transfer. While modern communication technology, such as video conferencing and chat rooms, has allowed for smoother and richer communication across distance, researchers have pointed out that co-location still matters in the age of information technology (Gray *et al.*, 2015).

Not surprisingly, agile project management, a methodology to improve the effectiveness of software development and other projects, emphasizes the benefits of co-locating team members. Coworking spaces – a new form of flexible office space for employees of different organizations – also emphasizes the importance of locating remote employees together with other professionals (albeit from different teams or organizations), rather than at their homes, for their work to benefit from serendipitous encounters (Spreitzer *et al.*, 2015).

There is a substantial history of firms using co-location successfully to improve knowledge sharing. Ford, McDonnell-Douglas, Honda and Boeing have used a co-location approach for years, bringing together engineers, designers and manufacturing to develop new products (Bergstrom, 1991; Kahn and McDonough, 1997; Kotha and Srikanth, 2013; Peitrangelo, 1993). Dyer and Nobeoka (2000) uncovered how Toyota has effectively created and maintained a knowledge sharing network between themselves and their supply base. Toyota created and executed an initiative called Interfirm Employee Transfers (i.e. co-location). This initiative transfers 120–130 employees to other firms within the value chain (i.e. suppliers) each year. The result is an improved level of knowledge transfer and the creation of a shared purpose between Toyota and its suppliers. Toyota sees this initiative as a way to enable better tacit knowledge transfer. Interestingly, the authors found that Toyota was not conducting these interfirm transfers with any of its suppliers outside Japan.

Lawson and Potter (2012) discuss *causal ambiguity* and *absorptive capacity* in the context of knowledge transfer. Both concepts lead to an incomplete understanding of the transferred knowledge. The recipient cannot fully utilize the knowledge without complete understanding, leading to suboptimal results. The authors contend that firms must invest in "relationship-specific human investments" (p. 1242), like co-location. The practice reduces causal ambiguity and increases absorptive capacity within the knowledge recipient.

These papers show that co-location can be of great value in a manufacturing environment, especially regarding the transfer of tacit knowledge or "know-how" (Edmonson *et al.*, 2003). When firms can more effectively transfer this "sticky" knowledge (Szulanski, 1996) within and between firms, it should lead to a quicker ramp-up post-transfer. We, therefore, hypothesize the following:

H2A. Co-location of source and recipient team members to transfer production knowledge will lead to faster assembly time than without such co-location.

While studying the average performance of teams is paramount to understanding productivity, examining the variance of performance across teams is also essential. Performance differences across teams indicate inconsistent process application and imply learning opportunities between different teams. A recent study of learning curve variance (Bavafa and Jonasson, 2021) highlights that people do not only increase their performance over time, but they also become more consistent. Ignoring this effect could lead to a significant underestimation of the importance of learning.

Without co-location, knowledge is transferred predominantly through codified instructions such as templates or augmented reality applications. Such instructions are inherently incomplete, failing to capture all tacit knowledge from the source (Epple *et al.*, 1991). Team members at the recipient site interpreting these instructions may fill these gaps with their assumptions and heuristics, leading to performance variance between teams. Co-location can make a difference here since instead of individuals making assumptions to fill in gaps, the co-located team member can contribute their tacit knowledge to assist the transfer. As a result, task and process understanding among team members should be more consistent, thus reducing variance and increasing production dependability. We hypothesize the following:

H2B. Co-location of source and recipient team members to transfer production knowledge will lead to less variable assembly time than without such co-location.

As hypotheses 2 A&B indicate, co-location has advantages. But the practice does not always work. For example, Kahn and McDonough (1997) found that although co-location improved collaboration between research and development, and manufacturing, it did not improve performance. And co-location can lead to significant expenses. During the offshoring boom to China in the 1990 and 2000s, many firms co-located their US technical personnel with production teams in China. Further, firms would periodically deploy other company personnel (e.g. supply planning, purchasing, finance and general management) to China to ensure the business ran smoothly. Such practices led to significant travel costs and the opportunity costs of co-located personnel being unable to work on alternate projects. Large multinational companies have the financial base to make these investments. However, the net effect may be that despite the benefits of co-locating personnel across country borders, some firms may find the approach too costly or time-consuming (Kahn and McDonough, 1997). It is, therefore, essential to examine when and why co-location can be a helpful approach to facilitate knowledge transfer.

An essential insight here comes from Bhagat *et al.* (2002). Co-location is particularly relevant for transferring tacit knowledge. Collectivist cultures value tacit knowledge more than explicit knowledge. Thus, co-location should be particularly important for knowledge transfer received in collectivist cultures. Kotha and Srikanth (2013) also argue that in integration projects, there is an "indispensability of some co-location in such situations, regardless of cost" (p. 37). We, thus, anticipate that when transferring knowledge to a collectivist culture (e.g. China), co-locating a source team representative with the recipient team will improve post-transfer performance, generating a reduction in the overall assembly time. Conversely, co-location will not have as much impact when transferring knowledge to an individualist culture (e.g. the United States). We, thus, hypothesize the following:

H3A. The impact of co-location on assembly time will be greater if the recipient teams are from collectivist rather than individualist cultures.

Along similar lines, given the arguments of Bhagat *et al.* (2002), collectivist cultures may expect that a co-located team member will fill any gaps in the instructions; individualist cultures may be more inclined to notice the gap and highlight the incompleteness of instructions, rather than expect a co-located team member to fill these gaps. Thus, variance reduction through co-location will be more pronounced in collectivist cultures. We hypothesize the following:

> *H3B.* The impact of co-location on assembly time variability will be greater if the recipient teams are collectivist rather than individualist cultures.

3. Experimental design

We interviewed several executives whose firms had undergone production process moves between dissimilar cultures. These executives included a Sales Director of a pharmaceutical company with over $1bn (USD) in yearly revenue, a Vice President of a medical device manufacturer with over $10bn (USD) in revenue, and a Vice President of Strategy with a Chinese contract manufacturer that generates over $200m (USD) in yearly revenue and conducts business with several Fortune 100 customers in the United States. We developed several key takeaways from these conversations. First, even with the best plans, unforeseen issues caused delays. Second, due to cultural differences, moving between countries is fraught with risk, especially with a labor-intensive process. Last, due to these national culture differences, firms often had to adjust their move strategies mid-project. Based in part on these insights, we developed a cross-cultural behavioral experiment executed in the United States and China to test our hypotheses.

Before discussing our experiment in detail, we review several key terms. *Performance* is the time to complete the assembly task without error (speed) and the variance in assembly time between teams. The experimenter only accepted the assembled product if it conformed to specifications, and any assembly errors had to be corrected (decreasing speed) before the task was considered complete. Speed is thus a good proxy for efficiency and cost (Darr *et al.*, 1995; Edmonson *et al.*, 2003; Epple *et al.*, 1991). A *Source Team* is a group of four people that created the production template used by recipient teams. Our study has two final source teams: one from the United States and one from China. No teams had mixed team members from the two countries because we wanted to isolate the impact of national culture in the experiment. A *Recipient Team* is a group of four students recruited from a leading university in the United States or China. Eighty recipient teams (40 in the United States and 40 in China) participated in the experiment, performing an assembly task using the production templates created by the previously mentioned source teams. A *Production Template* is a codified set of directions describing an efficient way to assemble the device used in the experiment. The source teams create two templates for this experiment: one in the United States and one in China (see Appendix B). Templates contain the same process information but were encoded differently by their respective source teams; they were cross-checked with each other by the experimenters to ensure that they were consistent before the experiment began. We achieve *co-location*, a key manipulation within our experiment, when one of the Source Team members is physically present, participates with a recipient team, and advises them on implementing the template created by the co-located member and their source team. The co-located member does not help build the device and only verbally assists the recipient team with implementing the template.

3.1 Treatments and participants

We varied three factors as treatments in the experiment: source national culture, recipient national culture, and co-location, for a $2 \times 2 \times 2$ design. This design allowed us to identify the impact of national culture and co-location on performance.

We vary culture within the experiment by exclusively recruiting students from the two cultures of interest, the United States and China, to serve on their respective teams. Our approach in this experiment is consistent with past national culture studies (Buchan and Croson, 2004; Ho and Weigelt, 2005; Özer *et al.*, 2014; Roth *et al.*, 1991). As in these previous studies, we controlled for four factors when recruiting subjects and running the experiment: subject pool equivalency, experimenter effect, language effect and currency effect. To achieve *subject pool equivalency*, we recruited business, engineering and general science students at two highly ranked universities (one in the United States and one in China) with large student populations. While we did not collect team-specific demographics, our pre-screening software allowed us to recruit similar student profiles at both universities. Özer *et al.* (2014) and Berry *et al.* (2006) argue that residence in a country of over six years "results in an individual's significant adaptation to the cultures and social norms of the host country" (Özer *et al.*, 2014, p. 2454). All the student participants on the experiment's source and recipient teams were native to the country where we recruited them. To control for the *experimenter effect*, we developed a standard set of instructions (see Appendix A) that the experimenter read to the subjects at the beginning of each experiment session in both the United States and China. We translated and back-translated all instructions to ensure they delivered the same message without confusion, whether in English or Chinese. We translated and back-translated each template to control for the *language effect* (see Appendix B). Only the local language (United States – English, China – Mandarin) was spoken during the experiment. Lastly, we controlled for the *currency effect* by structuring compensation from the experiment in line with what was customary in that country. For the US experiments, the compensation range was between \$5 and \$35 per team member, based on performance. In China, the compensation range was \$60–110 RMB or \$9–17 (USD) per team member, based on team performance (see Appendix A). We established these compensation ranges with guidance from the university's lab management team in both countries (United States and China) based on the expected compensation in their lab when considering experiment duration. The average payout was \$17 per person for the US teams and \$10.15 per person for the Chinese teams. Considering that the average cost of living in the experiment's Chinese city is approximately 40% lower than in the experiment's US city, the average payout across the experimental pool was equivalent in purchasing power.

3.2 Operationalizing production, national culture and co-location

We used Lego building sets (Sunset Speeder – #31017, 119 pieces) as a product to simulate a production process. Using Lego building sets has a history in academic research (e.g. Ariely *et al.*, 2008; Moreau and Engeset, 2016; Staats *et al.*, 2012) and within corporate and university training settings to simulate real-world phenomena. We tasked each team with building the Lego Sunset Speeder device for five rounds as quickly as possible without defects. The team started with a bag of unsorted pieces at the beginning of each round. Everyone had a written template to follow. Half of the teams had a co-located source team member sitting with them.

Our design required one source template from the United States and one from China. Therefore, we recruited six teams (three from the United States and three from China) to audition to be their country's "source" team. We verbally instructed each source team to use a previously developed template for the assembly task – the same template used in (BLINDED FOR REVIEW). Over one hundred four-person teams thoroughly tested and used this template in the previous study. We had evidence that it effectively transferred knowledge between a source and a recipient team. Therefore, we know the template "works." While the Lego assembly set has directions to put it together, there is no guidance on material flow or how to divide the labor among four people efficiently. Defining this workflow is the essence of the template. It contains explicit knowledge from the instructions and some codified tacit knowledge from team interactions. This form of tacit knowledge is often undocumented or tribal. It lies at the heart of research on frontline employee knowledge sharing (e.g. Siemsen *et al.*, 2007; Tucker, 2007) and manufacturing improvement (e.g. Cornelius *et al.*, 2021).

Led by the experimenters, the auditioning source teams were verbally guided through the template in detail, never being shown the template in a written form. We then asked them to build the Lego device five times, strictly following the template. After thoroughly understanding the assembly task, we instructed them to codify what they had experienced into a written template that future recipient teams could use. This approach guaranteed that all source teams were creating a template for the same production process and workflow. Any deviations between templates across different source teams were due to the encoding of the same process into a template and not due to fundamentally different production processes being encoded.

Afterward, a team of four supply chain doctoral students in each country, who were very familiar with the original template, tested each template by building the device with it. Ultimately, they reached a consensus and chose one written template from each country based on how well the template represented the original one and based on coherence and clarity of writing. Before recruiting the recipient teams, we confirmed that the two final templates were consistent (in that they described the same process) so that they would start from a similar baseline. Once we selected the two final source templates (one from the United States and one from China, see Appendix B), we recruited 320 students to serve in 4-person recipient teams: 160 students from a large research university in the Midwest region of the United States and 160 students from a large research university in China. We divided both schools' recruits into 40 teams of 4 people, for a total of 80 teams (40 United States and 40 Chinese). We randomly assigned each team to an experiment condition related to their country of origin (Table 1 details experimental treatments). The merits of using students vs. professionals in behavioral science research have been discussed at length in the literature, and the prevailing finding is that most studies find similar results regardless of the subject pool (Bolton *et al.*, 2012; Croson, 2007; Croson and Donohue, 2006; Özer *et al.*, 2014). In this study, we mainly use college students because the age of many contract manufacturing workers in China, putting together mobile phones, vacuum cleaners, toys, etc., is college-age or younger. We recognize that in the United States, manufacturing workers can be older.

While we cannot manipulate culture as a randomized treatment, creating variation along this dimension by recruiting subjects in different cultures is appropriate and consistent with prior cross-cultural research (Buchan and Croson, 2004; Özer *et al.*, 2014; Roth *et al.*, 1991). We also emphasize that we randomly allocate co-location, which is the critical treatment in our study.

As mentioned, co-location is "bringing together personnel from different departments into the same location" (Kahn and McDonough, 1997, p. 162). Regarding a production process move, that means bringing together personnel from the source and recipient locations so that the source personnel can provide production process knowledge and insights to enable a faster/more efficient ramp-up at the recipient location. We accomplish this by having a team

Treatment	Source	Recipient	Co-location
1	United States	United States	No
2	United States	United States	Yes
3	United States	China	No
4	United States	China	Yes
5	China	China	No
6	China	China	Yes
7	China	United States	No
8	China	United States	Yes

Source(s): Created by authors

Table 1.
Experimental treatments

member who created the source template sit with half of the recipient production teams (randomly assigned). In reality, co-locating members of the source and recipient teams would likely include the need to displace the source member for an extended period, which we do not capture in our experiment. However, based on our conversations with executives who have experienced production moves, we are confident that we replicated co-location as closely as possible in a lab setting.

Note that to facilitate having a co-located source team member sit with all recipient teams within that treatment, a Chinese source team member was physically co-located in the United States to support the US teams receiving a Chinese template within the co-location treatment. Even though the Chinese source team member was located in the United States, she still actively helped her China-based source team members create China's source template by virtually participating (via video conference) in the China team sessions. Similarly, a US source team member was physically located in China to support the Chinese teams receiving a US template. While actively creating the US template, he participated only virtually in the US source team sessions. There was also a Chinese source team member physically co-located in China and a US source team member physically located in the United States to support their respective local teams, bringing the total of co-located participants to four–two US source team members and two China source team members.

Within the experiment, the role of the co-located source team members was to help guide the recipient teams through their sessions. The co-located person would observe each recipient team and suggest changes between rounds to help improve template implementation and answer questions from the recipient team if asked. To reduce the co-located team member's learning effect, we instructed them to only provide guidance about a focal recipient team's adherence to the proven template and to disregard previously observed recipient team actions. While the co-located person actively advised the recipient team, they did not help build the device physically. Lastly, the recipient team was not obligated to use the advice the co-located team member offered.

Our experiment measures performance via assembly time as a proxy for speed, efficiency and cost (e.g. Darr *et al.*, 1995; Edmondson *et al.*, 2003; Epple *et al.*, 1991, etc.). During the experiment, teams had to reassemble faulty finished units to comply with specifications before a round counted as finished. Therefore, quality defects only register as time delays in our analysis. Taking longer to assemble the product is thus valued as lower production performance.

All teams were allowed five minutes to discuss their process before the start of the first round. They were also allowed three minutes between rounds to reexamine and adjust their approach. Note that we let all teams change their process between rounds since strictly enforcing the template in a labor-intensive process such as this can lead to detrimental results (BLINDED FOR REVIEW). For a visual description of our experimental design, see Figure 1.

Ten recipient teams of four participants each were assigned to every one of the treatments, resulting in a total of $2 \times 2 \times 2 = 8$ treatments. Table 1 provides an overview of our experimental design, which includes one US source template used four times (treatments 1–4) and one Chinese source template used four times (treatments 5–8). Due to the complex nature of performing team-based experimental research across multiple countries (Özer *et al.*, 2014), we collected 50 observations from 10 teams per treatment (10 teams *5 production rounds per team). This sample size is small; repeatedly observing teams reduces this concern, but insignificant effects in our analysis can result from insufficient statistical power.

4. Analysis and results

As mentioned, after instructions, we gave all teams five minutes to reflect on their task and strategize. How teams used this time was very distinct across countries. The US teams read

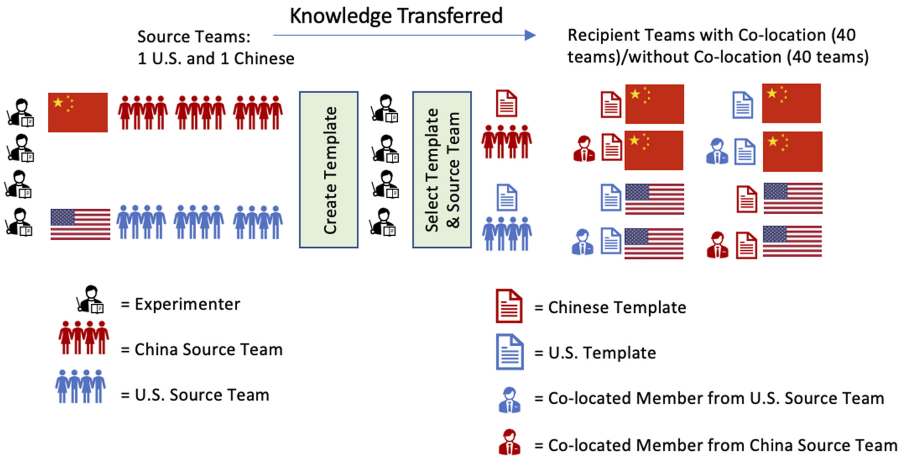


Figure 1.
Timeline and process of experiment

Source(s): Created by authors

the template and discussed what it meant, while the Chinese teams used most of their time questioning the experimenter. This tendency was exacerbated for co-located teams. The Chinese teams listened to and asked their co-located members many questions. The co-located US teams continued to focus primarily on the written template. These observations are consistent with the fundamental idea of our paper.

The teams were allowed several minutes between rounds to discuss their performance and make changes if desired. Again, the two cultures approached these between-round sessions differently. In the United States, the team members spent time conceptualizing potential changes to their production process. Conversely, the Chinese teams used their time discussing their roles/responsibilities and how they could better execute their template-mandated jobs. This observation could result from other cultural differences between the two countries, such as power distance (see section 5). Table 2 lists descriptive performance statistics for all eight experimental conditions across different periods.

These descriptive data yield several takeaways. First, the traditional learning curve pattern (i.e. completion time decreases at a decreasing rate; Yelle, 1979) is visible across all treatments. Similarly, as in Bavafa and Jonasson (2021), the standard deviation (variance) of task execution across teams generally decreases over iterations. Second, co-location did improve the performance of the Chinese teams and did not affect the US teams' performance. Co-location also reduced the standard deviation of average completion times for all teams except for China to US ones. Lastly, the US teams performed considerably better than the Chinese ones without co-location.

To analyze our data more formally, we take two different approaches. First, we aggregate our data across different periods, estimating the average performance across all five periods instead of performance by period. This approach allows us to reduce the complexity of our empirical estimation. Since our average completion times may not follow a normal distribution, we perform Skewness and Kurtosis tests, and they reveal that the distribution of average completion times exhibits both skewness ($p \leq 0.01$) and kurtosis ($p \leq 0.05$). Further, a Shapiro–Wilk test rejects normality ($p \leq 0.01$). We, therefore, used Wilcoxon rank-sum tests (see Table 3) to examine the difference in distributions between our treatments. Since treatments are balanced, pooling across treatments (e.g. co-located vs. non-co-located teams) will produce a balanced sample across the pooled factors. This strategy makes aggregate two-sample comparisons meaningful.

Condition		Iteration 1	2	3	4	5	Avg
United States to United States	Mean	11.05	8.12	6.71	6.08	4.91	7.37
	Std. Dev	1.00	1.98	1.68	0.87	0.53	0.83
United States to United States (co-located)	Mean	12.13	8.41	7.21	6.09	5.21	7.81
	Std. Dev	1.10	0.77	0.69	0.63	0.53	0.55
United States to China	Mean	16.56	11.25	8.53	7.20	6.07	9.94
	Std. Dev	2.64	1.91	2.16	2.48	1.28	1.58
United States to China (co-located)	Mean	11.78	9.09	8.02	6.56	6.06	8.30
	Std. Dev	1.18	0.40	1.15	1.40	1.39	0.75
China to China	Mean	18.13	10.36	8.95	6.53	7.11	10.22
	Std. Dev	3.51	1.65	2.14	0.69	3.57	1.58
China to China (co-located)	Mean	11.58	8.05	6.72	5.93	5.38	7.53
	Std. Dev	1.27	1.16	1.17	0.85	0.91	0.89
China to United States	Mean	13.41	8.70	6.99	5.91	5.74	8.15
	Std. Dev	1.76	0.91	0.99	0.63	0.78	0.68
China to United States (co-located)	Mean	12.60	8.96	7.29	6.19	5.75	8.16
	Std. Dev	1.55	1.23	1.09	0.87	0.88	1.03

Note(s): We measure time in minutes required to complete a product according to specifications. The average mean is the mean of means; the average standard deviation is the standard deviation of means
Source(s): Created by authors

Table 2. Time to complete product

Comparison	Test statistic	p-value	Conclusion
Average performance: cross-culture vs. within-culture	$z = -2.07$	$p \leq 0.05$	H1 supported
Average performance: co-located teams vs. non-co-located teams	$z = 2.78$	$p \leq 0.01$	H2A supported
Variance in performance: co-located teams vs. non-co-located teams	$f = 3.97$	$p \leq 0.01$	H2B supported
Average performance: Chinese recipient co-located vs. Chinese recipient non-co-located	$z = 4.22$	$p \leq 0.01$	H3A supported
Average performance: US recipient co-located vs. US recipient non-co-located	$z = -0.62$	$p = 0.55$	
Variance in performance: Chinese recipient co-located vs. Chinese recipient non-co-located	$f = 2.95$	$p \leq 0.05$	H3B supported
Variance in performance: US recipient co-located vs. US recipient non-co-located	$f = 1.05$	$p = 0.92$	

Source(s): Created by authors

Table 3. Hypothesis test summary

First, we examine whether the performance of teams where source and recipient teams originate from different cultures ($\mu = 8.63$) is different from those where source and recipient teams originate from the same culture ($\mu = 8.23$). A rank-sum test reveals significant differences between these two distributions ($z = -2.07$, $p \leq 0.05$), supporting Hypothesis 1.

To test Hypothesis 2A, we compare the performance of all co-located teams ($\mu = 7.94$) to that of all non-co-located teams ($\mu = 8.91$). A Wilcoxon rank-sum test here reveals that the two distributions are significantly different from each other ($z = 2.78$, $p \leq 0.01$), which supports Hypothesis 2A. To examine Hypothesis 2B, we perform a variance ratio test between co-located and non-co-located teams and report that the non-co-located teams have a higher performance variance than the co-located teams ($f = 3.97$, $p \leq 0.01$).

To examine Hypothesis 3A, we first compare the performance of Chinese recipient teams that are co-located ($\mu = 7.92$) to Chinese recipient teams that are not co-located ($\mu = 10.08$) to establish that co-location leads to a significant difference between these two distributions according to a rank-sum test ($z = 4.22, p \leq 0.01$). The same comparison for US recipient teams that are co-located ($\mu = 7.98$) and those that are not co-located ($\mu = 7.76$) reveals no difference between these two distributions ($z = -0.62$, $p = 0.55$). It appears that co-location loses its effectiveness entirely if the recipient team is within the United States but has a strong effect of 10.08–7.92 = 2.16 min reduction, or a (10.08–7.92)/10.08 = 21% decrease in the time to build the product if the recipient team is within China. Chinese recipient teams with co-location perform similarly to US recipient teams (with or without co-location). These results support Hypothesis 3A. To test Hypothesis 3B, we perform variance ratio tests on US recipient and China recipient teams by co-location. For US recipient teams, there is no difference in the performance variance for co-located and non-colocated teams ($f = 1.05, p = 0.92$). For Chinese recipient teams, co-located teams have significantly less variance in performance than their non-colocated counterparts ($f = 2.95, p \leq 0.05$). This observation confirms Hypothesis 3B. We summarize these tests in Table 3.

Our analysis so far supports our hypotheses. Aggregating performance across five time periods simplifies the analysis. It is adequate given our hypotheses, but this aggregation reduces our ability to study the impact of culture and co-location on the period-by-period dynamics implied by the learning curve. To increase the fidelity of our insights along these lines, we estimate a mixed effects regression model, with the unit of analysis being a team's by-period performance instead of a team's aggregate performance. Suppose we define the performance variable as T, time period by p, the team by the index i, the vector θ_i as a vector of dummy variables representing the cultural context (i.e. China to China, China to United States, United States to China, and United States to United States), and C_i as a dummy variable defining whether the team was co-located or not. In that case, we can specify the model as:

$$\ln(T_{i,p}) = a_i + b_i \ln(p) + \alpha_1\theta_i + \alpha_2\theta_i \times C_i + \beta_1\theta_i \times \ln(p) + \beta_2\theta_i \times C_i \times \ln(p) + \epsilon_p(C_i)$$

There are several essential elements of this model. We conceptualize the learning curve parameters a_i and b_i as random effects at the team level, with a joint normal distribution with mean zero and standard deviations σ_{constant} and σ_{lnp}, as well as the correlation coefficient ρ_{ab}. This specification allows each team to follow a different learning curve. Teams that start worse can also improve better or worse over time. The treatment effects θ_i and C_i are fixed shifts in the mean of this learning curve across teams. Finally, we conceptualize the error as heteroskedastic per Hypothesis 2B. The standard deviation of errors depends on whether the team is co-located ($\sigma_{\text{co-location}}$) or not ($\sigma_{\text{no co o-location}}$). We summarize the resulting estimation in Table 4.

We highlight a few insights from this analysis. The constant (i.e. a_i, the initial time to assemble the product) is slightly affected by a cross-cultural transfer since the coefficient on China-to-United States is significant ($b = 0.16, p \leq 0.05$), but the much more substantial effect here is related to the recipient teams being in China ($b = 0.41$ and 0.44, $p \leq 0.01$). The interaction effects of the national culture context and co-location essentially counter the main effects of context, indicating that in terms of initial time to assemble, co-location largely overcomes any cultural and cross-cultural issues in knowledge transfer. For example, the parameter capturing the initial time to make the product in a China-to-China context is 2.81 = 2.40+0.41 [1], which is higher than the same parameter in the US-to-US context (=2.40). However, once co-location is applied, the initial time to assemble the product in a China-to-China context is 2.39 = 2.40 + 0.41–0.42, which is again similar to the US-to-US context (=2.40).

Variable	Coefficient	Std. Error
China to China	0.41^{**}	(0.07)
China to US	0.16^{*}	(0.07)
US to China	0.44^{**}	(0.07)
US to US × co-location	0.10	(0.06)
China to China × co-location	-0.42^{**}	(0.09)
China to US × co-location	−0.13	(0.09)
US to China × co-location	-0.51^{**}	(0.09)
ln(p)	-0.48^{**}	(0.05)
ln(p) × China to China	-0.16^{*}	(0.06)
ln(p) × China to US	−0.07	(0.06)
ln(p) × US to China	-0.16^{**}	(0.06)
ln(p) × US to US × co-location	−0.03	(0.05)
ln(p) × China to China × co-location	0.24^{**}	(0.08)
ln(p) × China to US × co-location	0.08	(0.08)
ln(p) × US to China × co-location	0.20^{**}	(0.08)
Constant	2.40^{**}	(0.05)
σ_{lnp}	0.07^{**}	(0.01)
$\sigma_{constant}$	0.08^{**}	(0.02)
ρ_{ab}	−0.02	(0.35)
$\sigma_{no\_co\text{-}location}$	0.16^{**}	(0.01)
$\sigma_{co\text{-}location}$	0.09^{**}	(0.01)
N	400 [80]	
LL	203.69	
χ^2	$1,669.97^{**}$	

Note(s): $^{**}p \leq 0.01$; $^{*}p \leq 0.05$; $^{\dagger}p \leq 0.10$. *N* refers to the number of observations, with the number of teams in brackets
Source(s): Created by authors

Table 4. Estimation results from random effects learning curve model

As the interaction effects of ln(p) and context make clear, those contexts that see slower initial assembly time also see more substantial learning – teams are catching up. For example, the learning parameter in the US-to-US context is −0.48, with an initial time to complete parameter of 2.40. The learning parameter in a China-to-China context is −0.64 = −0.48–0.16, indicating much steeper learning. This observation is not surprising – teams that are further from efficiency initially can learn more. The three-way interactions between ln(p) and context also make clear that this more substantial learning disappears under co-location since co-location alleviates the context effects on initial assembly time. For example, in the China-to-China context under co-location, the initial assembly time parameter is 2.39 (see above) with a learning parameter of −0.40 = −0.48–0.16 + 0.24, which is again comparable to the US-to-US context without co-location (initial time = 2.40, learning parameter −0.48). These effects are consistent with our hypotheses. Co-location mitigates the challenges associated with knowledge transfer in a cross-cultural context, particularly if recipients are in a collectivist culture.

The random effects parameters $\sigma_{constant}$ and σ_{lnp} are significant, indicating heterogeneity across teams in their learning curve. Note that the correlation parameter ρ_{ab} is not significant, meaning that, initially, slower teams do not necessarily learn faster beyond the treatment effects measured by the fixed effects in our study. Further, the error standard deviation for non-co-located teams is much higher (=0.16) than the standard deviation for co-located teams (=0.09), indicating that co-located teams are much more consistent in their performance around the learning curve than non-co-located ones. Constraining these parameters to be equal and re-estimating the model significantly reduces fit. A likelihood ratio test between the unconstrained and constrained models confirms that these standard deviations are indeed different ($\chi^2(1) = 48.25, p \leq 0.01$). This observation is aligned with Hypothesis 2B.

We expanded this model to estimate eight different error standard deviations for all experimental conditions, which does significantly increase model fit ($\chi^2(6) = 28.26, p \leq 0.01$). Results show that error variances are lower in all co-location treatments. This effect is particularly pronounced for Chinese recipient teams. For example, the error standard deviation for China-to-US teams is 0.11 without co-location and 0.08 with co-location. The error standard deviation for US-to-China teams is 0.21 without co-location and 0.09 with co-location. This observation is consistent with Hypothesis 3B.

In summary, the data support our hypotheses. While barriers to knowledge transfer exist in both cross-cultural contexts (i.e. US to China or China to US), the much more substantial effect is in knowledge transfer to the collectivist culture (either from a US or a Chinese source). Co-location appears as an effective approach to facilitate knowledge transfer, particularly if recipient teams are in a collectivist culture.

5. Discussion, managerial implications, limitations and future research

One goal of our research was to assess the impact of national culture on knowledge sharing in a manufacturing context. Based on past literature, we were confident that culture would matter (Flynn and Saladin, 2006; Naor *et al.*, 2010; Özer *et al.*, 2014; etc.). But with the increase of globalization and cultural exchange in recent years (Ghemawat and Altman, 2019), replicating the test of this hypothesis is continuously essential. Culture impacts how knowledge is shared between teams in our experiment. Next, while the existing literature had painted national culture as a performance barrier, little was known about solutions to overcome this barrier. Therefore, another goal was to assess the efficacy of an approach often used by firms transferring knowledge within/between their business units in various countries/cultures: co-location. We demonstrate that co-location can be beneficial to enhance knowledge transfer with collectivist recipients but may be less effective for individualist recipients.

While co-location has benefits (fosters increased levels of collaboration and knowledge sharing–Dyer and Nobeoka, 2000; Peitrangelo, 1993; increases absorptive capacity and reduces causal ambiguity – Lawson and Potter, 2012), it also has drawbacks (cost, time consumption, Kotha and Srikanth, 2013; may lead to reduced performance, Kahn and McDonough, 1997). While past research has offered propositions or case study examples of the pros and cons of co-location, little empirical research empirically has studied the impact of co-location impact on team-based manufacturing performance. To contribute empirical research to this critical area, we created and executed a team-based experiment in an individualist country (United States) and a collectivist country (China) to isolate the impact of national culture and co-location. We chose these two countries because they are at the center of global production today (Chen *et al.*, 2015; Cohen *et al.*, 2016). They are also on the opposite ends of many cultural dimensions, including *individualism/collectivism* (Hofstede, 1980, 2010; Özer *et al.*, 2014).

Past research (e.g. Kedia and Bhagat, 1988; Bhagat *et al.*, 2002; Özer *et al.*, 2014) has shown that these cultures share and process knowledge differently, which in a production setting can lead to a slower ramp-up, steeper learning curve, and increased variance between teams. That is not to say that the "cross-culture" transfer teams cannot catch up over time, but there is a lag leading to increased costs or a loss of revenue. Within our experiment, we demonstrated that culture does matter, as the teams transferring knowledge within their same country/culture assembled the product faster (Hypothesis 1) than teams transferring knowledge between a different country/culture. But one key takeaway is that it is possibly less the cross-culture aspect of a knowledge transfer that matters, but the destination.

Transferring knowledge to a collectivist culture was far more challenging than doing so in an individualist culture. Co-location was necessary for a collectivist culture, whereas individualist cultures could rely more readily on a detailed written template. The best approach to manage the transfer depends on the recipient team's culture.

We chose speed and variance as our dependent variables. This choice is a standard in the learning curve literature. Speed is a good proxy for costs, particularly if we control the error rate. Further, when conceptualizing a firm moving their production process to a new geographic area, the speed with which they can assemble the product, or the lack of progress in ramping the speed of the process, is a crucial barrier to the firm realizing the advantages of the move. We demonstrated that co-location significantly reduces assembly time and the reduction in the assembly time variance between teams (H2A and H2B). We also show that co-location has a more significant impact (more considerable assembly time reduction and reduction in variance) if used in a collectivist culture (China) than it does if used in an individualist one (United States) (H3A and H3B). Consistent with Bhagat *et al.*'s (2002) conceptual study, we argued that collectivist cultures respond favorably to tacit knowledge, while individualist cultures respond favorably to explicit knowledge. In our experiment, we use a detailed template that leverages some codified knowledge regarding how labor should be divided among the four team members and how materials should flow. The teams exposed to co-location receive this template and real-time guidance from a team member who helped create the template, giving access to more tacit knowledge from the source team. Our empirical results confirm our hypotheses.

While the context of our study is within-firm knowledge transfer, much knowledge transfer in supply chains happens between firms. Manufacturers may need to move parts of a process to their suppliers, and buyers could insist that their suppliers implement procedures to comply with market requirements or regulations. Our research would suggest that co-location is particularly important if these supply chain considerations involve recipients in collectivist societies; at the same time, co-location may also be more challenging to implement if source and recipient sites do not belong to the same organization. Suppliers may not be interested in being transparent to a co-located employee from a buyer and may not trust the co-located team members' intentions.

5.1 Managerial implications

Our study demonstrates that when moving production process knowledge between two locations with distinct national cultures, the approach used to transfer knowledge matters. We show that one such approach, *co-location*, can minimize the adverse effects of cultural diversity, at least for some cultures (e.g. collectivist cultures like China). Hence, there is no "one size fits all" method. Firms must craft a plan unique to the needs of the recipient cultures involved in the move. Otherwise, the results will likely postpone the start-up at the recipient facility, which would not only delay the benefits of the move (e.g. cost savings, increased revenue, etc.) but may also place current and future business at risk while damaging the reputation of the firm.

Culture is thus not a barrier to knowledge transfer *per se* but a moderator on the effectiveness of different modes of knowledge transfer. With production moving at an increasing rate from China to other Southeast Asian countries such as Vietnam – which is also more collectivist than individualistic – our research would suggest that co-location is necessary for the production process moves within that context. Conversely, suppose a firm is planning a production process move to individualist countries like the United States or Australia. In that case, co-location may not be as effective as developing a proven template that has both explicit ("know what") information as well as externalized and codified tacit ("know-how") knowledge embedded within.

It is worth mentioning that over the last 20–25 years, as firms in the western hemisphere have moved production to China and other "low-cost" countries, these recipient countries have become more accustomed to hosting partners from source countries like the United States and those in Western Europe. Therefore, countries like China, Vietnam and India may be more adept than the US and Western Europe at receiving knowledge and utilizing it to ramp-up quickly following a production process move. It is also important to note that we can observe national culture on multiple levels (Global, National, Organizational, Group/Team and Individual), nested within one another (Erez and Gati, 2004). We chose to study culture at the team level, understanding that it would reflect national culture dynamics at the individual level and that what we observed at the team level would likely impact the national culture dynamics at the organizational level.

Co-location is likely costlier than creating a template, but these costs may be necessary for effective knowledge transfer into a collectivist society. This is not to say that personnel located at the source of the production move are not of value to the individualist recipient. Instead, source members may not need to be deeply embedded with the individualist recipient location to transfer production process know-how effectively. Firms should consider these differences when developing strategies to transfer knowledge between different cultures.

5.2 Limitations

While this study advances our understanding of the relationship between national culture, knowledge sharing, co-location and manufacturing performance, there are limitations. Our study does not emphasize external validity as with all data captured in a lab setting. However, we grounded our theory and research design by talking with multiple firms that have undergone production moves between cultures while using co-location as a critical part of their knowledge management strategy. We based the four-person team structure used in the experiment on a typical manual assembly production environment, like those in China-based contract manufacturers. However, real-world assembly settings are more complex and technology-intensive.

Second, as we mentioned in section 3, due to the complex nature of performing team-based experimental research across multiple countries (Özer *et al.*, 2014), we collected 50 observations per treatment (10 teams $\times$ 5 production rounds per team). The number of teams observed per treatment limits our statistical power, and insignificant effects in our analysis may be due to that.

Last, we focus our study on one cultural dimension, individualism/collectivism, because many scholars (Ardichvili *et al.*, 2006; Bhagat *et al.*, 2002; Erez and Earley, 1993; Hofstede, 1980; Triandis, 1989) argue that it is the dimension of culture that is the most differentiating way in which various global societies analyze social behavior and process information. However, we recognize that other factors may contribute to the effects we find in our study. Future research could build on this study and explore other possible factors.

5.3 Future research

While this study explores how to transfer production knowledge across different cultures effectively, several research topics could extend our analysis. First, while our present study primarily focused on the recipient's national culture regarding how knowledge is transferred, it could be interesting to explore further the source culture's impact on performance. Second, revisiting the co-location concept in a post-coronavirus disease 2019 (Covid-19) manufacturing environment would be interesting. With the advent of even better technology to help facilitate work during the pandemic, co-location may look different in the future, which may change how firms utilize it. It is possible that future augmented or virtual reality applications will make it unnecessary to fly employees across the world and embed them at recipient sites for extended periods.

Third, exploring how to effectively retain or sustain knowledge after a successful transfer would be interesting. The literature examines the concept of *organizational forgetting* (de Holan and Phillips, 2004). The authors of that study stress the importance of organizations being able to forget the knowledge that is no longer useful and having systems in place to retain valuable knowledge. The de Holan and Phillips (2004) study focuses on service industry (hospitality) knowledge. Exploring organizational forgetting from a manufacturing standpoint could be beneficial, using primary data instead of archived secondary data (Thompson, 2007).

Last, while this paper situates itself in a production or manufacturing environment, these findings may also apply to service industry firms looking to *replicate* their processes rather than move them. Leading firms like Target (Dahlhoff, 2015, Harvard Business Review (HBR)) and Disney (Gumbel, 2012, Time) have learned through expansion failure that expanding into new and dissimilar cultures is fraught with challenges. Future research could explore ways service firms can create strategies to minimize their risk when transferring knowledge, whether by internal expansion or franchising.

Note

1. These are on a logarithmic scale, due to learning curve estimation being non-linear in nature.

References

Ardichvili, A., Maurer, M., Li, W., Wentling, T. and Stuedemann, R. (2006), "Cultural influences on knowledge sharing through online communities of practice", *Journal of Knowledge Management*, Vol. 10 No. 1, pp. 94-107.

Ariely, D., Kamenica, E. and Prelec, D. (2008), "Man's search for meaning: the case of Legos", *Journal of Economic Behavior and Organization*, Vol. 67 No. 3, pp. 671-677.

Bavafa, H. and Jonasson, J.O. (2021), *The Variance Learning Curve*, Management Science, forthcoming.

Bergstrom, R.P. (1991), "The magic in small numbers (McDonnell Douglas project team)", *Production*, Vol. 103, pp. 70-72.

Berry, J., Phinney, J., Sam, D. and Vedder, P. (2006), "Immigrant youth: acculturation, identity and adaptation", *Applied Psychology: An International Review*, Vol. 55 No. 3, pp. 303-332.

Bhagat, R.S., Kedia, B.L., Harveston, P.D. and Triandis, H.C. (2002), "Cultural variations in the cross-border transfer of organizational knowledge: an integrative framework", *Academy of Management Review*, Vol. 27 No. 2, pp. 204-221.

Bockstedt, J., Druehl, C. and Mishra, A. (2015), "Problem-solving effort and success in innovation contests: the role of national wealth and national culture", *Journal of Operations Management*, Vol. 36, pp. 187-200.

Bolton, G.E., Ockenfels, A. and Thonemann, U.W. (2012), "Managers and students as newsvendors", *Management Science*, Vol. 58 No. 12, pp. 2225-2233.

Buchan, N. and Croson, R. (2004), "The boundaries of trust: own and others' actions in the US and China", *Journal of Economic Behavior and Organization*, Vol. 55 No. 4, pp. 485-504.

Chen, Y., Cohen, M., Cui, S., Dong, M., Liu, S. and Simchi-Levi, D. (2015), "Global operations sourcing strategy: a Chinese perspective", Working Paper, SSRN, available at: https://ssrn.com/abstract=2623770

Cohen, M., Cui, S., Ricardo, E., Huchzermeier, A., Kouvelis, P., Lee, H., Matsuo, H., Steuber, M. and Tsay, A. (2016), "OM Forum - Benchmarking Global Production Sourcing Decisions: where and Why Firms Offshore and Reshore", Working Paper, Stanford University Graduate School of Business Research, Paper No. 16-28.

Cornelius, P.B., Gokpinar, B. and Sting, F.J. (2021), "Sparking manufacturing innovation: how temporary interplant assignments increase employee idea values", *Management Science*, Vol. 67 No. 4, pp. 2231-2250.

Croson, R. (2007), *The Use of Students as Participants in Experimental Research*, University of Texas at Dallas.

Croson, R. and Donohue, K. (2006), "Behavioral causes of the bullwhip effect and the observed value of inventory information", *Management Science*, Vol. 52 No. 3, pp. 323-336.

Dahlhoff, D. (2015), "Why target's Canadian expansion failed", *Harvard Business Review*, January 20, 2015, available at: http://hbr.org/2015/01/why-targets-Canadian-expansion-failed.html (accessed 2 February 2020).

Darr, E.D., Argote, L. and Epple, D. (1995), "The acquisition, transfer, and depreciation of knowledge in service organizations: productivity in franchises", *Management Science*, Vol. 41 No. 11, pp. 1750-1762.

Dyer, J.H. and Nobeoka, K. (2000), "Creating and managing a high-performance knowledge-sharing network: the Toyota case", *Strategic Management Journal*, Vol. 21 No. 3, pp. 345-367.

Edmondson, A.C., Winslow, A.B., Bohmer, R.M. and Pisano, G.P. (2003), "Learning how and learning what: effects of tacit and codified knowledge on performance improvement following technology adoption", *Decision Sciences*, Vol. 34 No. 2, pp. 197-224.

Epple, D., Argote, L. and Devadas, R. (1991), "Organizational learning curves: a method for investigating intra-plant transfer of knowledge acquired through learning by doing", *Organization Science*, Vol. 2 No. 1, pp. 58-70.

Erez, M. and Earley, P.C. (1993), *Culture, Self-Identity, and Work*, Oxford University Press, New York, NY, p. 280.

Erez, M. and Gati, E. (2004), "A dynamic, multi-level model of culture: from the micro level of the individual to the macro level of a global culture", *Applied Psychology*, Vol. 53 No. 4, pp. 583-598.

Fatehi, K., Priestley, J.L. and Taasoobshirazi, G. (2020), "The expanded view of individualism and collectivism: one, two, or four dimensions?", *International Journal of Cross-Cultural Management*, Vol. 20 No. 1, pp. 7-24.

Flynn, B.B. and Saladin, B. (2006), "Relevance of Baldrige constructs in an international context: a study of national culture", *Journal of Operations Management*, Vol. 24 No. 5, pp. 583-603.

Gaimon, C., Hora, M. and Ramachandran, K. (2017), "Process capabilities and leveraging advances in science and technology", in *Routledge's POM Companion Book*, Taylor & Francis Group, New York, NY.

Ghemewat, P. and Altman, S.A. (2019), "The state of globalization in 2019, and what it means for strategists", *Harvard Business Review*, February 6, 2019.

Grant, R.M. (1996), "Toward a knowledge-based theory of the firm", *Strategic Management Journal*, Vol. 17 No. S2, pp. 109-122.

Gray, J.V. and Massimino, B. (2014), "The effect of language differences and national culture on operational process compliance", *Production and Operations Management*, Vol. 23 No. 6, pp. 1042-1056.

Gray, J.V., Siemsen, E. and Vasudeva, G. (2015), "Co-location still matters: conformance quality and the interdependence of R&D and manufacturing in the pharmaceutical industry", *Management Science*, Vol. 61 No. 11, pp. 2760-2781.

Gumbel, P. (2012), "The not so magic kingdom: why Disneyland Paris has yet to pay off for Disney", *Time*, January 3 2012, available at: http://content.time.com/time/subscriber/article/0,33009,2122686-2,00.html (accessed 2 February 2020).

Gupta, M. and Gupta, S. (2019), "Influence of national cultures on operations management and supply chain management practices—a research agenda", *Production and Operations Management*, Vol. 28 No. 11, pp. 2681-2698.

Hennart, J. (2009), “Theories of the multinational enterprise”, in Rugman, A. (Ed.), *The Oxford Handbook of International Business*, Oxford University Press, Oxford, pp. 125-145.

Ho, T.H. and Weigelt, K. (2005), “Trust building among strangers”, *Management Science*, Vol. 51 No. 4, pp. 519-530.

Hofstede, G. (1980), “Culture and organizations”, *International Studies of Management and Organization*, Vol. 10 No. 4, pp. 15-41.

Hofstede, G., Minkov, M. and Hofstede, G.J. (2010), *Cultures and Organizations: Software of the Mind*, 3rd ed., McGraw-Hill, New York, NY.

Holan, P.M.D. and Phillips, N. (2004), “Remembrance of things past? The dynamics of organizational forgetting”, *Management Science*, Vol. 50 No. 11, pp. 1603-1613.

House, R., Javidan, M. and Dorfman, P. (2001), “Project GLOBE: an introduction”, *Applied Psychology*, Vol. 50 No. 4, pp. 489-505.

Kahn, K.B. and McDonough, E.F. (1997), “An empirical study of the relationships among co-location, integration, performance, and satisfaction”, *Journal of Product Innovation Management*, Vol. 14 No. 3, pp. 161-178.

Kedia, B.L. and Bhagat, R.S. (1988), “Cultural constraints on transfer of technology across nations: implications for research in international and comparative management”, *Academy of Management Review*, Vol. 13 No. 4, pp. 559-571.

Kent, P. and Siemsen, E. (2018), “Production process moves: template use and the need to adapt”, *Production and Operations Management*, Vol. 27 No. 3, pp. 480-495.

Kogut, B. and Zander, U. (1992), “Knowledge of the firm, combinative capabilities, and the replication of technology”, *Organization Science*, Vol. 3 No. 3, pp. 383-397.

Kotha, S. and Srikanth, K. (2013), “Managing a global partnership model: lessons from the Boeing 787 ‘Dreamliner’ program”, *Global Strategy Journal*, Vol. 3, pp. 41-66.

Kotlarsky, J., Scarbrough, H. and Oshri, I. (2014), “Coordinating expertise across knowledge boundaries in offshore-outsourcing projects: the role of codification”, *MIS Quarterly*, Vol. 38 No. 2, pp. 607-627.

Kuwabara, K., Willer, R., Macy, M., Mashima, R., Terai, S. and Yamagishi, T. (2007), “Culture, identity, and structure in social exchange: a web-based trust experiment in the United States and Japan”, *Social Psychology Quarterly*, Vol. 70, pp. 461-479.

Lawson, B. and Potter, A. (2012), “Determinants of knowledge transfer in inter-firm new product development projects”, *International Journal of Operations and Production Management*, Vol. 32 No. 10, pp. 1228-1247.

Leoni, L., Ardolino, M., El Baz, J., Gueli, G. and Bacchetti, A. (2022), “The mediating role of knowledge management processes in the effective use of artificial intelligence in manufacturing firms”, *International Journal of Operations and Production Management*, Vol. 42 No. 13, pp. 411-437.

Letmathe, P. and Rößler, M. (2019), “Tacit knowledge transfer and spillover learning in ramp-ups”, *International Journal of Operations and Production Management*, Vol. 39 Nos 9/10, pp. 1099-1121.

Li, Y., Tarafdar, M. and Rao, S.S. (2012), “Collaborative knowledge management practices: theoretical development and empirical analysis”, *International Journal of Operations and Production Management*, Vol. 32 No. 4, pp. 398-422.

McDonald, C.J. (1998), “The evolution of Intel’s Copy EXACTLY! technology transfer method”, *Intel Technology Journal*, Vol. 4 No. 1, pp. 1-6.

Moreau, C.P. and Engeset, M.G. (2016), “The downstream consequences of problem-solving mindsets: how playing with LEGO influences creativity”, *Journal of Marketing Research*, Vol. 53 No. 1, pp. 18-30.

Naor, M., Linderman, K. and Schroeder, R. (2010), “The globalization and operations of Eastern and Western Countries: unpacking the relationship between national and organizational culture and its impact on manufacturing performance”, *Journal of Operations Management*, Vol. 28, pp. 194-205.

Nelson, R.R. and Winter, S.G. (1982), "The Schumpeterian tradeoff revisited", *The American Economic Review*, Vol. 72 No. 1, pp. 114-132.

Özer, Ö., Zheng, Y. and Ren, Y. (2014), "Trust, trustworthiness, and information sharing in supply chains bridging China and the United States", *Management Science*, Vol. 60 No. 10, pp. 2435-2460.

Özkan-Seely, G.F., Gaimon, C. and Kavadias, S. (2015), "Dynamic knowledge transfer and knowledge development for product and process design teams", *Manufacturing and Service Operations Management*, Vol. 17 No. 2, pp. 177-190.

Peitrangelo, J. Mustang (1993), "Engineers slash cycle time", *Ward's Auto World*, Vol. 29, p. 71.

Roth, A., Prasnikar, V., Okuno-Fujiwara, M. and Zamir, S. (1991), "Bargaining and market behavior in jerusalem, ljubljana, pittsburgh, and tokyo: an experimental study", *American Economic Review*, Vol. 81 No. 5, pp. 1068-1095.

Siemsen, E.S., Balasubramanian, S. and Roth, A.V. (2007), "Incentives that induce task-related effort, helping, and knowledge sharing in workgroups", *Management Science*, Vol. 53 No. 10, pp. 1533-1550.

Sirkin, H.L., Zinser, M. and Rose, J. (2014), *The Shifting Economics of Global Manufacturing*, Boston Consulting Group, available at: https://www.bcg.com/publications/2014/lean-manufacturing-globalization-shifting-economics-global-manufacturing.aspx (accessed 19 August 2019).

Spreitzer, G.M., Garrett, L.E. and Bacevice, P. (2015), "Should your company embrace coworking?", *MIT Sloan Management Review*, Vol. 57 No. 1, pp. 27-29.

Staats, B.R., Milkman, K.L. and Fox, C.R. (2012), "The team scaling fallacy: underestimating the declining efficiency of larger teams", *Organizational Behavior and Human Decision Processes*, Vol. 118 No. 2, pp. 132-142.

Szulanski, G. (1996), "Exploring internal stickiness: impediments to the transfer of best practice within the firm", *Strategic Management Journal*, Vol. 17 No. S2, pp. 27-43.

Thompson, P. (2007), "How much did the Liberty shipbuilders forget?", *Management Science*, Vol. 53 No. 6, pp. 908-918.

Triandis, H.C. (1989), "The self and social behavior in differing cultural contexts", *Psychological Review*, Vol. 96 No. 3, pp. 506-520.

Triandis, H.C. (2001), "Individualism-collectivism and personality", *Journal of Personality*, Vol. 69 No. 6, pp. 907-924.

Tucker, A. (2007), "An empirical study of system improvement by frontline employees in hospital units", *Manufacturing and Service Operations Management*, Vol. 9 No. 4, pp. 492-505.

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*, Vol. 44 Nos 11-part-2, pp. S1-S18.

Winter, S.G. and Szulanski, G. (2001), "Replication as strategy", *Organization Science*, Vol. 12 No. 6, pp. 730-743.

Wuttke, D., Upadhyay, A., Siemsen, E. and Wuttke-Linnemann, A. (2022), *Seeing the Bigger Picture? Ramping up Production with the Use of Augmented Reality*, Manufacturing & Service Operations Management, forthcoming.

Yelle, L.E. (1979), "The learning curve: historical review and comprehensive survey", *Decision Sciences*, Vol. 10 No. 2, pp. 302-328.

Further reading

Bernstein and Ethan, S. (2012), "The transparency paradox", *Administrative Science Quarterly*, Vol. 57 No. 2, pp. 181-216.

DeLong, D.W. and Fahey, L. (2000), "Diagnosing cultural barriers to knowledge management", *Academy of Management Executive*, Vol. 14 No. 4, pp. 113-127.

Garud, R. and Nayyar, P.R. (1994), "Transformative capacity: continual structuring by intertemporal technology transfer", *Strategic Management Journal*, Vol. 15 No. 5, pp. 365-385.

Javidan, M., Stahl, G.K., Brodbeck, F. and Wilderom, C.P. (2005), "Cross-border transfer of knowledge: cultural lessons from Project GLOBE", *The Academy of Management Executive*, Vol. 19 No. 2, pp. 59-76.

Kent, P. (2018), *Production Process Moves and the Effective Management of Process Knowledge*, Retrieved from the *University of Minnesota Digital Conservancy*, available at: https://hdl.handle.net/11299/198385

Michailova, S. and Hutchings, K. (2006), "National cultural influences on knowledge sharing: a comparison of China and Russia", *Journal of Management Studies*, Vol. 43 No. 3, pp. 383-405.

Noorderhaven, N. and Harzing, A.W. (2009), "Knowledge-sharing and social interaction within MNEs", *Journal of International Business Studies*, Vol. 40 No. 5, pp. 719-741.

Power, D., Schoenherr, T. and Samson, D. (2010), "The cultural characteristic of individualism/collectivism: a comparative study of implications for investment in operations between emerging Asian and industrialized Western countries", *Journal of Operations Management*, Vol. 28 No. 3, pp. 206-222.

Slack, N. and Lewis, M. (2002), *Operations Strategy*, Pearson Education, London.

Timiraos, N., "General electric says to move 500 U.S. Jobs overseas blaming ex-IM bank closure", *WSJ, com September 15, 2015*, available at: https://www.wsj.com/articles/general-electric-says-to-move-500-u-s-jobs-overseas-due-to-ex-im-bank-closure-1442322192 (accessed 20 January 2018).

Trompenaars, F. (1994), *Riding the Waves of Culture*, Nicholas Brealey, London.

Vlasic, B. (2017), *Ford Chooses China, Not Mexico, to Build its New Focus*, NY Times, *com June 20, 2*017, available at: https://www.nytimes.com/2017/06/20/business/ford-focus-china-production.html (accessed 20 January 2018).

Wayland, M. (2020), "Toyota shifts Tacoma pickup production from Texas to Mexico; continues $13 billion US investment", *CNBC.com January*, Vol. 17, p. 2020, available at: https://www.cnbc.com/2020/01/17/toyota-shifting-tacoma-production-to-mexico-as-it-invests-13b-us.html (accessed 24 January 2020).

(The Appendix follows overleaf)

All Appendices: Created by Authors
Appendix A
Experiment Instructions

Production Process Moves Experiment (US instructions)
"Sunset Speeder" (four-person team)

Thank you for participating in our experiments:

(1) You will build the Lego Sunset Speeder device five times, working together as a team.

(2) Cost (completion time) and quality (# of errors) are very important and will be tracked. Your objective is to build this device as quickly as possible with zero defects. Completion time will serve as a proxy for cost, so each round will be timed from start to finish. "Finish" will be when your team has submitted the device for final inspection and there are no defects/errors.

(3) When building the device, your team may organize your operation however you like. To help facilitate this, you will be given 5 min before you begin the first round to organize.

(4) In addition to your base pay, you can earn additional compensation each round if you are able to complete the device, **without defects,** in the following times:

- 8 min = $1
- 7–8 min = $2
- 6–7 min = $3
- 5–6 min = $4
- 4–5 min = $5
- 4 min = $6

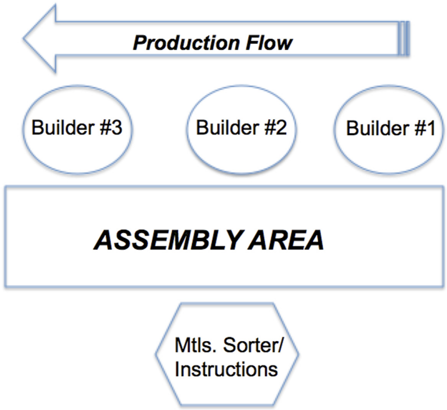
(5) Each round ends when the team has fully assembled the device. Between rounds, your team will be given 3 min to strategize ways to improve your operation. If there are changes you want to make to the way you are organized, feel free to do so between rounds.

(6) When the 3-min strategy session has been completed between rounds, each team will be notified and a new bag of device components will be placed on the table signifying the start of the next round. This will continue until the fifth round is completed.

Appendix B
Experiment Templates – United States and China versions in both English and Chinese

How to Build a Lego Car – US template in English

Team members should sit in the following fashion while making this device:



Team Member Assignments

Position: Builder #1

(1) Responsible for steps 1–16 in Lego instructions.

Position: Builder #2

(1) Responsible for steps 17–32 in Lego instructions, except for the three subassemblies in steps 20, 24 and 32.

(2) Will coordinate with Builder #3 to affix the subassemblies to the device at the appropriate time.

Position: Builder #3

(1) Responsible for steps 20, 24 and 32, which are the subassemblies.

(2) Will coordinate work with Builder #2 to affix the subassemblies to the device at the appropriate time.

(3) The goal is to have the subassemblies completed by the time builder #2 begins building in step 17, therefore Builder #3 should start building subassemblies at the same time as Builder #1.

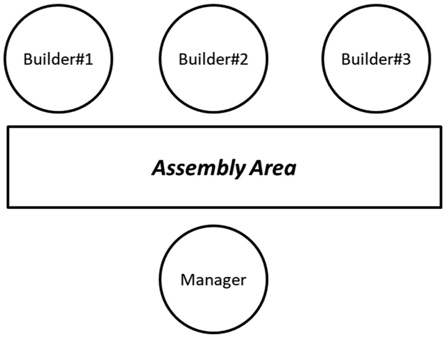
Position: Material Sorter and Manager of Instructions

(1) Responsible to manage Lego instructions, working alongside each of the builders to ensure the device is built accurately.

(2) Responsible for sorting materials, helping each builder identify the correct parts to use to build the device. Need to avoid using the defective/wrong materials that can lead to finish product errors.

How to Build a Lego Car – China template

Team members should sit in the following fashion while making this device:



Team Member Assignments:

Builder#1: Responsible for building body frame

Builder#2: Responsible for building parts and final assembly

Builder#3: Responsible for building parts

Manager: Responsible for sorting materials for Builder #1, helping each builder identify the correct parts to use to build the device.

Building Process:

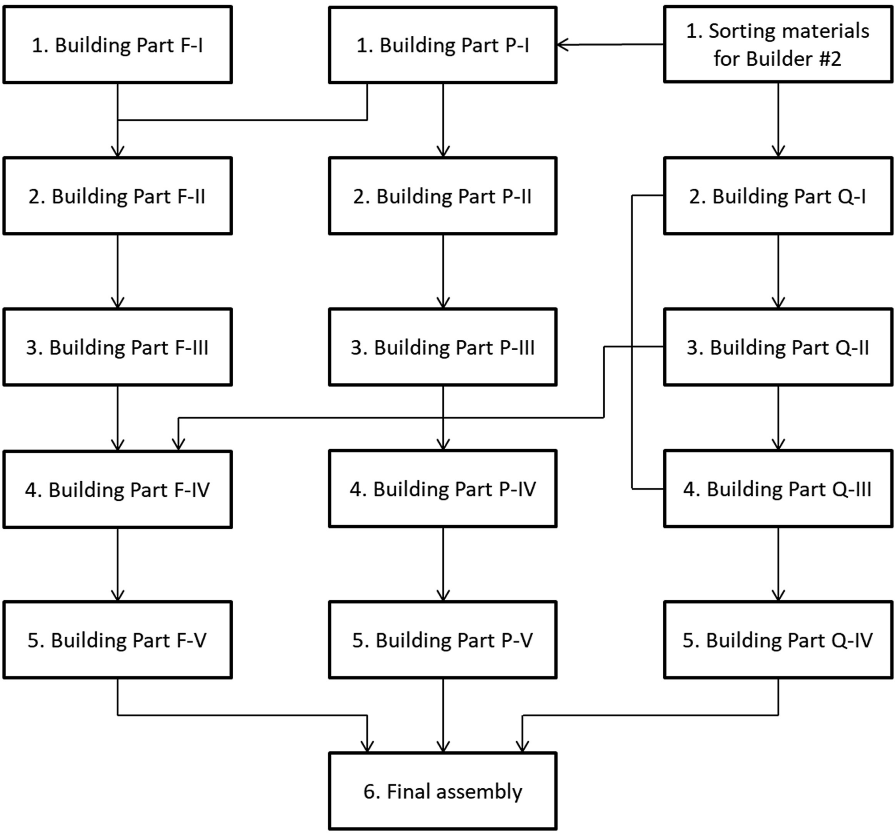


Table A1. BOM (bill of material)

Builder #1		Builder #2		Builder #3	
Part F-I	4211860X2	Part P-I	303426X1	Part Q-I	4211395X1
	4211002X1		346026X1		4118782X2
	4210633X2		362201X1		4211001X1
	4113993X1		4211386X1		243126X1
	614124X6		303926X1		306924X1
	4211001X2		306924X2		4251969X2
	4160228X2				6035764X2
	4210633X4				
Part F-II	F-I	Part P-II	4121741X1	Part Q-II	4211001X1
	P-I		4158355X2		302301X1
	4616279X4		4121742X2		306924X1
	4118787X2		4218749X2		4125278X2
			4251969X2		243126X1
			4504371X2		4210633X2
					4222960X2
					3005741X2
Part F-III	F-II	Part P-III X2	4158355X1	Part Q-III	4140593X1
	302301X2		6019987X1		4542590X1
	4616245X1		4206482X1		4153044X1
	4211353X2		6052989X1		
	4211395X2				
	4118790X1				
	302226X1				
	4504382X2				
Part F-IV	F-III	Part P-IV X2	242026X1	Part Q-IV X4	4541455X1
	Q-I		243101X1		4211807X1
	Q-II		6034044X1		6044729X1
	Q-III		6055069X1		
Part F-V	F-IV	Part P-V	302026X1		
	4211056X2		302226X1		
	302301X1		6047276X2		
	4118790X2				

Corresponding author
Pettis Kent can be contacted at: pkent@luc.edu