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CAPABILITIES REQUIRED TO TACKLE BARRIERS TO REMANUFACTURING

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Abstract: The transition towards a circular economy proposes to deliver sustainable, lower carbon opportunities to society, governments and companies. This paper focuses on finding barriers encountered during remanufacturing activities and interpreting the barriers by using a framework for dynamic capabilities. Dynamic capabilities enable companies to adjust to changes in their business activities. In the literature, remanufacturing is described as a process to restore used products to a 'as good as new' condition, through a series of steps. This paper discusses the analysis of in-depth interviews with a selection of five remanufacturing companies. The companies are from the following sectors: automotive, IT, photocopiers, industrial robots and building components. Results show they have a tendency to put technical capabilities at the core of their research, leaving 'softer' capabilities, such as sensing and learning, less developed.

1. INTRODUCTION

A range of different drivers steer companies to invest in strategies to prolong product lifetime. Remanufacturing is a promising example of such recovery strategies. Drivers to pursue this strategy vary from intrinsic to regulatory drivers and from environmental to financial, with an emphasis on the financial. Products which would otherwise be discarded at the end of use are reintroduced to the market for, at least, a second time, allowing businesses to generate revenue, with a lower energy and material investment, when compared to newly produced goods.

Remanufacturing has already been established in sectors with capital-intensive, (semi-) professional products, often operating in Business-to-Business (B2B) markets. There are, however, further opportunities regarding value recovery. The underlying reasons for product remanufacturing not currently operating to its full capacity are disparate [16]. This paper focuses on the dynamic capabilities needed to help remanufacturers overcome barriers in order to start up or scale up their remanufacturing activities. Dynamic capabilities are the capabilities needed to adjust to new situations and therefore can help interpret barriers [33]. Technical capabilities are well represented in literature, while significantly less attention is paid to the 'soft' capabilities. Soft capabilities are crucial for strategic positioning of a company, as well as for learning how to re-shape existing capabilities into new ones to grow a circular, sustainable business.

A literature review is conducted to identify barriers, followed by in-depth interviews in selected companies for validation and to establish a deeper understanding of the barriers. Finally, the results were interpreted by means of a framework for dynamic capabilities.

1.1 Remanufacturing entrepreneurship

Remanufacturing is defined as bringing back the functionality and appearance of a used product, through a series of standardized process steps, to a

like-new condition and with a customer warranty to match [6][25][43]. Even though remanufacturing activity has grown in recent years, the remanufacturing approach has been applied since the 19th century. In recent decades the industrial fields where remanufacturing has been more prevalent are mobility and energy generation. Product examples include: steam engines, railway infrastucture, power & machine tools and aerospace [28]. Consequently other sectors moved into remanufacturing including products such as medical devices, photocopiers and professional coffee machines [17][22][37][39][45].

The motives for developing product recovery strategies, like remanufacturing, are likely to mitigate environmental concerns, even though that may not be the driver [11]. Typically the main driver is the financial potential of the strategy, due to the comparatively competitive sales price for a remanufactured product, compared to other product recovery strategies [26][27][37][40]. However, since remanufacturing operations are typically more labor-intensive than the operations of other recovery strategies, it is often restricted to higher-value product markets [14][15].

Another important driver is cost reduction and the potential energy and material savings range from 30-90%, leading to significant cost reductions [1]. This can be achieved because the energy used during manufacturing, to produce a part's functionality, also known as emergy (embodied energy), is maintained [3][32].

It is not unusual for third party remanufacturers to be the first to anticipate business opportunities, with the Original Equipment Manufacturer (OEM) being the second mover, in order to protect brand quality, or to realize market expansion. Moreover, product recovery strategies allow companies to maintain control over the materials in the product, potentially including critical raw materials. Threats from material supply shortage becomes increasingly apparent over the years [35].

Imperative to the success of remanufacturing activity, is the overlap of remanufactured product demand and the availability of used products which are retrieved, called cores [13]. To secure the return of these used products and to obtain information about quality and quantity, a number of companies have adopted different forms of customer service models, allowing customers to pay for a product's function, or performance results, instead of ownership [4][28][43].

In regards to the design of a product in the remanufacturing context, the most essential requirements are: sufficient potential useful life after use and the ability to restore a product to its original, or higher, state. The first critical contributor to this ability is whether disassembly and reassembly is possible [32]. Also important is a stable product technology profile and the tendency to reach end-of-use due to functional failure [15][27][28]. Designs which can further facilitate remaufacturing are those with the ability to be upgraded, allowing remanufactured products go beyond their original product design specification [5][34].

As societies approach and exceed planetary boundaries for a healthy living environment, it has become increasingly urgent to facilitate businesses to adopt strategies which emit less carbon [36]. For this reason, it is of interest for the Government, businesses and society to equip companies with a set of capabilities to help remanufacturing activity to grow. This paper therefore focuses on presenting a detailed overview of some barriers encountered by remanufacturers in relation to dynamic capabilities. The following section explains the set-up of the qualitative data collection and analysis, including the literature review and a framework for dynamic capabilities, developed to interpret the barriers found during the data collection.

3. METHOD

The set of collected data is derived by conducting qualitative research, through a literature review and by conducting interviews. The data analysis is achieved by mapping the barriers onto a framework for dynamic capabilities, which aims to find patterns and support the drawing of conclusions.

3.1 Literature review

A selection of peer-reviewed literature, published in journals, forms the initial data input for this paper. This literature is collected on Scopus and Web of Science. The titles, abstracts and keywords are searched for the combination of:
((remanufactur* OR "repair W/2 overhaul" OR "extensive refurbishment") AND barrier*).
Using this approach, the search yielded 86 abstracts. The primary selection criterion is that the papers have the potential to reveal barriers or drivers in relation to remanufacturing activities. Also important is that the targeted company uses technical materials'. In this preliminary research, papers with a restriction to the European context were selected to be studied in more detail. An initial scan through the non-Euopean literature did not immediately reveal many additional unique barriers. Following this first filter phase the literature set was reduced to 37 papers of which 16 were included in the overview. This selection is done on basis of their broad and generic view on remanufacturing and their impact.

Referral code	Industry	Remanufacturing activity
Interviewee 1	Automotive parts	A third-party and independent remanufacturer of motors and gear boxes
Interviewee 2	IT	A non-for-profit IT company that remanufactures phones and other IT hardware
Interviewee 3	Industrial robots	A third-party and independent remanufacturer of industrial robots
Interviewee 4	Building components	A third-party and independent remanufacturer of building parts like windows
Interviewee 5	Photocopiers	A third-party and independent remanufacturer of IT products like printers

Table 1 Interviewed remanufacturing experts

3.2 Interviews

Since a gap was found regarding soft barriers during the literature review, five in-depth expert interviews were conducted to further explore this topic. Representatives from existing remanufacturers in the following sectors were selected: automotive, IT, photocopiers, industrial robots and building components (Table 1). This selection was made to get a mix different of products and therefore different material streams, recovery processes and target markets. But also the maturity of recovery activities of the companies varied, which helped to assess barriers at different stages. In a semi-structured setting, all facets of the business model were discussed as well as the barrier gap found during literature study.

3.3 Framework for dynamic capabilities

A framework for dynamic capabilities is used to interpret data and draw conclusions. Most of the barriers companies experience result from inadequate or missing capabilities in order to resolve a particular problem. Barriers which cannot be resolved internally are then external barriers, concerning, for example, legislation or sectoral technological readiness. In order to obtain insight in the type of capabilities needed to overcome the identified barriers, the framework of Pavlou & El Sawy for dynamic capabilities in the context of New Product Development (NPD) was used [33]. In the context of remanufacturing 'New Product' does not refer to the pristine nature of a product, but to the value potential of the product, which is 'as good as new'. The work of Pavlou & El Sawy is used to explain the framework in the following text.

In literature two different types of capabilities have been distinguished: operational and dynamic capabilities. Herein a capability is defined as (a collection of) high-level routines. Operational capabilities are sets of routines needed to execute a plan in detail, whereas dynamic capabilities cover routines which contribute to the innovative nature of processes and products, routines where adoption to changes takes in a central position. Dynamic capabilities can be used to adjust misaligned operational capabilities to regain their effectivity. Dynamic capabilities can be divided into the following four (reciprocal) categories:

- Sensing Capability – The ability to recognize, and anticipate on, market opportunities, taking into account internal strength and external opportunities
- Learning Capability – The ability to apply new knowledge to conceptualize and realize ideas resulting from market opportunities
- Integrating Capability – The ability to let newly obtained knowledge become part of the routines of the entire unit
- Coordinating Capability – The ability to find and effectively allocate resources to tasks

4. RESULTS

In this section an overview is provided of barriers to remanufacturing based on literature and interviews and their matching dynamic capabilities. First, the results of linking the focal points of the papers with dynamic capabilities are presented, according to the framework of Pavlou and El Sawy, subdivided over the four dynamic capabilities [33]. Thereafter, the four categories of barriers are discussed in more depth.

4.1 Framework of dynamic capabilities

The aim of this overview is to describe the focus of the literature which discusses potential areas of improvement for the remanufacturing industry. Even though the focal points of the papers are diverse, they demonstrate a clear pattern of attention paid to each capability. To make this pattern visible an overview is presented, for which the objectives of the papers were linked with the targeted dynamic capability, and this is shown in table 2. A quote has been included from each of the papers, which conveys the link with the capability.

Article details		Dynamic capabilities			
Author	**Year**	**Sensing capability**	**Learning capability**	**Integrating capability**	**Coordinating capability**
Thierry, M., Salomon, M., Nunen, J . Van, Wassenhove, L. van	1995	"Analyzing these [Product Recovery Management] PRM opportunities and threats sould be the first step for any company that is (forced to get) involved in PRM."			
Ferrer, G.	2001	„This paper analyzes a generic widget, to understand what makes a strong or weak candidate for a remanufacturing operation.“			„This paper analyzes a generic widget, to understand what makes a strong or weak candidate for a remanufacturing operation.“
Ijomah, W.L., Childe, S., McMahon, C.	2004				„This paper presents a robust remanufacturing definition and a comprehensive generic remanufacturing business process model that can be used to improve remanufacturing expertise.“
Toffel, M.W.	2004	„This article has described several factors that motivate manufacturers to engage in voluntary product recovery: reducing production costs, enhancing brand image, meeting customer demands, protecting aftermarkets, and preempting regulations.“			
Sundin, E., Bras, B.	2005	„[T]he objective of this study was to investigate and evaluate in what manner products can be designed in order to facilitate remanufacturing and functional sales“			
Guide, V.D.R., Jr, Li, J.	2010		„In this research, we use a novel research strategy by auctioning products donated by Robert Bosch Tools, NA and Cisco Systems, Inc. to determine the difference between consumers' willingness to pay (WTP) for new and remanufactured products and to help assess the extent of cannibalization of new product sales by remanufactured products“		

Article details		Dnamic capabilities			
Author	**Year**	**Sensing capability**	**Learning capability**	**Integrating capability**	**Coordinating capability**
Sundin, E., Lee, H.M.	2012				„The aim of this paper is to explore the environmental performance of remanufacturing in comparison to material recycling and manufacturing of new products. The different kinds of studies in quantifying the environmental impacts of remanufacturing were reviewed. Investigations made were relating to the kinds of products, the system boundaries and the measurements taken.“
Goepp, V., Zwolinski, P., Caillau, E.	2014				„The objective of this paper is therefore to develop such models [,eco-design process and data models,] for sustainable design of remanufactured products by instantiating and completing the reference model of the eco-design process in general, proposed in [paper reference].“
Kurilova-Palisaitiene, J., Sundin, E.	2014				„The need to improve vital indicators remanufacturing business is of the revealed. The major remanufacturing challenges are identified and classified into three categories: product quality, lead time and inventory level challenges.“
Matsumoto, M., Yang, S., Martinsen, K., Kainuma, Y.	2016			„Research on forecasting, product scheduling, capacity planning, production planning, inventory management, and others for remanufacturing is necessary, and further integrated methodologies are expected to be developed“	„various conditions such as OEM and/ or remanufacturer costs/benefits, demand side acceptance, legislation, and other relevant factors, have to be coordinated. This article highlighted four topics on R&D for remanufacturing.“

Article details		Dynamic capabilities			
Author	**Year**	**Sensing capability**	**Learning capability**	**Integrating capability**	**Coordinating capability**
D'adamo, I, Rosa, P.	2016				„This paper aims to improve the understanding of management practices concerning remanufacturing activities.“
Hartwell, I. & Marco, J.	2016			„This paper addresses two of the barriers, often cited, that inhibit organizations from adopting a remanufacturing strategy—ambiguity regarding the meaning of remanufacturing and uncertainty in how to manage intellectual property (IP).“	
Esmaeilian, B., Behdad, S., Wang, B.	2016			„Recent research in remanufacturing is explored under the following categories: • Business models [..] • Production, scheduling and inventory planning. • Determination of recovery options. • Environmental and cost analyses of remanufacturing operations. • […] product design. • Industrial case studies.“	
Lieder, M., Rashid, A.	2016				„[…] major part of these attempts has been lacking a systematic approach […]“
Karvonen, I., Jansson, K., Behm, K., Vatanen, K., Parker, D.	2017			"[…] to identify and sort out central barriers that currently prevent large scale capitalisation of remanufacturing potential."	"[…] to identify and sort out central barriers that currently prevent large scale capitalisation of remanufacturing potential."
Zlamparet, G.I., Ijomah, W., Miao, Y., Kumar Awasthi, A., Zeng, X., Li, J.	2017			„This paper will articulate the remanufacturing typologies from different aspects, as implementation strategies, and a strategic solution for sustainable global WEEE management […]“	
Total		**4**	**1**	**5**	**9**

Table 2. Article objectives linked with targeted capabilities

The overview points out that the main focus has been to develop integrating and coordinating capabilities, the more technical capabilities, in order to optimize the ongoing processes. Few papers exist with a core focus on the sensing and learning dynamic capabilities, the softer capabilities.

4.2 Barriers per dynamic capability

4.2.1. Sensing capability

The sensing capability, earlier described as a SWOT-like capability, where opportunities provided by the market can be realised by finding the internal strength to acticipate them. It is essential to retrieve the right information from the market and transforming this information into viable business concepts. The barriers relating to the dynamic capability are described next.

Typically, the sales of remanufactured products will take place in different markets from the virgin product sales, mainly due to consumer perception of non-virgin products (Interviewee 1; Interviewee 5). The reduced sales price of remanufactured products merely strengthens this perception. Since the product quality is brought back to as-new, or even better than new, the sales prices could potentially be equally high or even higher. However, offering remanufactured products at 60-90% of the initial sales prices, made possible by more cost-effective operations, can foster a competitive advantage [2]. In the IT-industry the lack of customer acceptance can be turned into a unique selling point when combined with, for example, smart phone user training for elderly people (Interviewee 2). In an example from the building parts industry, remanufacturing has more than doubled the life-time of a window, with a significant lower increase in amortization time, invalidating the suspicion towards remanufactured products (Interviewee 4).

The original product design determines the potential of a product to be remanufactured and this can be accounted for in different ways. On the one hand, changes in product design can be approached in incremential steps, by optimizing a product design for the remanufacturing process. This is further discussed in section 4.2.3. On the other hand, it can also be addressed in a more radical way, by integrating remanufacturability in the conceptual design of a product. The second option, for example, allows design for product upgrades, increasing the economic viability of a product for multiple use cycles. Product design changes have the biggest potential when taken into account during new product development process of the original product (Interviewee 2; Interviewee 3).

Characteristics of the sensing capability of this section are:

- The ability to develop new value propositions for a previously owned product, which the market is willing to accept
- The ability to understand the consumer needs of the new target group and anticipate on this by offering for example extra services.
- The ability to set a price for a previously owned product, which the market is willing to accept
- The ability integrate design for remanufacturing on a conceptual leven into the new product development process

4.2.2. Learning capability

Absorbing new knowledge is key for the learning capability. It functions as the link between the data collected from the market and incorporating it into operations. New knowledge needs to be transformed into meaningful and useful information for a company.

A misalignment has been observed between existing educational programs and practice. According to three out of five interviewees, education of staff happens in-house since the existing labor market (and the corresponding educational activity) is strongly focused on linear business activities (Interviewee 1; Interviewee 3; Interviewee 5). Even more so, two interviewees believe that education can only take place in practice (Interviewee 1; Interviewee 3). In addition they see a competitive advantage in such knowledge being hard to obtain.

In the literature there are gaps regarding the learning capability of remanufacturers. Only one of the articles is fully devoted to learning. It studies a method with the aspiration to learn about consumers' willingness to pay for remanufactured products [18]. Another paper recommends the development of learning materials in general, with an emphasis on cross-disciplinary teaching [21].

Characteristics of the learning capability of this section are:

- The ability to dissiminate knowledge to (new) colleagues as a compensation for the fact no formal education exists
- The ability to convert the scarcity of education into competitive advantage
- The ability to (apply methods to) draw learnings from consumer behavior
- The ability to convert learnings from one industry to another

4.2.3. Integrating capability

Before knowledge is operationalized it needs to be adjusted to the contex, adoped and put into practice by those allocated to the task considered. The interrelations between the entities of groups are central

to this capability and determine its success. A thin line exists between this and the previous capability, allowing certain characteristics to fit with both capabilities, for example when looking at product design or education. The capability will be further explained using the following barriers.

In order to maintain a product's original brand identity with regards to product quality, it is vital to produce good quality remanufactured products. Re-certification can be a means to ensure this quality and is in some cases inevitable, often leading to additional costs. Generally, tests to generate proof of sufficient remaining useful life, are scarce or not economically viable [1]. In-house experimentation labs are, possibly, seen as the answer to this problem (Interviewee 1)[28].

Design for remanufacturing is rarely considered during new product development. Occasionally, during disassembly, no other option exists but to destructively break connections between parts, causing damage to an otherwise useful part. As discussed in section 4.2.1, value destruction of this kind can easily be avoided during new product development. Moreover, products have tended to increase in complexity, driving up the difficulty of remanufacturing operations as well, especially in the absence of good alignment with a product development department (Interviewee 1). Since adopting design for remanufacturing guidelines has the potential to increase costs, a balance needs to be found between this investment and the generated value during remanufacturing operations. Options to design for product upgrades, potentially affecting markets positively, are less likely to happen if not taken into account during initial NPD (Interviewee 2; Interviewee 3).

Apart from tendencies of products to degrade heterogeneously, the cleanliness of a product coming back from the market also highly varies. Often, traces of use, oil in particular, contaminate clean transportation and workshop equipment. Some remanufacturers have developed product packaging in order to keep equipment clean.

Technological readiness with regards to closed loop business activities is low. For example, there is limited facilitation to retrieve technical data from the products to support inspection or testing, which also has an effect on the development of metrics for remanufacturing.

Remanufacturing tends to be labor intensive, because of the diversity of tasks and difficulty of implementing automated processes. Therefore, the potential for job creation is often put forward as a one of the positive effects of remanufacturing in academic literature. This is underscored by the research performed by the European Remanufacturing Network [30]. [13][28][29][31]. However, the exact effect on job creation remains unclear [1]. Besides the question of the number of jobs that could be created, considerations of the working conditions and the quality of work, should not be missed out. Presley argues safety measures need to be always carefully addressed. In particular during disassembly, where worn out, damaged or corroded components can prove troublesome, or when handling chemical and toxic materials [36].

Characteristics of the integrating capability of this section are:

- The ability to demonstrate a certain product quality by means of collecting proof of remaining product lifetime
- The ability to optimize product design for remanufacturing operations
- The ability to find a economically viable balance between increases in product complexity and standardization
- The ability to find an economic optimum between design efforts for remanufacturing and value generated during remanufacturing operations
- The ability to transport cores to the remanufacturing facility, without contaminating surroundings
- The ability to recruit, maintain and develop a team of trained staff
- The ability to provide safe conditions when working with used products

4.2.4. Coordinating capability

Once staff are sufficiently trained and developed to the required level, the day-to-day operations need to be effectively executed. The cooridating capability ensures the management of the available resources with respect to tasks which need to be performed. Barriers in relation to this capability are discussed next.

With regards to offering products at lower sales prices, OEMs need to take into account the threat of cannibalisation of existing markets [18]. Cannibalisation can take place when remanufactured products infiltrate markets of original OEM products, lowering their market share [28]. The real advantage of sales of remanufactured products will become apparent when product remanufacture reaches an economy of scale, which is prevented by various barriers like consumer acceptance and sourcing of cores [13]. In addition, the financial models supporting remanufacturing need dedicated research (Interviewee 4).

Resource information for remanufacturing is hard to obtain. Whereas information like location, availability and price of resources are fixed or predictable for virgin product manufacturing.

Information about the time of release of resources from the market, in the form of cores, is highly unpredictable [21][37]. It depends strongly on the real life-time of products and the types of products present in the field. Matching the information regarding the availability of resources with the demand for remanufactured products is an additional challenge. In Business to Consumer (B2C), markets product returns are even harder to control [21]. The products are more difficult to locate and tend to be scattered out through the market than in Business to Business (B2B) markets.

Careful selection prior to collection can prevent unnecessary transportation of cores. Cores which do not meet requirements of a certain product type, such as for quality or timing, can be selected out. Making well-informed acquisition decisions, however, requires extensive data collection, whereas particular data sets might not be available at all. Examples of useful data could, for instance, be maintenance and repair data (Interviewee 1). In the IT industry the requirement for the ability to delete user data is crucial. If this option is not available, then the product is rejected for remanufacturing (Interviewee 2). Further diagnostics and inspection will take place during remanufacturing operations, to prevent sending faulty products to the market and to avoid unnecessary value destruction [10].

Spare parts are ideally sourced from similar end-of-life products since original parts are more expensive [27]. It can be noted, that maintaining a growing inventory of spare parts retrieved the field, can result in a significant increase of costs [1](Interviewee 2). Close collaboration within the supply chain can help bring back the costs associated with the provision of spare parts, especially when product variety increases (Interviewee 1)[21][28]. When it comes to collaboration between third-party remanufacturers and OEMs, the relationship could be strengthened. OEMs often do not appoint contact persons responsible for remanufacturing-related issues (Interviewee 1). When this is done, the third-party remanufacturers can receive important information, but in exchange, they can provide valuable user and design feedback to the OEM (Interviewee 2).

Government policy does not support remanufacturing sufficiently. Rules and regulations can prohibit remanufacturers from further developing business activities; one example is the possibility to enter international markets (Interviewee 1; Interviewee 2). A possible rebound effect when new rules are imposed, is that new regulation is mainly developed for large manufacturers, complicating business for smaller remanufacturers (Interviewee 5). Importantly, there are no dedicated standards or certifications available (Interviewee 5). This is likely to be affected by the ambiguous nature of the definition of the field (Interviewee 2). A two-step approach was suggested in an interview, to start with a more widely applicable standard, and to further specify this for different industries (Interviewee 3). It would make a great difference to the percieved quality by the consumer (Interviewee 5).

Characteristics of the coordinating capability are:

- The ability to coordinate sales of remanufactured product, avoiding cannibalization of sales of original products
- The ability to ramp up sales of remanufactured products on a large scale by managing influencing factors like consumer expectations and core sourcing
- The ability to develop financial models to support product remanufacturing
- The ability to obtain information about cores, like location, availability and costs
- The ability to timely locate available cores, matching the customer's demand
- The ability to make well informed core acquisition decisions
- The ability of having spare parts available when needed
- The ability to collaborate within the supply-chain to exchange information or spare parts

4. DISCUSSION AND CONCLUSION

In order to grow the remanufacturing industry, businesses need to know what dynamic capabilities they need to develop to overcome the broad range of barriers. This paper presents the results of an analysis of barriers linked to dynamic capabilities, to point out what dynamic capabilities remanufacturers require. The overview resulting from this analysis made clear that the focus in literature thus far has predominantly been on the technical capabilities, developing integrating and coordinating capabilities. Soft capabilities, like sensing and learning, remain less developed. Interviews were conducted to further investigate the need for soft capabilities.

Input found in literature regarding sensing and learning capabilities was limited. The main topics addressed for the sensing capability were determining the right price for remanufactured goods and the potential of integrating design for remanufacturing into the product development process. While additional barriers for the sensing capability found during interviews concerned the ability to develop new value propositions for previously owned products and to anticipating on additional consumer needs, by for example developing services.

Regarding the learning capability market analysis for insights in willingness to pay as well as the development of educational tools and cross-disciplinary learning was present in the literature. Interviewees additionaly discussed the need for educational programs tailored to remanufacturers.

Fewer discrepanties between theory and practice were identified for the technical capabilities.

6. RECOMMENDATIONS

The recommendation for further work is the development of tools and methods to improve existing sensing and learning capabilities, to allow remanufacturers make use of them effecitively. Moreover, more empirical research is needed to expand the exploration of the field of soft capabilities and find out whether the overview of soft capabilities is complete.

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