Cross-fertilization of knowledge and technologies in collaborative research projects

Manel González-Piñero, Cristina Páez-Avilés, Esteve Juanola-Feliu and Josep Samitier

Manel González-Piñero is based at the Department of Economics, Universitat de Barcelona, Barcelona, Spain, and Research Centre for Biomedical Engineering, Universitat Politècnica de Catalunya, Barcelona, Spain. Cristina Páez-Avilés is based at the Department of Electronics and Biomedical Engineering, Universitat de Barcelona, Barcelona, Spain. Esteve Juanola-Feliu is based at the Department of Electronics and Biomedical Engineering, Universitat de Barcelona, Barcelona, Spain, and the Institute for Bioengineering of Catalonia, Barcelona, Spain. Josep Samitier is based at the Institute for Bioengineering of Catalonia, Universitat de Barcelona, Barcelona, Spain, and CIBER-BBN, Zaragoza, Spain.

Abstract

Purpose – This paper aims to explore how the cross-fertilization of knowledge and technologies in EU-funded research projects, including serious games and gamification, is influenced by the following variables: multidisciplinarity, knowledge base and organizations (number and diversity). The interrelation of actors and projects form a network of innovation. The largest contribution to cross-fertilization comes from the multidisciplinary nature of projects and the previous knowledge and technology of actors. The analysis draws on the understanding of how consortia perform as an innovation network, what their outcomes are and what capabilities are needed to reap value.

Design/methodology/approach – All the research projects including serious games and/or gamification, funded by the EU-Horizon 2020 work programme, have been analyzed to test the hypotheses in this paper. The study sample covers the period between 2014 and 2016 (June), selecting the 87 research projects that comprised 519 organizations as coordinators and participants, and 597 observations – because more organizations participate in more than one project. The data were complemented by documentary and external database analysis.

Findings – To create cross-fertilization of knowledge and technologies, the following emphasis should be placed on projects: partners concern various disciplines; partners have an extensive knowledge base for generating novel combinations and added-value technologies; there is a diverse typology of partners with unique knowledge and skills; and there is a limited number of organizations not too closely connected to provide cross-fertilization.

Research limitations/implications – First, the database sample covers a period of 30 months. The authors' attention was focused on this period because H2020 prioritized for the first time the serious games and gamification with two specific calls (ICT-21–14 and ICT-24–16) and, second, for the explosion of projects including these technologies in the past years (Adkins, 2017). These facts can be understood as a way to push the research to higher technology readiness levels (TRLs) and introducing the end-user in the co-creation and co-development along the value chain. Second, an additional limitation makes reference to the European focus of the projects, missing strong regional initiatives not identified and studied.

Originality/value – This paper has attempted to explore and define theoretically and empirically the characteristics found in the cross-fertilization of collaborative research projects, emphasizing which variables, and how, need to be stimulated to benefit more multidisciplinary consortia and accelerate the process of innovation.

Keywords Innovation, Technology, Management research, Knowledge management, Cross-fertilization of knowledge

Paper type Research paper

1. Introduction

A system of innovation (SI) (Lundvall, 2007) refers to all the organizations, institutions and interactions that contribute in one way or another to innovation (Niosi, 2008), providing a framework that integrates key science, technology and innovation institutions (Niosi, 2011).

Therefore, a good understanding of an SI can lead policymakers to propose strategies aimed to enhance innovative performance and competitiveness, but also to identify bottlenecks that can hinder technology development and diffusion (Islam and Ozcan, 2015). SI stresses the importance of the knowledge flow in innovation processes and it can be applied at different levels: national, regional, sectorial and technological (Cooke, 2001; Islam and Ozcan, 2015; Lundvall et al., 2002).

To stimulate, create, use and recombine new and existing knowledge, the interaction and connectivity of multiple actors is required (Bogers et al., 2018; Laursen and Salter, 2006, 2014; Van Looy et al., 2004). New technology-based firms are most successful when they are moderately embedded in networks, with a mix of strong (efficiency) and weak (exploratory) ties (Bliemel and Maine, 2008). Networks have emergent properties (Eslami et al., 2013; Martinez-Torres, 2014; Sedighi, 2013) and having the right connections becomes as important as the actual generation and ownership of knowledge (Reagans and McEvily, 2003). In fact, there is growing evidence that networking is a beneficial mode of operation in innovation in any area (Harvey et al., 2013, 2015). When knowledge is emerging in two or more distinct fields simultaneously, teams need to be organized to allow for deep collaboration, essentially tacit knowledge exchange (Juanola-Feliu et al., 2012; Maine et al., 2014).

An efficient coordination facilitates the process of mutual transfer of knowledge and competences, improving learning and consequently producing positive effects on innovation (Soda, 2011). However, the impact of many network characteristics on knowledge creation and innovation production remains unclear because of the inconsistency of the conclusions from various research studies (Eslami, 2013). The knowledge and technological diversity evolves as new knowledge and technological alternatives appear and are subsequently applied in new innovation projects (Murmann and Frenken, 2006; Páez-Avilés et al., 2018a, 2018b; Van Rijnsoever et al., 2015). One of the most influential ways to accelerate the implementation of knowledge and technology and its long-term viability is the use of funding instruments supported by policymakers (Munari et al., 2015; Nepelski et al., 2019; Pandza et al., 2011; Van Rijnsoever et al., 2015). In particular, European collaborative R&D projects initiatives are expected to address technological and economic transformation by creating and exploiting networks that generate socially desired innovations (Leyden, 2016). So, the public sector seeks to increase the effectiveness of knowledge networks and gives rise to a discovery process by which organizations attempt to bring the desired innovation to the market and society (Audretsch and Link, 2016).

This study relates the change produced by the cross-fertilization of knowledge and technologies while influencing the following variables: multi-disciplinarity, knowledge base and organizations (number and diversity). It shows that the largest contribution to diversity comes from the multi-disciplinary nature of the projects and the previous knowledge and technology of these actors (Páez-Avilés et al., 2018b; Van Rijnsoever et al., 2015). To that end, a database focused on the 87 EU-research projects, including serious games and gamification – including 519 organizations and 597 observations – was created to analyze the influence of the suggested variables in the creation of new combinations and the cross-fertilization of knowledge and technologies to increase the possibilities of transferring new outputs into the market. In this paper, the focus is on serious games and gamification technologies because we consider them a critical component to favour the collaborative innovation projects for:

■ providing an innovative user's experience, generating new relationships that push projects to determine the best approach for managing direct-to-consumer relationships, preventing loss of user engagement (Alsawaier, 2017; Klevers et al., 2016);

■ being the first time that the EU Comission created specific calls on gaming technologies (ICT 21-2014; ICT 24-2016)[1], with a special focus on serious games and gamification.

2. Theory

Collaboration with fringe stakeholders has been advocated as a means to achieve creative destruction and innovation beneficial to both business and society (Gardetti, 2006; Gupta and Westney, 2003; Hart and Sharma, 2004; Tennyson, 2003). The idea, supported by innovation studies (Chesbrough, 2003; von Hippel, 1998), is that the knowledge essential to disruptive innovations is located outside the boundary of the organization and its most powerful stakeholders. Diversity unlocks innovation and gives more knowledge and technology alternatives, providing flexibility (Frenken and Nuvolari, 2004; Stirling, 2007) and drawing in ideas to deepen the pool of technological opportunities available to organizations (Engel, 2018; Laursen and Salter, 2006).

2.1 Diversity through cross-fertilization of knowledge and technologies

The ecosystem in which research is taking place and the roles of the actors within this ecosystem are under change. Today, research and innovation are taking place in the practitioners' community (Starkey and Madan, 2001; Søraa et al., 2017), generating advances and breakthroughs in science and technologies opening up opportunities for new interdisciplinary combinations (Juanola-Feliu, 2012). The use of funding instruments by governments is a form of influence in the level of knowledge and technological diversity of the organizations and its long-term viability (Adler and Heckscher, 2006; Edquist and Hommen, 1999). Moreover, the use and recombination of some specific technologies with others is encouraged to create new applications or uses to existent technologies.

Developing dynamic alliance capabilities for R&D partnerships, crossing knowledge and technologies, provides a way to enhance the competitive position of partners when looking for a collaborative advantage (Martínez-Noya and Narula, 2018; Wang and Rajagopalan, 2014). Institutions are forced to innovate at a faster rate so as to maintain their competitiveness in the market. As a result, they see technological or research alliances not as an option, but as a strategic need (Cassiman and Veugelers, 2006), to foster the institutions to exchange technologies; engage in developing expensive technologies; exploring new technology applications; and specializing, complementing and/or sharing knowledge and technologies (Dussauge and Garrette, 1999).

Cross-fertilization refers to the interdisciplinary combinations of different knowledge and technologies, creating extensive technological opportunities in terms of product performance and functionality (Björkdahl, 2009; Bogers and Horst, 2014). The concept of convergence of technologies is often associated with the process of cross-fertilization (Páez-Avilés et al., 2018a). The rationale is that "convergence" specifically involves conflation between previously distinct knowledge, technology, product or industry domains (Jeong and Choi, 2015) but cross-fertilization based on knowledge and technology is more focused on the diversity (instead of distinctness) to drive radical changes. Additionally, empirical evidence is needed to determine which variables are most closely related to the existence of greater multidisciplinarity in innovation projects.

Diversity is linked to the network position and composition of an innovation project, putting emphasis on the structure of the network as one of the key aspects to make a technology successful in the long term (Van Rijnsoever et al., 2015). The cross-fertilization in collaborative research projects should be beneficial to knowledge and technological diversity creation (Páez-Avilés et al., 2018). But to give more empirical evidence, we propose to analyze additional variables to understand how technological multidisciplinarity creation is influenced in EU-funded collaborative research projects including serious games and gamification. Previous analyses of technological multidisciplinarity were focused on the network of citations of the documents (Rafols and Meyer, 2010) or used pre-existing categories such as patent classes (Jonard and Yfldizoglu, 1998; Rafols and Meyer, 2010) but not on H2020 projects (with the exception of Paez-Aviles et al., 2018b). Hence, topic

modelling has been used to study cross-fertilization in an efficient manner (Leydesdorff et al., 2014; Paez-Aviles et al., 2018b) as a novel approach to categorize the topics and thematic areas described in 87 collaborative research projects.

2.2 Networks of innovation projects

There is a need to increase capacity for carrying out open-ended and non-linear problem-solving involving a wide participation of people in knowledge-rich environments. These collaborative projects can be seen as planned tasks that actors execute over a settled period of time to reach a desirable outcome (Páez-Avilés et. al, 2018a). Actors contribute knowledge, resources and skills required for successful innovation to these projects, sharing the risks of failure (Atkinson et al., 2006)

From the perspective of this study, the interrelation of actors and the collaborative research projects are seen as networks of innovation for the successful knowledge generated by the consortia but also for the successful transfer of this novel knowledge to other consortia and organization – internal research and business networks (Takahashi et al., 2018). This study analyzes those variables that, from a cross-fertilization perspective, determine a collaborative research project: the degree of multidisciplinarity; the prior knowledge base of the consortium's organizations; the number of actors; and the diversity of actor types.

2.2.1 Degree of multidisciplinarity. New approaches and different types of expertise are needed to face new challenges. A first approach to multidisciplinarity makes reference to the expertise from different disciplines but within their limits, whereas inter-disciplinarity refers to the interplay of disciplines into a single and coherent whole (Choi and Pak, 2006). According to Rafols and Meyer's perspective (2010), multidisciplinarity is seen as the spread of a diversity of knowledge areas that could be disciplines, technological fields or industrial sectors (Rafols and Meyer, 2010). Other perspectives put more focus on the analysis of the collaboration between team members (Chin et al., 2002; Cummings and Kiesler, 2005; Van Rijnsoever and Hessels, 2011; Teasley and Wolinsky, 2001), the skills required to manage these consortia (Dewulf et al., 2007; Bontis and Serenko, 2009; König et al., 2013) or, recently, the diversity of topics within a project (Paez-Aviles et al., 2018b; Van Rijnsoever et al., 2017). But no further research has been based on the degree of multidisciplinarity of projects and how it relates to the diversity of knowledge and technology, although there are good reasons for suspecting such a relationship.

A multidisciplinary environment favours a more diverse generation of ideas and fosters creativity (Alves et al., 2007). Knowledge processes thus become intense and the knowledge creation is frequent (Lofsten and Lindelof, 2005; Seufert et al., 1999; Iyer et al., 2017). These collaborative environments lead to better use of limited research resources (Laursen and Salter, 2014; Roper and Brookes, 1999) and to the creation of new and more innovative ideas and solutions adapted to the increasing complexity of problems. Therefore, they are more effective in the pursuit of creativity, innovation and product development than monosectoral environments (Hargadon, 2003).

The recombinant creativity is stimulated by multidisciplinarity within projects (Anderson et al., 2014; Baber et al., 1995; Fernández-Ribas and Shapira, 2009; Schmickl and Kieser, 2008), increasing the possibilities of creating, emerging and transferring new technologies into the market (Paez-Aviles et al., 2018a). This leads to the first hypothesis:

H1. The degree of multi-disciplinarity within a project is positively associated with the creation of technological diversity in collaborative research projects.

2.2.2 Knowledge base. Organizations complement their internal activities to seek for external knowledge, involving these providers in long-term relationships to perform functions beyond simple information retrieval and dissemination (Becker and Gassmann, 2006; Benassi and Di Minin, 2009; Lannon and Walsh, 2019; Sawhney et al.,

2003; Steward and Hyysalo, 2008). Specially, consultancies exploit existing specialist solutions to come up with new managerial approaches to bridge the gap between technological opportunities and user needs (Bessant and Rush, 1995; Hargadon and Sutton, 1997; Khedhaouria and Jamal, 2015). This diversity of knowledge generation and partners in H2020 consortia is also associated with the technological diversity (Lazear, 2004; Lettl et al., 2009), contributing with different visions and solutions to tackle the user needs (Di Gangi and Wasko, 2009; Ma et al., 2019; Yang and Li, 2019).

The prior knowledge enhances the absorptive capacity of organizations by increasing "the prospect that incoming information will relate to what is already known" (Cohen and Levinthal, 1990). A larger previous knowledge provides a greater ability to make new combinations in an organization. Hence, joining the knowledge base of all the consortium partners, there is a higher contribution of experiences and routines that will increase the chance of having new combinations (Kogut and Zander, 1992; Paez-Aviles et al., 2018a).

> *H2.* The size of the joint knowledge base of organizations within a project is positively associated with the creation of technological diversity.

2.2.3 Number of organizations. Number of organizations refers to "the size of the project consortium in terms of distinct actors" (Van Rijnsoever et al., 2015). Dailey (1978) stated that a larger team size decreases team cohesiveness and collaborative problem-solving. Parties have a certain expertise that they make repeated use of and it affects new types of projects and solutions even though that is usually the aim of the innovation policy of the European Commission. In fact, Van Rijnsoever et al. (2015) think that when it takes subsidy decisions, the government should also consider whether applicants are involved in any other collaborative programmes.

A common position in literature considers that larger project teams have a greater ability to incorporate more experiences, skills, ideas and hence innovation (Powell et al., 1996; Ruef, 2002). Thus, studies analysing the influence of the number of organizations on the creation of technological diversity show a negative correlation (Van Rijnsoever et al., 2015). The inclusion of new actors in a consortium is subject to decreasing returns, indicating that there is a point in which additional partners become unproductive (Audretysch and Belitski, 2019; Laursen and Salter, 2006, 2014). According to Tatikonda and Rosenthal (2000), intense collaborations could result in conformity of norms and conventions producing less novelty.

> *H3.* The number of organizations in a project has a negative association with the creation of technological diversity.

2.2.4 Diversity of organizations. Innovation projects commonly involve universities, research institutions and industry (Hsu et al., 2011) but the rise of a global knowledge economy has intensified the need for strategic partnerships that go beyond the traditional funding of discrete research projects. The most productive collaborations are strategic and of long term. They are built around a shared research vision, establishing deep professional ties, trust and shared benefits that work to bridge the sharp cultural divide between academia and industry (Edmondson et al., 2012).

The new challenges in research require solutions from different perspectives, interacting organizations from different domains and traditions (Belitski, 2019; Juanola-Feliu et al., 2012; Pandza et al., 2011; Park and Eun-Jee, 2018). Their diversity in the workforce, or the combination of various cultural and demographic categories, can increase creativity, innovativeness, performance and the quality of work (Florida, 2002, 2014; Herring, 2009; Hubbard, 2004; Page, 2007). Meanwhile, other studies found that diversity harms cohesiveness in groups, hinders the establishment of trust among members, causes conflicts and leads to both poor performance and low quality of work (Allen et al., 2003; Dimitrova and Kaishev, 2010; Jackson et al., 2003; Jackson and Joshi, 2004; Kirkman and Shapiro, 2001; Li and Hambrick, 2005; Mathieu et al., 2008; Olson et al., 2008). But referring diversity as a form of social capital, social network analysts argue that diverse ties bring in

more resources for network members (Erickson, 2003; Lin, 1999, 2001; Lin and Erickson, 2008).

A project is the result of integrating and recombining knowledge and skills from different organizations (Mo, 2016) to obtain more technological cross-fertilization and diversity (Van Rijnsoever *et al.*, 2015; Paez-Aviles *et al.*, 2018b). This cultural diversity combines ideas to arrive at a new knowledge (Sobel *et al.*, 2010; Qian and Acs, 2013), and organizations rich in knowledge benefit more from diversity than the organizations with paucity of knowledge (Audretsch *et al.*, 2010; Gambardella and Giarratana, 2010). In fact, knowledge-intensive sectors have positive implications for high growth (Audretsch and Belitski, 2019). This leads to a positive association between the diversity of the organizations participating in a project and the multidisciplinary knowledge and technology created.

> *H4.* The diversity of organizations in a project has a positive association with the creation of technological diversity.

3. Methodology

3.1 Sample selection and data collection

All the research projects including serious games and/or gamification, funded by the EU-Horizon 2020 work programme, have been analyzed to test our hypotheses. The reasons for selecting these particular projects are the high level of innovation; the transversal role of serious games and gamification in cross-sector alliances; and the involvement of the cross-fertilization process – three requirements that meet the inclusion criteria from the Programme.

The serious games and gamification market are promising in terms of research, development and impact market; they also represent scattered industries with a variety of application areas and characteristics. So, the integration of certain elements and mechanics from the field of gaming and game design into an existing (non-gaming) environment (Klevers *et al.*, 2016) is starting to realize to the business community the power these technologies have to improve customer engagement, build loyalty and incentivize employees and partners to perform at high levels. Furthermore, it is the first time that the EU Commission created specific calls on gaming and gamification technologies (ICT 21–2014; ICT 24–2016) in a research framework programme.

It explains why the study sample covers the period between 2014 and 2016 (June), selecting the 87 research projects, including serious games and/or gamification technologies. Those projects comprised 519 organizations as coordinators and participants, and 597 observations – because more organizations participate in more than one project. All these organizations were classified into five categories according to the established categories from H2020 (Figure 1):

1. private for-profit entities (PRC);

2. research centres (REC);

3. higher or secondary education establishments (HES);

4. public bodies (PUB); and

5. others (OTH).

3.2 Measures

We calculated the level of cross-fertilization in the population of *N* projects (Páez-Avilés *et al.*, 2018b; Van Rijnsoever *et al.*, 2015). For that purpose, we used Shannon's entropy statistic measure (Shannon, 1948). A positive value of entropy indicates that cross-

Figure 1 Sample selection pathway
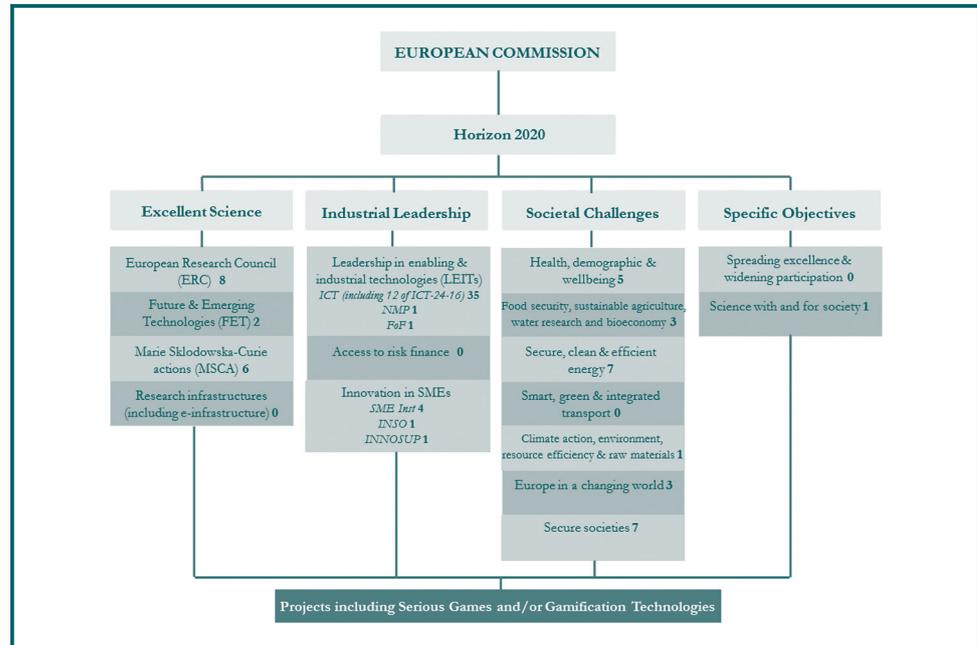
fertilization is fostered. A negative value indicates reduction of cross-fertilization in the system of projects. These calculations revealed that there were four different levels of cross-fertilization.

The variables previously introduced were measured on the basis of several categorical indicators, which are summarized in Table 1.

3.2.1 Degree of multidisciplinarity. There is an increasing emphasis in teamwork that involves multiple disciplines (Barr *et al.*, 1999; Nolan, 1995; Tress *et al.*, 2005; Wilson and Pirrie, 2000). It is generally assumed that efforts to involve more than one disciplines are valuables and beneficial (Evely *et al.*, 2010; Whitfield and Reid, 2004). A multiple disciplinary approach is emphasized in H2020 and breeds diversity.

To analyze the creation of multidisciplinarity, we need to identify the technological alternatives existing in our project system. Citation patterns or pre-existing categories (Boschma, 2005; Rafols and Meyer, 2010; Zhang *et al.*, 2016a, 2016b) are used in case of publications and patents. But when only abstracts are accessible, topic modelling is used to evaluate the semantic structure that will be used to identify topics among documents (Leydesdorff *et al.*, 2014; Yegros-Yegros *et al.*, 2015). In our study, we used the abstracts of each project.

For the first indicator (*I1.1*), we measured the degree of multi-disciplinarity by the diversity of topics (Rafols and Meyer, 2010; Yegros-Yegros *et al.*, 2015). Instead of looking at how often a combination of topics occurs at the system level, we calculated the diversity of topics within a project, using the probabilities from the latent Dirichlet allocation (LDA), which is a common type of topic model that uses discrete probabilistic techniques for information retrieval, text and data mining (Páez-Avilés *et al.*, 2018b; Van Eck and Waltman, 2010, 2014) and the entropy (Páez-Avilés *et al.*, 2018b).

The second indicator (*I1.2*) for this variable is based on the wide range of the projects' thematic areas. It is analyzed in two ways: first, by descriptive analysis, and, second, by a

Table 1 Measures: variables, indicators, source and scales

Variables	Indicator	Source	Measurement scales
V1. Degree of multidisciplinarity	I1.1. Number of topics (colorimetric map)	*	Multiplicity of topics
	I1.2. Thematic areas	*	Wide range of thematic areas
	I1.3. Number of projects coordinated by country and main thematic area	*	Multiplicity of projects coordinated by country and main thematic area
V2. Knowledge base	I2.1. Type of organizations	*	Diversity of types of organizations
	I2.2. Percentage of projects coordinated by HEC and REC	*	High number of HEC and REC coordinating projects
	I2.3. Knowledge-providing institutions in 2017 Ranks	**	Number of universities and research centres in top positions
V3. Number of organizations	I3.1. Average number of organizations per project	*	Relevant number of organizations in a research collaborative project
V4. Diversity of organizations	I4.1. Diversity of typology of organizations per project	*	Multiplicity of types of organizations
	I4.2. Correlation between type of organizations and thematic areas	*	Percentage of knowledge-providing institutions per thematic area

Source: *Database analysis; **other external sources

level plot graph developed by using the lattice package in R (Steyvers and Ths, 2006) to visualize the distribution of topics per project.

Finally, a third indicator (*I1.3*) considers the multiplicity of projects coordinated by country and the main thematic area. The way in which the different thematic areas are coordinated by teams from different countries shows us the relevance of coordination. It may need to be thought of as a much more inclusive process, being accomplished when developing and enacting strategies, which aim to pull together everything needed to carry out project tasks (Fujimura, 1987; Takahashi *et al.*, 2018). Therefore, projects with greater diversity of coordinators and thematic areas, the greater the resultant technological diversity among projects.

The diversity of topics within a project using the probabilities from LDA and the entropy allows us to measure the degree of multi-disciplinarity (Rafols and Meyer, 2010; Yegros-Yegros *et al.*, 2015).

3.2.2 Knowledge base. Knowledge is a starting point for developing open innovation approaches to R&D, combining in-house and external resources, and aiming to maximize economic value from their intellectual property. The use of knowledge is only possible when individuals and their organizations can share their knowledge and can generate news from the knowledge of others (Devezas *et al.*, 2007). So, the importance of sharing between the internal knowledge and the external one in collaborative R&D environments is recognized. It shows how nowadays knowledge is property of a diverse range of organizations although universities and research institutions have a key role in opening new research fields (*I2.1*).

The impact of universities' collaboration with private organizations depends on the company size (Okamuro, 2007). In general, SMEs can benefit more from R&D collaboration with universities rather than larger firms because large companies are less willing to share their economic knowledge with smaller rivals and have preference to collaborate with other large firms to maximize the internalization of spillovers (Röller *et al.*, 2007). The innovations co-developed with universities and private companies have equal chances of commercial exploitation as those introduced by private–private collaborations; and the 70% of innovations with high potential are co-developed with universities (Pesole and Nepelski, 2016). This strategic role of universities let us define the second indicator (*I2.2*): the bigger the percentage of HECs and RECs (knowledge producing institutions), the greater knowledge base in the project.

Finally, to have a whole view of the knowledge producing institutions, this third indicator (*I2.3*) measures the number of universities included in the QS World University Rankings, in particular the 2017 European Universities Rank. It is accompanied by the measure of research centres according to the European Ranking Web of Research Centres 2017. This methodology has as the unit of analysis the institutional domain, so only universities and research centres with an independent Web domain are considered. If an institution has more than one main domain, two or more entries are used with the different addresses. Also, a third ranking, the 2016 European Research Ranking, is used to complement those previous findings. Indicator *I2.3* complements qualitatively *I2.2*, more focused on the number of HEC and HES.

3.2.3 Number of organizations. There is a high number of organizations in H2020 projects creating value together. Larger project teams provide a larger chance of recombining different types of knowledge, expertise and ideas and thus innovation (Powell *et al.*, 1996; Ruef, 2002). That is why this indicator (*I3.1*) gives importance to the average number of organizations per project. This variable had a skewed distribution; therefore, we used its natural logarithm. It makes the assumption that attaining an additional level of this variable results in a decrease in marginal returns for cross-fertilization.

3.2.4 Diversity of organizations. Applied research conducted in universities and workplaces generally demonstrates a positive association between diversity and various learning outcomes (Hololen, 2013). Ignoring these differences in teams and organizations may inhibit information system's implementations in global settings and increase the risk of project failure (Harris and Davison, 2002). Cultural diversity is an integral structural attribute of any community and is powerful enough to condition the impact of knowledge outcomes (Audretsch *et al.*, 2019; Rauch *et al.*, 2013). In this context, the first indicator (*I4.1*) contemplates the diversity in actor types per project.

According to Frey *et al.* (2011), a diverse intensity of projects in each field boost the demand and supply of innovation to deliver a more valuable product to market. That is why the third indicator (*I4.2*) for this variable identifies if percentages of organizations are similar or different in each thematic area. Thereby, information about preferences of organizations for some specific fields could be obtained.

Based on the standard classifications of actors from H2020, we calculated the diversity in actor types per project, using the Shannon entropy.

3.3 Analysis

This study has used the indicators previously described (Table 1) to analyze the variables. We tested our hypothesis using a cumulative (ordinal) logit regression.

The level of cross-fertilization in a project was our dependent variable, adding the independent variables as predictors.

4. Results

4.1 Countries

From the set of projects, it was found that there were 40 participant countries, including 36 member state countries of the European Union and their overseas departments, and 4 non-member states: Canada, Colombia, Japan, Uruguay, Spain and Italy. The country with the greatest number of organizations was Spain (with 77 organizations), followed by the United Kingdom (65) and Italy (62).

Countries that participate in more collaborative consortia are Spain, United Kingdom, Italy, France, Greece, Germany and The Netherlands. Those countries evidence how they play a centrality role in the network (Figure 2 and Appendix 1). The PageRank uncovers nodes

Figure 2 Centrality representation of countries in the system of projects
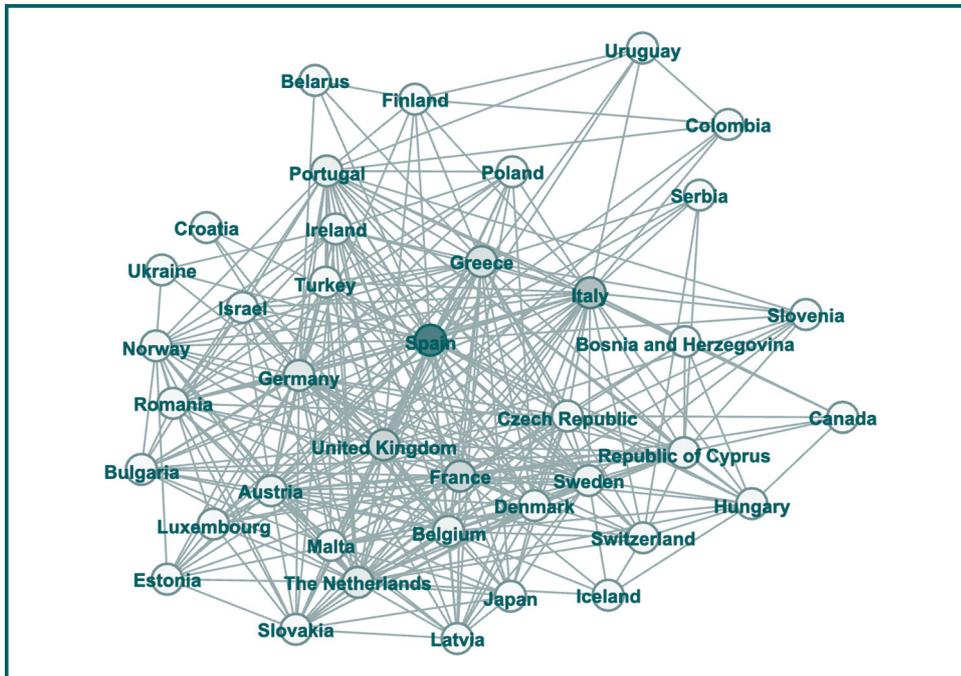
whose influence extends beyond their direct connections into the wider network, showing in our analysis a relevant role of the United Kingdom and France (Figure 2 and Appendix 1).

Figure 3 plots out the correlation matrix between countries and thematic areas, representing the correlation coefficients using the library lattice. The colour level is proportional to the value of the observations: pure blue corresponds to the highest value of number of projects. There is a clear concentration of projects in the area of education led by the United Kingdom and Spain, followed by projects in health care and environment also led by Spain.

4.2 Organizations

The network of organizations and their connections between projects is presented in Figure 4, showing how knowledge is interconnected between projects.

The majority of participant organizations are PRC (42%), followed by HES (29%) and REC (14%). The sample also shows a lower participation of PUB (8%) and OTH (7%). Having into account that in many cases the existence of HES and REC depends on the organizational knowledge system of each country (Martynenko and Menshykov, 2017), the sum of both variables has a percentage (43%) very well balanced with the number of companies (42%). This diversity of types of organizations and the relevant number of HES and REC support *Indicator 2.1*.

When we cross the type of organization with the type of project – according to whether they are collaborative (H), individual (I) or European Research Council (ERC), we observe that the individual projects are clearly developed by PRC and the ERC by HES. To explore the diversity of typology or organizations per project, we calculated the number of organizations per type (Table 2) and the projects in which they participate (Table 2). After this, we determined the average of each type of organization based on the total number of projects (although only 62 of the 87 are collaborative projects). So, we determined that there are 2.66 private companies participating in each project whereas the number of HES is 2.15

Figure 3 Number of projects per main thematic area and country using the library lattice
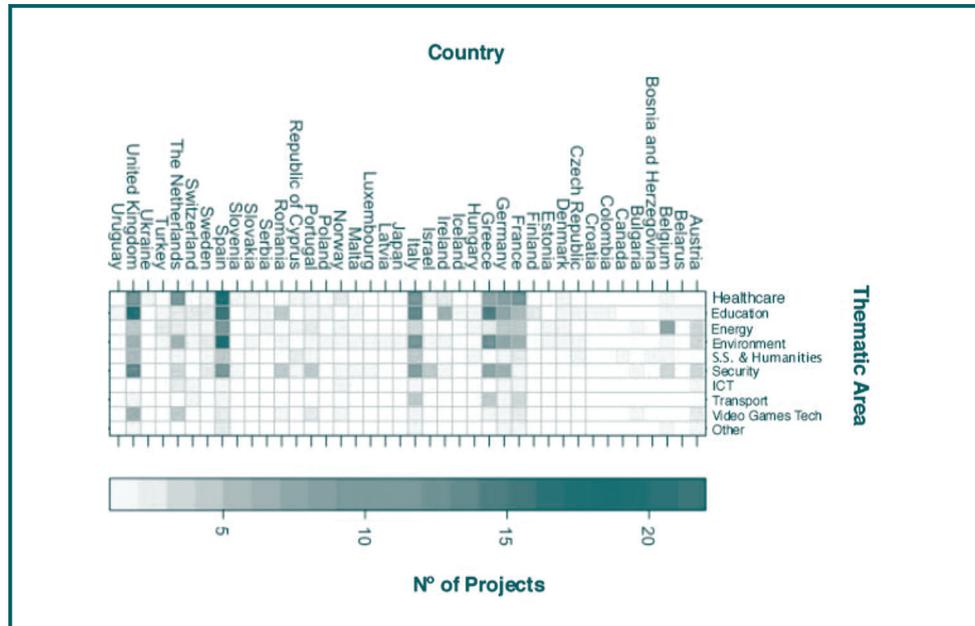
and REC 1.11. A PUB participates in the 0.53 of projects and OTH in 0.41. This information helps us to support the existence of a multiplicity of types of organizations per project (supporting *Indicator 4.1*) and a high percentage of knowledge-producing institutions.

The creation of value takes place along the value chain, from research to market. That is why the collaboration between knowledge-producing institutions and private companies is needed. After analysing the percentage of partnerships between HES/REC and PRC in the 62 collaborative projects, it achieves 98.34%. It means that *Indicator 3.1* is fully supported because a bigger number of partnerships between HES/REC and PRC could be influencing the level of cross-fertilization.

According to the idea that that larger project teams provide a larger chance of recombination (Powell *et al*., 1996; Ruef, 2002), we have calculated the average of partners in the 62 collaborative projects. The result is that there are 9.2 partners per project, a very high number when we reviewed the recommendations of different bodies of the European Union. Specifically, it is recommended per project at least two mutually independent legal entities established in two different countries and a reasonable number of associated partners to avoid administrative difficulties. According to the average of partners per collaborative projects, this finding fully supports *Indicator 3.1* being a relevant number of organizations in the collaborative projects.

HES and REC lead the participation in all the fields with the exception of the projects in Energy (PRC 48%) and equal those in ICT (50%). It evidences that the base and applied knowledge provided by universities and research centres could be a key element to define and accelerate the projects. This relevance of knowledge-providing institutions in almost all the fields and the high number of private companies let us say that there is a well-balanced representation of PRC and knowledge-providing institutions confirming *Indicator 4.2*.

The analysis of knowledge-providing institutions shows a full support for *Indicator 2.3* because in independent rankings, HEC and REC are not too relevant but when comparing them with the rest of institutions in other H2020 calls, the data demonstrate how relevant they are. A summary of the information discussed is shown in Table 3. In global terms, there

Figure 4 Centrality representation of organizations and their connections within projects
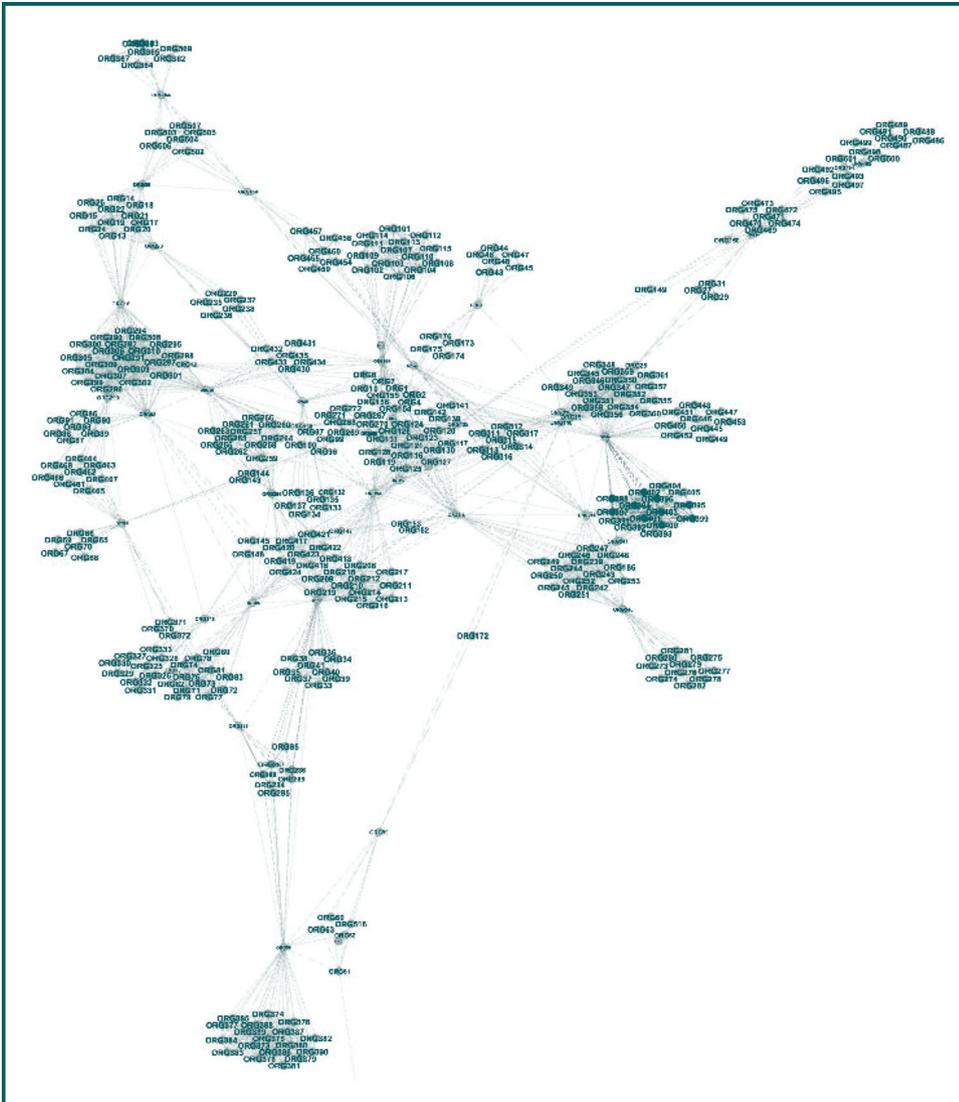
Table 2 Number of participations in projects per type of organization

| | Organizations | | Participations | | Org/total projects | Participations/total projects |
	N	%	N	%	N	N
PUB	41	8%	46	8%	0.47	0.53
HES	151	29%	187	31%	1.74	2.15
REC	75	14%	97	16%	0.86	1.11
PRC	217	42%	231	39%	2.49	2.66
OTH	35	7%	36	6%	0.40	0.41
Total	519	100%	597	100%	5.97	6.86
Total projects: 87						

is a high percentage of knowledge-producing institutions leading projects (65%), what confirms positively *Indicator 2.2*.

4.3 Topics

The analyzed database has a wide range of projects from different fields led by the health and the education areas, each of them with 18 projects. Projects in the energy field are 12, followed by 10 in Environment and Climate Action and 9 in Social Sciences and Humanities. The next are the fields of Security and ICT with six each. Finally, Transport (3), Video Games Technology (2) and other diverse fields such as Chemistry (1), Mathematics (1) and Sport (1) close the list. This result confirms the multidisciplinarity of fields, fully supporting *Indicator 1.2*.

In addition, a text exploratory analysis of all the projects was done to visualize the word trends using LDA. Figure 5 shows those words with more density in the text: "device", "serious gaming", "digital game", "energy consumption" and "energy efficiency", among others. These findings give a general vision about what are the projects mainly focusing on and the discourses that can be found in the system. This multiplicity of topics is interpreted as a full support for *Indicator 1.1*.

Table 3	Presence of knowledge-producing institutions in the European rankings		
	Categories	2018 European universities (QS World University rankings)	2017 European research centres (Ranking Web of research centres)	2016 European research ranking
Organizations	HEC	15		49
	REC		5	7
Projects	HEC	21		69
	REC		10	16

Figure 5	Density visualization map of terms

Regarding the number of projects coordinated by country and main thematic area, Spain leads clearly the coordination of projects (21), followed by Greece (14), The Netherlands (11), United Kingdom (9) and France (8). This multiplicity of projects in different thematic areas and coordinated by different countries corroborates *Indicator 1.3*.

4.4 Complementary analysis

Table 4 displays the descriptive statistics and the correlation matrix.

Table 5 shows the results of the cumulative logit model. The McFadden R^2 of the model is 0.11, which is an acceptable fit. The variance inflation factors are all below 10. We observe how the degree of multi-disciplinarity has a strong and significative association with the creation of diversity. This supports the idea that a multidisciplinary environment generates greater diversity and supports *H1*. The knowledge base variable also shows a significant positive association with the creation of technological diversity, proving how joining the knowledge base of all the consortium partners increases the chance of having new combinations (*H2*).

In the case of the number of organizations, we observe a negative association on the creation of technological diversity. We observe how the variance inflation factor of this variable is rather high, ratifying that there is a point in which additional partners become unproductive (Audretysch and Belitski, 2019; Laursen and Salter, 2006, 2014). This result is interpreted as a partial support result for *H3*.

Table 4 Descriptive statistics and correlation matrix						
	Mean	Standard deviation	Cross-fertilization	Degree of multi-disciplinarity	Knowledge base	No. of organizations
Cross-fertilization	−0.01	Level 1 (−0.027332) 8 obs; Level 2 (−0.00601) 47 obs; Level 3 (0.00182) 27 obs; Level 4 (0.00669) 5 obs.*				
Degree of multi-disciplinarity	0.11	0.04	0.35			
Knowledge base	0.85	2.94	0.12	0.14		
Number of organizations	6.86	8.98	0.08	0.00	0.44	
Diversity of organizations	−0.01	0.28	−0.10	0.00	0.41	−0.03

Notes: *Levels of cross-fertilization change and number of projects

Table 5 Results of the cumulative logit model		
	Estimate std.	Pr(>z)
Degree of multi-disciplinarity	2.03	0.01**
Knowledge base	2.07	5.06×10^{-12}***
Number of organizations	−1.35	0.02*
Diversity of organizations	2.10	5.17×10^{-12}***
LogLikelihood	−54.36	
No. obs.	87	
McFadden R^2	0.11	

Notes: *$p < 0.05$; **$p < 0.001$; ***$p < 0.0001$

The diversity of organizations is significantly related to our dependent variable, supporting *H4*. It is aligned with previous studies that say each organization brings to the project unique knowledge and skills which can be recombined to form novel outcomes (Mo, 2016), leveraging the cross-fertilization of knowledge and technologies.

Our analysis let us conclude that all the indicators are fully supported. It means that the variables measured through these categorical indicators were accepted, supporting the four hypotheses of this study.

5. Discussion and conclusions

5.1 Discussion and conclusions

Findings obtained in this research give rise to the belief that the cross-fertilization of knowledge and technologies in projects including serious games and/or gamification is a process developed through an open innovation strategy. The boundaries between an organization and its environment have become more permeable in a world of widely distributed knowledge, stimulating the use of internal and external ideas in highly cross-fertilized projects. This paper has attempted to explore and explain the process of cross-fertilization using some characteristics of the innovation projects, by distilling its enablers of knowledge-technology to ensure a better clarification of concepts, discussing them in the theoretical field and understanding their influence. We tested our hypothesis on data from EU-funded collaborative research projects, including serious games and gamification, whose H2020 calls prioritize the cross-fertilization of knowledge and emerging technologies.

Our main addition to the literature is that the degree of multi-disciplinarity of a project and the size of the joint knowledge base of project partners are strongly predictive for cross-fertilization. In this context, we find support for the hypothesis that different disciplines and larger and broader knowledge base increase the chances of recombinant innovations (Cohen and Levinthal, 1990; Fernández-Ribas and Shapira 2009; Khedhaouria and Jamal, 2015; Páez-Avilés *et al.*, 2018a; Schmickl and Kieser, 2008; Yang and Li, 2019), increasing the opportunities of emerging and transferring the new technologies into the market. Homogeneity of knowledge must be avoided venturing further afield but balancing the composition of clustered networks for not overlapping knowledge and skills, favouring most diverse and disruptive innovations (Noteboom, 1999; Boschma, 2005; Laursen and Salter, 2006,2014).

Second, the results mostly support findings and theoretical expectations with regard to the number of actors (Tatikonda and Rosenthal, 2000; Van Rijnsoever *et al.*, 2015; Páez-Avilés *et al.*, 2018a). Every organization brings to the project unique knowledge and skills that can be recombined to form novel concepts and designs (Mo, 2016), creating more technological diversity (Van Rijnsoever *et al.*, 2015). But there is a point in which additional partners become unproductive (Audretysch and Belitski, 2019; Laursen and Salter, 2006, 2014), affecting negatively innovative performance (Laursen and Salter, 2006; Bogers *et al.*, 2018).

In reference to the diversity of organizations, we support the claim that organizations' diversity influences technological diversity creation (Tatikonda and Rosenthal, 2000; Van Rijnsoever, 2005) but contradicts Páez-Avilés *et al.* (2018b) results. The comparison at this point with the study of Páez-Avilés *et al.* (2018b) is relevant because they analyzed a specific field, nanotechnology-related projects in H2020; meanwhile, we focus our research on H2020 projects, including serious games and gamification with a result at this point aligned with previous research based on broader samples in terms of topics (Van Rijnsoever *et al.*, 2005).

This study has used the indicators described for each variable and we decided to test our hypothesis using a cumulative (ordinal) logit regression. This approximation provides a view

to further develop a theory on the stimulation of cross-fertilization. Findings could be used for policymakers and project coordinators that aim to foster innovation on the basis of the cross-fertilization of knowledge and technology. So, findings suggest that public funds should favour those projects where:

- partners concern various disciplines;

- partners have an extensive knowledge base for generating novel combinations and value-added technologies;

- there is a diverse typology of partners with unique knowledge and skills; and

- there is a limited number of organizations not too closely connected to provide cross-fertilization of knowledge and technologies.

The first three points are already explicit or implicit criteria in H2020. Managing knowledge base is essential to increase the creation of knowledge and technology, to understand the competitive implications of partners' selection and to develop strategies or actions to influence the productivity and the development of collaborative strategies. Findings also recommend reducing the size of some consortia for not overlapping knowledge and skills that later could be used to develop new combinations. These projects often involve large consortia but our results suggest that it is better for diversity smaller one. But these cases should be handled with care, as this could decrease the technological diversity.

5.2 Limitations and future research

First, the database sample covers a period of 30 months. Our attention was focused on this period because H2020 prioritized for the first time the serious games and gamification with two specific calls (ICT-21–14 and ICT-24–16) and second for the explosion of projects including these technologies in the past years (Adkins, 2017). These facts can be understood as a way to push the research to higher technology readiness levels (TRLs) and introducing the end-user in the co-creation and co-development along the value chain. Second, an additional limitation makes reference to the European focus of the projects. This decision implies that there were possibly missed strong regional initiatives that have not been identified and studied. Empirical evidence suggests that business formation and survival in high-sectors are systematically greater in regions rich in knowledge (Audretsch et al., 2010, 2019). These environments could have developed specific policies that could explain these regional differences in knowledge bases. Third, this study focused on four variables (degree of multi-disciplinarity, knowledge base, number of organizations and diversity of organizations) and their relationship with cross-fertilization. Future research should add other variables and consider other calls including strategic sectors.

Further investigation is also necessary with regard to the processes and outcomes of research collaboration between partners at different stages of the value chain. Additional research on the processes and outcomes of the cross-fertilization process (knowledge and technologies) would be useful for fostering the transfer, accelerating its intensity and determining whether collaboration with external partners improves over time. Longitudinal research is needed to more fully understand long-term outcomes, both for society and partner organizations. Also, it would be interesting to analyze how the variables that determine the cross-fertilization of knowledge and technologies affect the speed of innovation, e.g. market dynamism and uncertainty, market size or access to resources.

Note

1 The ICT 21-2014 refers to "advanced digital gaming and gamification technologies" and the ICT 24-2016 to "gaming and gamification".

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Appendix

Table A1	Centrality measures				
	Degree	*Eigen*	*Closeness*	*Betweenness*	*Page rank*
Denmark	54	0.175613	0.677966	0.633517	0.005889
Greece	246	0.849991	0.8	32.844551	0.008717
Germany	247	0.845605	0.8	23.754183	0.008831
The Netherlands	187	0.590165	0.784314	19.697000	0.008007
Spain	357	1.000000	0.930233	177.603981	0.015454
Sweden	106	0.351139	0.727273	9.343489	0.007381
Belgium	88	0.276269	0.727273	9.433016	0.007852
Italy	295	0.906709	0.851064	83.243334	0.010545
Republic of Cyprus	46	0.138477	0.677966	6.030352	0.007424
Slovenia	18	0.071534	0.563380	–	0.004250
United Kingdom	323	0.988523	0.816327	49.273747	0.009534
France	212	0.677650	0.816327	45.066388	0.009177
Norway	41	0.121613	0.666667	1.943153	0.006259
Switzerland	30	0.094226	0.597015	2.266382	0.006029
Portugal	107	0.363112	0.754717	11.966948	0.009034
Serbia	7	0.021851	0.540541	–	0.004230
Austria	104	0.323512	0.740741	7.932751	0.007114
Ireland	56	0.191539	0.625000	1.664893	0.005766
Slovakia	63	0.200229	0.666667	0.954138	0.005746
Romania	118	0.380728	0.655738	2.342977	0.005383
Czech Republic	48	0.136286	0.701754	3.644420	0.007055
Hungary	18	0.041023	0.597015	1.944816	0.006530
Iceland	6	0.010800	0.5	–	0.004506
Poland	32	0.134207	0.579710	0.009543	0.004358
Turkey	49	0.173192	0.615385	0.208045	0.004877
United Kingdom	1	0.005239	0.487805	–	0.003703
Bulgaria	27	0.087651	0.606061	0.034134	0.004719
Malta	41	0.126233	0.655738	0.268879	0.005506
Ukraine	4	0.012119	0.506329	–	0.003989
Croatia	5	0.021600	0.506329	–	0.003836
Luxembourg	34	0.118043	0.579710	0.066144	0.004631
Israel	41	0.128819	0.597015	0.044635	0.004538
Japan	19	0.053292	0.615385	–	0.004909
Latvia	24	0.074512	0.615385	–	0.004961
Canada	9	0.017658	0.519481	–	0.005127
Bosnia and Herzegovina	9	0.017658	0.519481	–	0.005127
Belarus	5	0.018750	0.506329	–	0.004279
Finland	12	0.041627	0.555556	0.750256	0.006060
Estonia	19	0.055961	0.579710	0.343260	0.004538
Uruguay	8	0.027488	0.533333	–	0.005007
Colombia	8	0.027488	0.533333	–	0.005007

About the authors

Dr Manel González-Piñero is the Head of innovation management at the Research Centre for Biomedical Engineering of the Technical University of Catalonia (UPC). Also, he is Adjunct Professor of Innovation and Cultural Management and Researcher of the Research Group of Digital contents and culture of the University of Barcelona (UB) School of Economics. He completed his PhD in Economics (Society and Culture) and a MBA (UB). Previously, he got a Bachelor's degree in Business Administration and in English Studies – Extraordinary Award – (UB). He worked in the Business Development area at the University of Technology Sydney and the BRI National Research Council Canada (Montreal). Manel González-Piñero is the corresponding author and can be contacted at: manel.gonzalez@ub.edu

Dr Cristina Paez-Aviles has a doctoral degree on Nanosciences from the University of Barcelona, Spain. After obtaining her degree as Biotechnology Engineer by the Army Polytechnic School ESPE in Quito, Ecuador (2012), she went to Barcelona to complete her Master degree in Pharmaceutics Industry and Biotechnology from the University Pompeu Fabra (2013). Her research is focused on the processes and ecosystems of innovation, challenges of technology transfer and commercialization for nanobiotechnologies and nanomedicine with a multi-KET (key enabling technologies) approach in European and Latin American regional innovation systems. Additional research interests include innovation in medical devices, entrepreneurship and innovation.

Dr Esteve Juanola-Feliu is Researcher and Innovation Adviser at the Institute for Bioengineering of Catalonia and at the University of Barcelona. After obtaining his degree in Physics from the UB (1995), he went on to complete a PhD in Engineering, Electronic Materials and Optics and a master's in human resources management. His main research interests and activities focus on regional innovation and creative systems and adding value by cross-fertilization of key enabling technologies (KETs). He was Visiting Research Fellow at the University of Western Sydney (Australia), University of Montreal (Canada) and LAAS-CNRS laboratory (France).

Prof. Josep Samitier is Director of Institute for Bioengineering of Catalonia and Full Professor in the Physics Faculty (Electronics and Biomedical Department), University of Barcelona. He is also the Coordinator of the Spanish Platform on Nanomedicine and the President of the Catalan Association of Research Centres (ACER), Group Leader of the Nanobioengineering Group at IBEC; EIT Health Supervisory Board member; and Spanish delegate in the Working Party on Biotecnology (OECD). From March 2001 to June 2005, Prof. Samitier was Deputy Head of the Barcelona Science Park (PCB), and in 2003, he received the Barcelona city Prize of the Barcelona Council in the Technological Innovation category.