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A Complexity-based Framework for Social Product Development

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Abstract

The development of new products using social technologies among defined crowds of individuals or groups, commonly known as Social Product Development (SPD), has become a growing trend in engineering design and manufacturing literature. This paper proposes an approach to studying the actors involved in SPD from a complexity science point of view. Specifically, we suggest that organizational efforts towards SPD must be concentrated on human and technological elements to achieve success in New Product Development (NPD). The paper explores the differences and similarities between the creation of new products and SPD and proposes a differentiated approach, based on complexity science for the different stages of NPD and SPD. Our findings show that SPD requires the integration of the complexity approach due to the combination of the knowledge, skills, and abilities of those involved during the development of new products. In addition, it is recommended that engineering design managers consider the importance of leadership styles, work structure, and organizational culture to achieve the expected outcomes of SPD.

Keywords: complexity; engineering design; social product development; open innovation.

1. Introduction

The development of new products that are well received by customers in a target market depends on several human and technological factors [1]. Nowadays, product innovation relies heavily on incremental changes to existing products, rather than the creation of radical products. As a result, NPD requires the involvement of various internal and external actors. Such a collaborative approach to new product development involves the use of numerous SPD tenants (e.g., crowdsourcing, mass collaboration, etc.), but due to the large amount of data and information transferred during such activities, the SPD process can become chaotic [2]. Consequently, the success of SPD programs can be directly related to the effectiveness of engineering design teams and the leadership style of the manager(s) leading the SPD program.

In engineering organizations, NPD is an activity that must be established and maintained to create competitive advantage in the market [3]. Creating new products that are successful is a cyclical process beginning with the development of an organization's innovative capability, which involves designing products with a clear value proposition [4]. Each process begins with the intention of satisfying the needs demanded by customers or end-users or, in other words, attending to a detected problem that has not been fully resolved. These needs can lead to novel solutions or alternatives to already existing products but, in both cases, innovation, technology, and employees' skills are required to design and develop new products that add real value for customers and end-users.

Complexity, as an analysis strategy for defining a process or an event, is implemented in different areas of knowledge. From this perspective, the problem to be solved is treated holistically using an approach that is determined by its systemic properties, as well as by those emerging effects that the organization causes in the environment, and by the participation of the actors involved in the development process [2]. This variability requires the generation of a conceptual structure that guides managers of engineering teams [5].

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This paper identifies the processes involved in the creation of new products, following the traditional NPD process, as well as the process of creating products using SPD. We identify the different stages involved in NPD and SPD, and the equivalence between them. Subsequently, we propose an approach to studying the agents involved in SPD from a complexity science perspective and explore the creativity, collaboration, and special requirements needed to build value propositions that are well received by a target market [6]. Further, we explore how complexity is constituted as an approach for studying multivariate and social phenomena. In this sense, our analysis places special emphasis on the agents, their non-linearity, the absence of central control, and emerging behaviors [7].

2. Social Product Development

2.1. Definitions

Developing new products or improving existing product portfolios has become a critical activity for many organizations. As organizations start to open-up their product development activities to both internal and external stakeholders, we now find ourselves engaging in SPD, a group of social tools and technologies that come together through the interaction of various agents, such as the organization, its employees, and external collaborative groups [8]. Ultimately, SPD can be defined as an open innovation business model that monetizes collaboration between organizations and virtual communities to deliver new products to the target market [9].

SPD is a relatively new concept in the fields of engineering design and manufacturing. It refers to the development of products using a social lens, i.e., through collaborative working teams focused on producing value propositions [10]. SPD can also be understood as the design of products, involving the use of ICT to engage and co-create products with external actors, such as hobbyists, customers, and end-users. During the COVID-19 pandemic, the use of SPD tenants, such as crowdsourcing, mass collaboration, and online innovation communities, increased in popularity among organizations [9].

Different design and technological approaches have been associated with SPD, including co-creation, mass collaboration, crowdsourcing, open innovation, and cloud-based design and manufacturing, *inter alia*; all allow for the emergence of collaborative ideas and knowledge. The use of ICT has driven this phenomenon, but there are also fortuitous events that have reinforced it. Among these events, we can mention the emergence of remote working, the need to modify the work dynamic from emerging situations, such as COVID-19, and the need to acquire the knowledge of individuals and groups located in other regions of the world and whose mobility is not feasible at the time of requiring such support.

Social communication tools, such as social media platforms, have enabled remote collaboration between organizations, their employees, and other external actors. Using social computing technologies, the products developed as part of complex NPD projects can receive feedback and ideas for improvement. This is achieved by connecting people with companies using Enterprise 2.0 platforms where collaborative work is successful in creating value-added products [11]; for example, in 2012, the computer game organization, Activision, used Salesforce, a SaaS platform, to improve communication within the gaming community and record problems being experienced.

2.2. SPD Processes

Social product development is related to the use of various tenants, such as crowdsourcing, mass collaboration, and online innovation communities during the product development lifecycle [12]. Access to such tenants allows for the socialization of novel ideas and the improvement of products based on feedback and suggestions made by various actors involved in the product development lifecycle; this is the basis of SPD. Similarly, when members of engineering design teams exchange ideas for creating products, the SPD process takes shape [13].

Among the approaches to SPD, those based on the nature of the product and those that focus on the organization stimulate innovation the most [14]. First, the teams that are characterized by their structure and nature, including members that possess the right skills and abilities required to obtain an optimal result in product development, are the most effective. This approach is based on 'finding the right people for the job' who are already employed by the organization developing the product; quite clearly, it is possible that within the same organization, there are some teams that are efficient, creative, and innovative, while others may not be [15]. The second approach is based on analyzing the organization as an entity to determine whether it contains appropriate human and technological elements to encourage the development of collaboration with internal and external entities. SPD processes are established in organizations that encourage intelligence, sustainability, resilience, change, and adaptation to market evolution and the environment in which new ideas and products are created, but also now from a social perspective where teams are more open and include external actors, such as customers [16].

SPD requires the creation of components that are configurable by work teams based on the human element of those teams which are the result of the internal policies of the organization; both the organization and its employees become intelligent, functional, creative, and collaborative entities in this process. The elements involved in these actions are required to establish the basis of SPD to support the integration of SPD tenants at different stages of the product development lifecycle. The various stages of product development are characterized as functional parts that arise in work teams and organizations that evolve toward knowledge and innovation in a creative and open process. Table 1 shows the general stages of the NPD and SPD processes to analyze their similarities and disparities [17].

Table 1. NPD and SPD frameworks

	NPD	SPD
Stage I	Idea generation	Social engagement
Stage II	Product definition	Ideation
Stage III	Prototype	Experiential communication
Stage IV	Initial design	Social validation
Stage V	Test and validation	Co-development
Stage VI	Commercialization	Co-commercialization

The creation of new products using an SPD approach has variations compared with the traditional NPD process of creating products solely internal to organizations. Table 1 shows that the most noticeable changes occur in stages I, III, and IV, where the need exists to establish an initial idea spillover to the collaborative group that supports the organization. A hook or rapport with consumers is proposed and, from this, the group idea is produced in stages III and IV where the initial designs are formed and validated through collaboration with external actors, such as online innovation communities and users [18].

The values proposed by new products are created by design teams that establish the needs, wants, and desires of customers and end-users. This implies that the initial intention to create a new product starts with satisfying the general needs of a selected market and continues towards the specific needs of individuals (end-users) [19]. However, when establishing values based on collaborative work, which is a characteristic of SPD, what is achieved is precisely that, arising from the identification of an individual consumer's idea, where their needs, wants, and desires, have been socialized, and a group solution is reached that satisfies most consumers in the selected market. This can be perceived as a contrary approach since it proceeds from the individual need to the socialized need.

3. Complexity Theory

3.1. Definition

To define complexity, it is necessary to find a theoretical foundation that encompasses the elements that compose it. This means that its ontological characteristics define the new approach to generating knowledge, i.e., its epistemology. For this, complexity is supported by an analysis that facilitates improved understanding. Among them are systemic, complex thinking, and complexity sciences approaches. By following a systemic approach, analysis is conducted by exploring the study's problem as a system, including its components, sub-components, and the relationships between them. By following a complex thinking approach, simplicity and linear relationships between input variables and expected results are avoided, and interpretation of a phenomenon is established. Finally, by following a complexity sciences approach, we innovate in thinking applied to problem-solving [7].

3.2. Problem of complexity

According to Weaver [20], to understand complexity as a scientific concept, we must divide the types of problems that can be studied and their levels of variability. In the first instance, the so-called "*simplicity problems*" are identified, which are those that are characterized by having few variables. These usually correlate with two or three variables, with such an approach being about simplifying the explanation and resolution of the research problem.

The second level is known as "*problems of disorganized complexity,*" where analysis focuses on the opposite end of the first level; in other words, it seeks to analyze a phenomenon from an infinite number of variables. With this approach, the possible solution becomes so complex that it becomes absolute relativity since a change in one of the infinite numbers of possible variables causes the result to be different and, therefore, impossible to replicate or understand. Finally, the third level is known as "*organized complexity problems*", which covers problems that are located between the first two instances; this means that a considerable number of variables are added which have the feasibility of being analyzed. For this, we mainly use new methods and tools based on ICT.

Table 2. Problem of complexity.

Problem	Variables	Methods	Examples
Simple complexity	2 – 3	Basic statistics	Pressure and temperature Population vs. time.
Disorganized complexity	Infinite	Average science Mechanical statistics	Understand the laws of temperature and pressure from the study of all the molecules involved.
Organized complexity	Moderate	Nonlinear variables interactions	A considerable number of variables are interrelated in an organic whole.

Table 2 shows the types of problems that can be analyzed using a complexity approach; those which are solved through the participation of people, such as in SPD projects, are considered "problems of organized complexity" [20] and can be analyzed using a moderate number of variables. Any activity that involves the participation of people in its processes tends to have characteristics that correspond to a complex problem. Such features may include:

- Agent-based (relative to the whole system)
- Nonlinear interactions among components
- No central control
- Adaptive nature
- Emergent behaviors
  - Hierarchical organization
  - Information processing
  - Dynamics
  - Evolution and learning

3.3. Complexity and its applications

To deepen our understanding of social problems, several methodologies and tools have been proposed to help reduce the uncertainty of multivariate problems [7]. By applying and using complexity tools, it is possible to analyze the emergence of collaborative work in organizations, including developing products based on social interactions with external actors (i.e., SPD). Such tools include network analysis, systems theory, adaptive systems theory, fuzzy logic, and the use of genetic algorithms. Their use can facilitate the study of systems that are not studied by traditional means, such as social networks, the dissemination of information on social media, and consumer behavior, among many other applications [21].

Analysis of complexity theory goes beyond dichotomous stakeholder responses and linear models for causal explanations. Complexity theory focuses on the dynamics of complex systems and the interactions that take place at the micro level which leads to new configurations and the emergence of differentiated properties at the macro level. It is an approach applied to the study of dynamic systems in which human beings participate; in such contexts, there is inherent complexity that causes the emergence of new behaviors.

The application of complexity theory tools, such as social network analysis and self-organization, have often been overlooked in social sciences research. Other studies in the physical sciences domain, however, like weather patterns, population increases, and other numerical-based studies, have used complexity theory tools for analysis purposes [7]. Some examples of complex theory applications are:

- **Social network analysis** (i.e., the application of network theory and data analysis tools to model social systems).
- **Earth systems science studies** which views the earth as a complex adaptive system. Such studies are inherently interdisciplinary and cross numerous scientific boundaries to treat the earth as an integrated system.
- **Complexity economics** is part of a new set of ideas surrounding economic theory. It sees the economy as a complex system that evolves through the interaction of multiple adaptive elements that gives rise to the emerging structures of organizations and complete markets.
- **Complex technology systems** are large networks of highly interconnected technologies.

The organization of such systems involves a network of connections and demonstrates self-directed adaptability and emergency behavior. Complexity theory tools are beginning to be applied to model these technologies and to help us better understand their operations in practice [22].

4. Proposed Complexity-based Framework for SPD

4.1. From NPD to SPD

This paper posits that NPD commences when engineering design teams identify creative solutions based on the specific needs, wants, and desires of consumers in a target market. However, during the life cycle of a product, one seeks to meet the needs of all individuals. Engineering design teams can do this by specializing in processes which consider the differentiated elements of each consumer. Now, when the development of new products becomes socialized, as part of an SPD program, the process begins when we create solutions for many consumers but start from a collaborative analysis of the particularities of consumers and then create the product which solves the issues experienced by the majority. This process depends on team collaboration, open leadership, entrepreneurial thinking, open innovation awareness, organizational structure, and environment configuration [19].

Complexity has been applied to the study of different problems related to people who are part of a group; one of the fields of knowledge in which it has been used is the study of economic development. Furthermore, interest in knowing the dynamics of knowledge creation and management in organizations is part of the application of the proposed complexity framework; likewise, in the decision-making process [23] and in the strategies for NPD [2].

Figure 1 shows the proposed SPD process framework where the essential elements for the paradigm shift between NPD and SPD are identified. This change is focused on the collaborative work produced in product development teams, which are highly complex due to the inclusion of multiple actors from different backgrounds and who have different cultural, social, labor, political, and governance influences [10]. Given this way of carrying out product development activities, new products must meet the expectations of consumers in a group format, something that goes in the opposite direction tothe traditional new product development process.

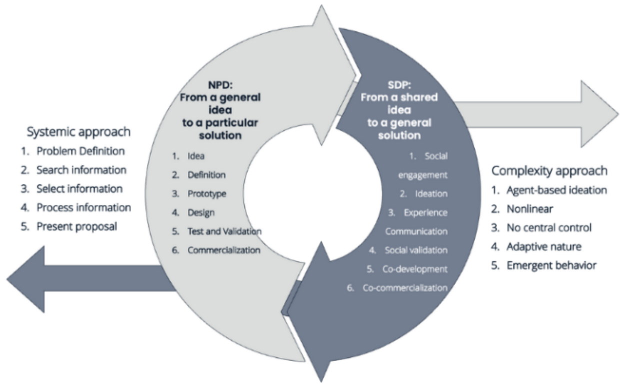

Fig. 1. NPD and SPD framework [21].

4.2. SPD Framework

The proposed complexity-based framework for SPD seeks to apply a complexity approach to the activities involved in SPD. Three levels of collaboration are identified, which are shown in Figure 2. The highest level includes the organization that proposes the construction of a product development team through its standard organizational structure and leadership styles. Before this, however, the organization must establish the basic inputs and rules, and culture of product innovation.

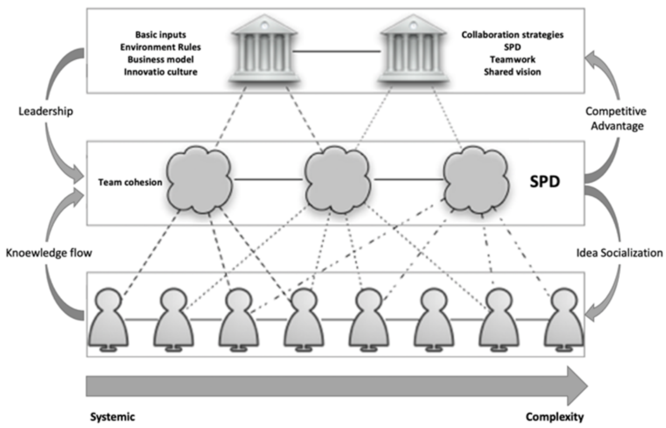

Fig. 2. Proposed Complexity-based Framework for SPD

Based on the collaboration between different teams that may come from one or more organizations, the flow of knowledge is fueled by the culture of product innovation and the collaboration of each member of these teams. In this context, teams collaborate to progress SPD. In addition to socializing the idea of the developed product and validating its feasibility, it causes a competitive advantage in organizations. This advantage causes collaboration strategies to be implemented to continue with the use of SPD, where teamwork is consolidated, and a shared vision is built throughout the organizations.

4.3. Case Study

To implement the proposed framework, a case study is chosen to demonstrate its effectiveness. The case study is related to a product called 'Medical Mailbox', which offers a personal digital medical record and access through ubiquitous ICT. The product was designed and developed through the technological innovation support program of the Mexican government, which funds collaborative technological development projects between companies, universities, and technological innovation development institutes.

Table 3 compares the dynamics of both NPD and SPD and identifies the complex collaborative activities that were involved in the design and product development of Medical Mailbox. Its development required socialization and the identification of the different levels of complexity by involving different entities to create knowledge. As a result of this collaboration, a software solution for medical records management was successfully developed. The use of business, technology, and project management tools was a product derived from the efforts made by each agent involved (i.e., company, university, government, and target market).

Table 3. Medical Mailbox, a case study.

NPD Steps	Internal Actions	SPD Steps	Complex collaboration actions
Idea	Market	Social engagement	Market, Universities, Government, Internal
Definition	Internal	Ideation	Universities, Internal
Prototyping	Internal	Experience communication	Universities, Internal
Design	Internal	Social validation	Market, Government, Internal
Text and validation	Market	Co-development	Universities, Internal
Commercia lization	Internal	Co-commercialization	Internal, Market

In the Internal Actions column, traditional elements of NPD are identified. These mainly include the market and the organization's internal structure. In both instances, interests focused on two actors involved in NPD, and they are the ones that can discreetly anticipate the new product market success. However, in the fourth column are the entities that participate in each stage from the complexity perspective. Being a project that involves multiple collaborations, several interests are present that facilitate the creative process. However, they can also delay those actions taken due to participants' interests.

The product developed covers all the requirements set by the Mexican Health Authority and was submitted for possible implementation under the company's supervision. The government, as the funding agent for the project, manages the budget, while the university has been a partner on other projects with the same company, and the researchers involved in the project continue to collaborate together. All of the agents are now involved in new projects using the lessons learned, providing evidence of the success of SPD and the complexity approach. Table 4 presents the participants identified for each agent, input, strategy, case, and complexity element. The success or failure of an SPD program depends on its complexity and requires leadership adjustment to handle variable conditions. This means that the proposed model is applicable to other environments and industries with different levels of complexity, depending on the SPD initiative.

Table 4. Agents' inputs, strategies, and complex elements.

Agent	Input	Strategies	Case Elements
Company	Structure Leadership Facilities	Product proposal Business model Leadership	Definition Prototyping Design
University	Researchers Facilities Knowledge base	Teamwork Research actions Simulation Software Dev.	Prototyping Design
Government	Financing Auditing	Regulations Funding Innovation Culture	Financing Supervision Validation
Market	New product requirements	Idea Social validation	Idea validation Commercia-lization
Complex elements in agents	Agent based ideation, Nonlinear, No central control, Adaptive nature, Emergent behavior		

5. Conclusion

Complexity theory provides the basic grounding for the proposed framework. In the case of collaborative work between people of different origins, the collaboration networks that are formed usually have chaotic behavior derived from the very nature of humans. People from different environments, with different cultures, aspirations, beliefs, intentions, and motivations, have emergent ways of carrying out the processes of collaboration and production. The SPD process requires that those involved in NPD collaborate effectively. The products developed represent a solution to the specific requirements that a market demands. For the process to work effectively, it is essential to have leadership that allows for collaborative work to take place and ideas to flow internally to the organization. Similarly, engineering design teams must be motivated to increase product innovation, creativity, and the development of new ideas under a collaborative approach. The characteristics of complexity within the framework are based on emergent properties from promoted interrelation teamwork. This approach is a novel involvement of complexity theory in NPD, which represents a new approach to SPD.

We present a perspective regarding the structure of collaborative working teams and their interactions. As this is a theoretical case study that recommends the use of a complexity science approach as part of an integrated management style for SPD, its main limitation is the application of management strategies in different scenarios. Therefore, the generalizability of our study is not demonstrated. In future work, and to extend the proposed framework, we will continue to apply the model in other industrial sectors and technological profiles; we call for and invite other applications for our proposed approach in other organizations. We consider that the applicability is appropriate for all types of organization although, in IT-based firms, the inclusion of complexity is facilitated due to their professional profile.

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