COOPETITION MODEL OF KNOWLEDGE SHARING IN SCIENCE: AN EASTERN-EUROPEAN CASE STUDY*

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(Received October 3, 2018)

The aim of this paper is to use case studies from physics collaborations to determine the influence of competition for both tangible and intangible resources as well as cooperative behavior among collaboration members representing different institutions on the quality of knowledge shared by the participants and their satisfaction by the collaboration practices. An interview study spanning 33 informants in 3 international scientific projects was launched to collect data on expert views concerning relationships of cooperation and competition. This work aims at verifying the research hypothesis which claims that both cooperation and competition between teams have positive effects on the quality of knowledge created by scientific projects. The sample is limited by its size by three projects. Another limitation is associated with a small variety of scientific disciplines, which may affect the relations of cooperation. The results indicate that the effectiveness is achieved as a result of the synergy of two contradictory relationships in the process of creating high-quality knowledge in the processes of a scientific nature. The paper reports on the views of experts from many countries representing both academia and practice.

DOI:10.5506/APhysPolBSupp.11.803

1. Introduction

Coopetition, which is defined as the relation of cooperative competition, has recently attracted significant interest in literature on knowledge management. It has been observed at both inter-organizational and intra-organizational levels. Coopetition occurs when organizations take actions of

* Presented at the II NICA Days 2017 Conference associated with the II Slow Control Warsaw 2017, Warsaw, Poland, November 6–10, 2017.

a dual nature: on the one hand, they cooperate with each other to reach a higher value as compared to the value created without cooperation and, on the other hand, they compete at the same time to achieve their own competitive advantages. Coopetition is a relatively new phenomenon in the history of science development, however, it is becoming more and more common. It is not a phenomenon typical only for business organizations, but also an integral part of life in the domain of science.

This paper aims at verifying the research hypothesis, which claims that cooperation between teams can have a positive effect on the quality of knowledge created as a result of scientific projects. This factor is crucial for entities from the field of science. The quality of knowledge is critical for further development prospects and for the strategic position of a scientific unit. The quality of knowledge created in scientific units manifests itself not only through the number and quality of publications but also through patents and industrial implementations. All these activities influence the position of a unit as a center of expertise (in the case of universities) and as a cooperation partner (in the case of organizational units of a scientific nature or of a business nature). It is an extremely important element of building the market position of an organization and then strengthening its competitive advantage. At the same time, the complexity of scientific projects, limited access to tangible and intangible resources makes it necessary to create partnerships and cooperate to achieve scientific goals.

The aim of this paper is to use case studies from physics collaborations to determine the influence of competition for both tangible and intangible resources as well as cooperative behavior among collaboration members representing different institutions on the quality of knowledge shared by the participants and their satisfaction by the collaboration practices. An attempt is made to elucidate the structure of work-related communications in the collaboration and their influence on cross-functional cooperation.

2. Coopetition: idea and definitions, cooperation relationships in organizations

All organizational activity intended to achieve predefined goals requires the commitment of resources. As the scope of activities undertaken is broadening and the complexity of tasks carried out is growing, these resources have to be more and more differentiated, and increasingly numerous. Initiating new measures requires the organization to make decisions concerning its relations with an environment. The ability to create competitive advantages is the factor which, to a great extent, determines future actions of the organization and influences its attractiveness for other market players. The aforementioned competitive advantages are built on the basis of resources owned or used by the enterprise.

Traditionally, the enterprise resources are divided into two categories: tangible and intangible. Tangible resources include fixed assets, real estates, machines, raw materials and financial resources. Intangible resources consist of various procedures, operational models, know-how, owned patents and human factors — employees and their experience, knowledge, skills. The classical definition of a resource states that it must be valuable, rare as well as difficult to copy and substitute. Dollinger [1] enumerates 6 types of strategic resources of the undertaking (PROFIT formula): physical, reputational, organizational, financial, intellectual, human and technological.

One may notice more and more discussions about global competitive advantages, which are the result of efficient linking between national circumstances and the company's strategy [2]. Even the operational excellence of an enterprise resulting in achieving leadership cannot guarantee success on a new market. Available resources constitute one of the pillars of the strategy, the second one being the surrounding of the organization. In the case of business organizations, we usually talk about competitive (market) environment where a customer is able to choose a supplier. In such a situation, the position can be expanded to new markets and new segments, and the actual market power can be strengthened through the strategy of finding a business partner. The current competitor can turn into a kind of partner.

In this way, apart from two classical modes of competitive relationships, namely cooperation and competition, the third form such as coopetition continues to increase [3]. This is a relation of indirect nature which involves the simultaneous occurrence of cooperation and competition [4]. Coopetition, contrary to traditional market relationships such as competition and cooperation, is not a paradigm. Depending on the market situation, coopetition takes different forms and includes various levels of organization management. Its material and personal scope can also take other forms, therefore, there is a plenty of definitions and topologies in the source literature.

The phenomenon of coopetition involves practically any sector of modern economy. It may refer to typically defined competitor, in other words the independent organizations which operate in a common sector and which compete on the market in a traditional way [3]. This phenomenon can be considered also in the case of intra-organizational relationships [5]. This is particularly noticeable in large enterprises with diversified structure. In such organizations, the act of cooperation between entities traditionally competing for the access to resources may be treated as the inter-organizational coopetition. The possibility to jointly benefit constitutes the basic factor contributing to the cooperative relationship between rivals. Bringing these gains is more probable and more effective due to joint action and use of a larger pool of resources than those available to individual partners before the launch of cooperation [6]. Any such actions are intended to use to the fullest extent the synergy principle. The principle implies that the effect achieved in the course of joint action should outweigh the sum of effects gained by individual actions. The resource theory, which emphasizes the importance of achieving the synergy effect, mentions the coopetition relationships most often (Table I).

TABLE I

Scientific sources which inspire the development of the notion of coopetition. Source: an elaboration on the basis of [7,8].

Theory	Implications
Game Theory (mathematics)	The non-zero-sum game, value network where added value is greater in the case of cooperation network than for individual players (PARTS model); "Prisoner's dilemma", when the greatest chance for payment occurs in the case of establishing cooperation.
Transaction Cost Theory (economic sciences)	High costs of hierarchical structures and costs of market transactions are encouraging collaborative activities.
Strategic Management (organization and management sciences)	Resource Theory — in virtue of cooperation partners have the resources which are they are not able to generate separately.

Coopetition is the relation of cooperation, where at least two entities share selected resources with the aim of achieving common objectives. Characteristic features of coopetition relations, which are emphasized in numerous publications and which are reflected in definitions of this notion, are as follows:

- the duality of relations — the co-existence of competition and cooperation, which is possible due to the division of areas devoted to specific actions as well as to the effective coordination of activities performed by cooperating organizations in these distributed operational zones;
- interdependence — which is demonstrated by mutual dependence of parties involved and also by sharing resources submitted to the coopetition relation in any form (as an item, a qualification or a skill);
- long-term character of the relation — the longer perspectives of cooperation, the more eager partners are to start collaboration; duration of cooperation affects also the amount and the variety of contracts signed within the framework of coopetition as well as the internal structure of this interaction;

— openness — the cooperation has to be established between two or more organizations; yet, there is no limit on parties involved. Openness concerns also markets which take part in this coopetition, because collaborating parties do not have to be exclusively direct competitors; cooperation can take any form or scope — the will of the parties and the capability of jointly identified goals are the only decisive factors in this case.

The growing popularity of coopetition in the area of science can be observed through the increase in the number of publications, which are, however, mainly devoted to relations between business enterprises [9–11]. Authors of these papers focus on the description and the analysis of coopetition areas and on the relations of collaboration, and not on the identification of the factors which determine acts of cooperation [3, 12]. Enterprises which start coopetition enter different kinds of strategic alliances, links, and clusters. The main objective of each of these organizational forms is to achieve goals which would be unattainable for an organization operating independently. Such actions are not typical exclusively of business organizations. Coopetition is increasingly frequent as a strategy in local government administration [13, 14] or in health care [15]. It is also an incredibly popular form of action in functioning of organizational units of a scientific nature (laboratories, research institutes, universities).

Among benefits which are a result of collaborative activities, these are enlisted most often: gaining access to resources valuable in terms of organizational objectives, the growth of innovativeness, the improvement in cost-efficiency, cutting down research and development expenses. All these factors lead to the strengthening of a competitive position of an organization and may be among the tools for reducing the operational risk.

This paper aims at verifying the research hypothesis that a cooperation between teams has a positive effect on the quality of knowledge created as a result of scientific projects. This factor is crucial for entities from the field of science. The quality of knowledge is critical for further development prospects and for the strategic position of every organization [16–18], and it is also truth in the case of a scientific unit. The quality of knowledge created in scientific units manifests itself not only in the number and quality of publications but also through patents and implementations. All these activities influence the position of a unit as a center of expertise (in the case of universities) and as a cooperation partner (on the part of other organizational units of a scientific nature or of a business nature). It is an extremely important element of building the market position of an organization and then strengthening its competitive advantages. At the same time, the complexity of scientific projects, limited access to tangible and intangible resources makes it necessary to create partnerships and cooperate to achieve scientific goals. Coopetition is a new phenomenon in the history of science development. The situation when rival scientific units start cooperating happens often in this market branch.

Coopetition that has a positive effect on the quality of knowledge is based on the assumption that relations like this are established. Observation of the market and the constantly growing number of international scientific projects prove that among scientific units, there is a willingness and readiness to cooperate. Authors of the paper are highly interested in conducting research on the nature of factors which influence the cooperation relations in scientific projects. Research task will involve indicating factors and their significance for the cooperation and competition relationships in scientific projects. The model of cooperation between teams proposed by Ghobadi [19] will be used as a subsidiary model, while conducting the research task. The article aims to identify factors that influence the knowledge management and implementation of projects by scientific institutions. Factors relevant to knowledge management will be identified on the basis of surveys. There will also be proposed a model of knowledge management in research projects.

3. The E&T-RAW project: the model of cooperation

One of the surveys was conducted with the members of the Energy and Transmutation of Radioactive Waste (E&T-RAW) international collaboration using particle accelerators and experimental setups at the Joint Institute for Nuclear Research (JINR) at Dubna, Russia. The E&T-RAW project is an applied project which is a satellite to the NICA project [20]. It was initiated in 1990s as a collaboration between JINR and Germany (Marburg University). It is aimed at producing nuclear reaction data relevant to nuclear energy production with prospective Accelerator-Driven Systems (ADS) as well as transmutation of radioactive waste of nuclear reactors. The E&T-RAW experiments are conducted at the proton and deuteron beams of the JINR LHEP Nuclotron (or JINR DLNP Phasotron) accelerators in the energy range of the primary beams from 0.5 GeV to 6 GeV. The "heart" of the experiments is the heavy-metal (lead or uranium) extended target (most recently a 500-kg uranium-238 target QUINTA or lead-graphite GAMMA-3), which is used by all the collaborators simultaneously in the course of experiment (see figure 1). The target is a tangible shared resource for the entire collaboration. However, each collaborating group (university or institute of a particular country) has its own area of responsibility, *i.e.* a task based on a particular piece of equipment (tangible resources) and related expertise in using it. These tangible resources are described below in more detail.

Fig. 1. Natural uranium target QUINTA.

The host, the JINR/LHEP local group, is responsible for maintaining and management of the shared commodities (targets and samples), allocation of the accelerator beamtime to the experiments. Another common tangible resource is the detector park, a set of high-purity germanium (HPGe) detectors, which are shared by several collaborating groups. Part of the detectors are maintained by the JINR/LHEP, while the other part — by another JINR-based participating group, the DLNP/Czech group.

Table II shows shared and assigned tangible resource of each collaborating group. Not all collaborators are usually involved in each experiment.

The hypothesis of the study is that the E&T-RAW Collaboration can be described in terms of a combination of cooperative and competitive behavior. The cooperative behavior is supported and promoted by inter-institutional agreements between the participating institutes and universities (under aegis of Joint Institute of Nuclear Research (JINR)) and common interests of participants from JINR member countries in developing innovative atomic energy programs (Accelerator-Driven Energy concepts). In the case of JINR non-member countries (Germany, Australia, Greece), these can be interests of participating universities, groups, and granting agencies. The cost of accelerator beamtime (which constitutes the major part of the expenses related to the E&T-RAW experiments) is covered by JINR from the funds contributed to its budget by the member countries. Participation of the

TABLE II

Shared and assigned tangible resource in the E&T-RAW project. Source: participant observation.

Group	Shared	Assigned
JINR/LHEP	QUINTA target Detector park	QUINTA target Detector park Beam monitors
JINR (mixed Czech/DLNP group permanently residing at DLNP)	QUINTA target Detector park	Transuranium samples
Kharkov (Ukraine)	QUINTA target Detector park	Uranium-238 pellets Bismuth-209 pellets
Poland	QUINTA target Detector park	Yttrium samples
JINR/FLNR	QUINTA target	Neutron detector
Czech	QUINTA target Detector park	Beam monitors
Australia	QUINTA target Detector park	Solid state track detectors Dosimeters
Germany	QUINTA target Detector park	Lanthanum-139 detectors Beam monitors
Belarus	QUINTA target Detector park	Solid state track detectors Beam monitors
Greece	QUINTA target	Helium neutron detectors

JINR-non-member groups is covered by their episodic contributions from their own grants or other extra-budgetary funding sources (not always commensurate with the beamtime costs). Nevertheless, their involvement in the experiments is partly subsidized by JINR as the host organization promoting a broad international cooperation in accordance with its Charter.

The cooperation is beneficial for the E&T-RAW Collaboration as a hole, because: (1) it allows to gain knowledge of better quality (the more collaborators participate conducting their own tasks, the more useful data is obtained in each experiment and the more papers can be published), (2) the more collaborators are interested in participation, the more strategic power the collaboration has (which is important when competing for resources such as beamtime or budget funds with other experiments and collaborations). The cooperation is reflected in: (1) cooperative task orientation (mutual help in setting up equipment and samples on the QUINTA target; joint publications), (2) cooperative communication (discussions of common problems and sharing of experiment-related information; common tea-time and banquets upon completion of experiments) with establishing collaborative interpersonal relationships. Below we will elaborate on these.

Competition can be internal (within collaboration between its university groups) or external (with other experiments/projects within the Laboratory, for example, for accelerator beamtime). Competition in E&T-RAW arises due to a number of circumstances. First, each participating university or institution has its own accountancy of scientific achievements. Teams are required to report their results to justify their share in collaborative results in order to assure their future funding, help develop scientific careers for their members, and prepare graduate theses for their students. Second, almost all teams are in a possession of certain tangible resources, samples or detectors. During experiments, they install their samples into the shared QUINTA target. Depending on a particular experimental program, certain locations in the target can be more or less suitable for data acquisition, and, therefore, that creates a competition for the access to those locations. After irradiations, most part of the samples has to be delivered to detectors in order to measure their residual activations. The detectors vary in quality (photon registration efficiencies and resolution), therefore, teams compete for the access to the best detectors. Also, detectors of certain groups (Greek or FLNP neutron detectors) require special regimes of irradiation (low beam intensity) that are useless for other teams, whereas the total duration of the irradiation cycle cannot be extended (being a subject of negotiations with other experiments). That creates another trade off as irradiation of the low-intensity detectors compromises the usefulness of the information acquired by the rest of the collaboration. All the above can be described as tangible resources and competition related to them.

Groups do not usually have proprietary rights on most of the tangible resources (samples, detectors) they use; those are of joint ownership of all JINR member countries and virtually any scientist from those countries can get access to their use. On the other hand, different samples and detectors have different scientific value as the better the detectors are, the more important results can be obtained on them. Also, the more various samples a group has at its disposal, the more scientific knowledge it can produce. Therefore, the distribution of the samples and detectors among groups cannot be made clearly on the basis of the formal proprietary rights and can have a potential for tensions. Usually, such distribution is grounded in such group features as: (1) its expertise (for instance, the DLNP/Czech group includes high-precision nuclear spectroscopists, who are the most expert in analyses of extremely complex photon spectra of transuranic samples, which, in turn, require highest resolution HPGe detectors), (2) previous history of success (the Belarus group has always used solid state samples, and the Ukrainian group — uranium pellets) or (3) history of commodity acquisition (some detectors were purchased with the funds raised by the Czech or Polish groups, whereas some transuranic samples — by the German one). However, to enrich their universities' scientific programs as well as due to certain new skills acquired in previous experiments, the collaborators can insist on redistribution for samples or detectors in their favor.

Sometimes groups demand such a redistribution of samples or detectors in their favor having raised funds to purchase certain shared commodity to the collaboration. Competition for intangible resources is linked to respective competition for tangible ones. Gaining strategic power by a group is a recipe for success in collaborative experiments. First, different universities have differing scientific programs with respect to ADS study and that affects the interests of the respective teams. For example, the DLNP-Czech group primarily explores reactions in transuranic samples, the Ukrainian group prefers to study high-energy neutrons produced in QUINTA under accelerated beams using activation of natural uranium pellets, and the Polish group studies the QUINTA's neutron spectrum activating yttrium samples; the Belarusian group employs solid state track samples. All of those samples after activation in QUINTA require subsequent measurements of their residual activity using the shared HPGe detector park. In order to obtain better detectors to their disposal, a group needs to convince the management that their scientific program is of a higher priority, which requires either more strategic power than the others or establishing more effective interpersonal relationships. However, as our analysis in Section 4 shows, in attempts to influence the common goals, the collaborators resort to competition for equipment is stronger than to competition for the attention from managers.

Second, group's home university or institution can prefer a particular aspect of the E&T-RAW scientific program and priorities. For example, the FLNP and Greek groups are more inclined to low-intensity irradiations of the QUINTA target to measure high-energy neutron spectra; Czech, Ukrainian, and Polish groups' programs require high-intensity irradiation as their samples have to be strongly activated in a short time; the German group is more interested in irradiations of GAMMA-3 target (lead target surrounded by a graphite moderator) instead of the entirely uranium QUINTA as their technique (lantanium-139 radiochemical sensors) is suitable for measuring low-energy neutron spectra. Third, if new potential collaborators intend to join the collaboration, current collaborators can use their strategic power to influence the decision of their acceptance or non-acceptance because new members on the one hand bring their own financial contribution (which gives them certain strategic power with respect to the JINR host) but, on the other hand, they can become able to shift the scientific program of the collaboration in the direction unintended by the other groups.

Another facet of competition is the external competition for the beamtime and shared facilities with other projects and experiments. In order to succeed in obtaining necessary beamtime, collaborators have to compete for attention of the top management. The factors creating their strategic power can be: (1) a record of their accomplishments (list of recent project's publications in refereed journals); (2) requests have to be supported by as many groups (countries) as possible; (3) groups need to demonstrate their intention to contribute to the experiment from extra-budgetary funds and/or by equipment.

Therefore, as we discussed above, cross-functional competition can arise between the groups for the choice of beam intensity (by which QUINTA is irradiated), beam energy, and target types (QUINTA or GAMMA-3), and is created by different groups proposing to explore different aspects of scientific program in the same experimental run in a case that all their requirements cannot be reconciled. On the other hand, methods employed by different groups are complementary and all of them are in one way or another different methods of measuring (directly or indirectly) the same quantity, *i.e.* neutrons spectra of the QUINTA (or GAMMA-3) target. Therefore, the E&T-RAW Collaboration groups cannot be deemed a traditional cross-functional type. However, as the differences in their scientific programs exist and they can cause certain tensions and competition, the E&T-RAW competition can be attributed to a special hybrid type. Competition, for example, for the detector park is not inherently cross-functional as the competing groups solve scientifically similar tasks — measurement of neutron or photon spectra. On the other hand, given the groups are affiliated at different universities and countries and, therefore produce results evoked by different programs and owned by different entities. In view of that, such groups and collaborations can be analyzed as cross-functional.

Cooperative interpersonal relationships are an important aspect of functioning of the collaboration. First, group managers carry out mutual visits, regularly exchange emails and holiday greetings. In certain cases, managers of university groups invite managers (or, in more rare cases, regular group members) to visit their universities and cover their expenses during the visits on a mutual basis. Upon completion of experimental runs, groups (or their representative members) are often invited to banquets to extend informal communications. One of important interaction zones of the E&T-RAW Collaboration is a room in the building No. 205 (adjacent to the Nuclotron accelerator), where the collaborators equip and set up their samples and detectors before the experiments as well as run shifts during the irradiations. During the days and hours when they prepare for or perform experiments, they talk informally on a variety of matters, hold joint tea and coffee breaks, and strengthen their interpersonal relationships. Thus, collaborators informally learn needs and plans of each other and how to appreciate them.

Formal agreements between the university groups facilitated by cooperative interpersonal relationships further cooperative task orientation. The groups have to adjust their scientific programs so as to make room for other groups' interests. The role of groups' strategic power and their abilities to attract attention of managers is crucial to achieve cooperative task orientation, which is also very important to alleviate tensions. Groups that require high-intensity beams usually agree to compromise statistical significance of their results and sacrifice a part of the total experimental run duration to the groups demanding low-intensity beams. Therefore, in many cases, the competition for intangible resources carried out by several participating groups simultaneously creates cooperative task orientation amid maintaining interpersonal relationships. However, sometimes the programs are tightly bound to institutional funding sources and a compromise cannot be achieved. In such cases, the groups whose interests are not sufficiently satisfied refrain from participation in the experimental runs. For example, the German group could not allocate funds to participate in a few QUINTA runs because their program and interests were primarily bound to the explorations of the low-energy neutron range and, therefore, the GAMMA-3 target rather than QUINTA. The Greek group had similar reasons to drop off the experiment.

Taking the E&T-RAW Collaboration as an example, we observe that jointly exercised by groups cooperative interpersonal relationships and task orientation create the context for the cross-functional cooperation between university groups within the E&T-RAW Collaboration. The cross-functional cooperation, therefore, can be directly linked to the quality of the produced knowledge (neutron spectra of the QUINTA target). In this paragraph, we have analyzed the E&T-RAW Collaboration as a cross-functional team of a special "hybrid" type. In such collaborations, the cross-functionality is created by not so much differences in functionality (from the scientific viewpoint) but primarily by complementarities of their research programs and ownership of the results. We have argued that the justification of such ascription of the collaboration to cross-functional can be found in differences in the groups' scientific programs as well as the fact that the produced knowledge, despite being interpersonal in nature, is owned by different institutions in terms of knowledge products. All these hypotheses require a quantitative analysis, which will be performed in the next paragraphs.

4. Model of cooperation and competition in E&T-RAW

Model of cooperation in the processes of knowledge creation, proposed and verified by Ghobadi describes the cooperation in the framework predicated on the functional task forces. Research carried out in that framework is focused on the implementation of projects of cross-functional organizations and at the same time has an international character.

The aim of the study is to verify the hypothesis and research tasks discussed above. We suppose that the quality of knowledge, generated in the scientific projects, depends on cross-functional coopetition of independent units. We also assume that cross-functional cooperation has a positive impact on the quality of the created knowledge. The first research task is to identify factors that influence the relationship of cross-functional cooperation in projects of a scientific nature. The aim of the study is not only to identify the factors affecting the relations of cooperation, but also to determine the character of their impact. The second research task is to identify factors that influence the competitive relationship between the units in projects of a scientific nature. We will specify which of the factors (tangible or intangible) and how affect the relationship of rivalry between cooperating units.

Basic auditing was conducted via an online questionnaire. The survey was addressed to 46 people involved in the implementation of 3 major research projects. One of them is already described in paragraph above, the E&T-RAW Collaboration. The other two project participants of which expressed their willingness to participate in the survey, also had an international character. All the three surveyed projects exhibited similarities in their organizational relationships as well as models of cooperation in the realization of their objectives. Thirty-seven questionnaires were returned and 4 of them were not completed and that is why they were excluded from the analyses. The questionnaire included 17 main and 5 additional questions requesting information about the people surveyed: their education title, place of employment, position in the project, gender and age (see Table III).

The model discussed above uses 3 constructs: knowledge quality, cooperation and competition. Knowledge quality is understood as the degree of compliance with the requirements of cooperating units which is declared by the degree of satisfaction with the quantity and quality of shared knowledge. Cooperation between project participants takes place on three levels: cooperation in task's realization (task orientation), interpersonal relationships and communication. Competition is the degree to which project participants have the tendency to contest. The phenomenon of competition is expected to occur in every implemented project, regardless of the venture's specifics. Competition is a natural consequence of dealing with the existence of objective constrains with respect to access to the project resources. All these constructs are reflected in the research questions (see Table IV) and their basic statistics are shown in Table V.

TABLE III

Respondent's particulars.

Sample characteristics	N	%
Affiliation		
University	12	36.4%
Scientific laboratory	18	54.5%
Business	3	9.1%
Role in project		
Project leader	3	9.1%
Team member	30	90.9%
Scientific degree		
Master's degree	6	18.2%
Doctoral degree	22	66.7%
Professorial degree	5	15.2%
Age		
Less than 30	3	9.1%
30–40	9	27.3%
40–55	7	21.2%
55+	10	30.3%
Refused to answer	4	12.1%
Gender		
Female	7	21.2%
Male	26	78.8%

The reliability scale and the results obtained as a result of the questionnaire analysis were estimated using Cronbach's alpha method. Cronbach's alpha factor can take any value less or equal to 1 including the negative ones, although only positive values make sense. If all items of the scale are perfectly accurate, then the reliability coefficient equals 1. Cronbach's alpha indicator value of 0.9 indicates a high accuracy of the measurement. Consistency of the questionnaire has also been verified by removal of certain questions that has not resulted in any significant change in Cronbach's alpha factor.

Table VI illustrates the correlation between analyzed factors. Strong correlation, that is, one for which the ratio is greater than 0.5 indicates that there is a functional relationship between the analyzed factors. In the table, the factors having intermediate or large correlation coefficients are highlighted. In order to verify the aforementioned hypothesis, the linear regression model was used. For the adopted model, R square ratio's value was found to be 0.48. Positive values of two factors (independent variables)

TABLE IV

Constructs and survey's questions.

Construct	Questions
Knowledge quality (KQ)	1. All participants are satisfied with the amount and quality of project-related information shared by other collaborators (universities and scientific units).
Cross-functional cooperation (CFUN)	1. The knowledge shared was estimated as useful and compatible with the project's requirements. 2. The information other collaborators share are helpful in accomplishing project-related goals.
(1) Task orientation (TASK)	1. Other groups work equally hard towards accomplishing joint project goals. 2. Participation of all other collaborators in the experiments is important for overall success of the project.
(2) Cooperative communication (COMM)	1. Participants often publish joint papers together. 2. Participants always discuss their goals and results. 3. Representatives of other collaborators often discuss common problems with other participants. 4. Participants always willingly help each other in accomplishing goals.
(3) Cooperative interpersonal relationships (IREL)	1. Participants often communicate with other collaborators outside the laboratory or office. 2. Participants maintain good relationships and close ties with other collaborators. 3. Participants do not create obstacles to their setting up and measuring of their samples.
Competition/Rivality (RIV)	1. Collaborators often try to gain more influence on the project's goals.
(1) For tangible resources (TGBR)	1. Collaborators regularly compete with each other for equipment (targets, detectors, samples, *etc.*). 2. When collaborators discuss distribution of equipment among their groups, tensions frequently occur.
(2) For intangible resources (ITGBR)	1. Collaborators regularly compete with each other for the attention of the project management. 2. Protecting publication "visibility" of their home institution is a way of life of other collaborators.

reflect their positive impact on the dependent variable (knowledge quality). The method of regression analysis was also used to determine the factors affecting the relationship of cooperation (research task No. 1) and the relationship of competition (research task No. 2). The results are shown in figure 2.

TABLE V

Basic descriptive statistics for the analyzed sample ($N = 33$).

Construct	Average	Standard deviation	Standard error	Variance
Knowledge quality (KQ)	5.18	1.21	0.21	1.47
Cross-functional cooperation (CFUN)	5.02	1.27	0.22	1.62
Cooperative Task Orientation (TASK)	4.98	1.55	0.27	2.40
Cooperative Communication (COMM)	4.44	1.34	0.23	1.80
Cooperative Interpersonal Relationships (IREL)	4.77	1.17	0.20	1.36
Cross-functional Competition (RIV)	5.42	1.12	0.19	1.25
Competition for Tangible Resources (TGBR)	4.80	1.34	0.23	1.80
Competition for Intangible Resources (ITGBR)	4.97	1.15	0.20	1.31

TABLE VI

Data's correlation ($N = 33$). Medium and strong correlations are highlighted.

	KQ	CFUN	TASK	COMM	IREL	RIV	TGBR	ITGBR
KQ	1							
CFUN	**0.596939**	1						
TASK	0.299487	**0.740242**	1					
COMM	**0.512422**	**0.848447**	**0.821765**	1				
IREL	**0.509547**	**0.693214**	**0.583493**	**0.850538**	1			
RIV	0.056622	**0.412663**	0.130886	0.147897	0.029948	1		
TGBR	0.051651	0.157681	0.001909	0.1671	0.03307	**0.526397**	1	
ITGBR	−0.00717	0.354398	0.144876	0.316823	0.337187	0.376164	0.326866	1

Among the factors identified were those that most significantly affect cooperation (significance measured by the coefficient of t-Student ratio). Factors with the strongest impact on the cooperation between research teams apply to all three mentioned above aspects of cooperation: task orientation, communication and interpersonal relationships (see Table VII).

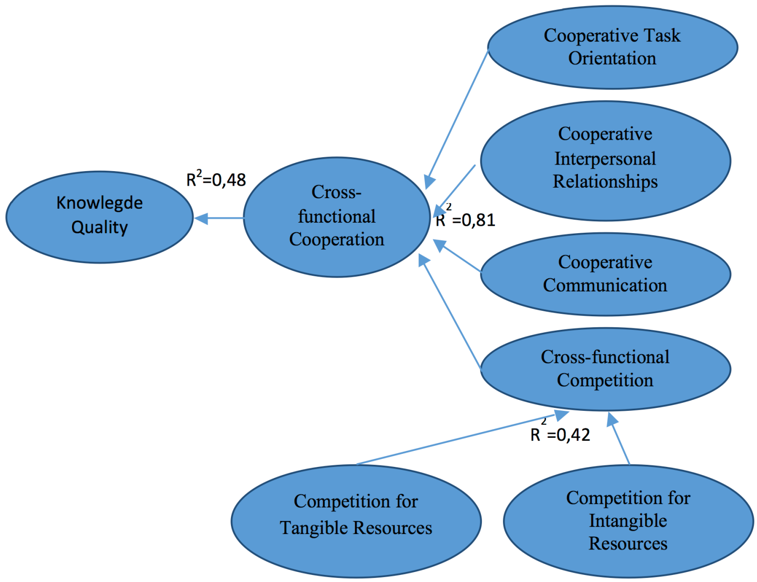

Fig. 2. Cooperation and competition model scientific projects (see also [19]).

TABLE VII

Selected indicators of regression analysis.

Regression statistics	
Multiple R	0.949659975
R square	0.901854068
Standard error	0.469889369
Observations	33

	Coefficient	Standard error	t Stat.	p-value
Intercept	−0.1630	0.8563	−0.1904	0.8507
TASK_11	−0.0596	0.1189	−0.5010	0.6211
TASK_12	0.2817	0.1540	1.8289	0.0804
COMM_1	−0.1570	0.1519	−1.0335	0.3121
COMM_2	−0.1329	0.0977	−1.3606	0.1868
COMM_3	0.4198	0.1069	3.9259	0.0007
COMM_4	0.4265	0.1129	3.7779	0.0010
IREL_1	0.3735	0.1559	2.3961	0.0251
IREL_2	0.0828	0.1109	0.7465	0.4629
IREL_3	−0.1479	0.0846	−1.7474	0.0939

The factor associated with the task orientation in the course of project implementation is the relationship between participation of all other collaborators in the experiments and overall success of the project (TASK_12).

Among the communication factors, a strong cooperative effect can be seen when representatives of other collaborators frequently discuss common problems with other participants (COMM_3) and when participants willingly help each other in accomplishing goals (COMM_4). Another factor that exerts a strong influence on the relations of cooperation in scientific projects is regular and frequent communication with the other collaborators outside the laboratory (IREL_1). That factor is associated with the cooperative interpersonal relationships in project management.

The study revealed the factors that impose negative effect on cross-functional cooperation (we call them destimulants). These are indicators pointing to relationships and communication in the project team. The most important cooperation (significance measured by the coefficient of t-Student ratio) is the one when participants do not raise difficulties when they set up and measure their samples (IREL_3). This is an important observation: cross-functional cooperation is negatively affected by compliant behavior with respect to others in situations of competition for using shared equipment (placing their samples in advantageous locations of the experimental setup). Such a result may suggest that effective cooperation involves and even requires certain competition. Among other possible destimulants is the habit of discussing goals and results between participants of scientific project (COMM_2), *i.e.* cross-functional cooperation does not always require discussing common goals and the results obtained (this agrees with the observation analyzed in the next section that the collaboration consists of the core participants who are involved in the discussions and the peripheral part that is not).

5. Conclusions

The phenomenon of knowledge management and, in particular, sharing knowledge resources, in scientific and research projects is influenced by many factors. Some of them are deterministic. This means that occurring processes are predictable and can be identified with high probability in the planning stage of the project. These are strictly organizational factors related to the material resources of the analyzed projects. Much more interesting group of factors that strongly influences the quality of the knowledge created by the projects are non-deterministic ones. These are the factors related to the intangible assets of the project, mainly the human factor. There are all kinds of relationships between the research team members. These are both relationships of cooperation and competition. The latter group of factors is a key element influencing the actual development of high quality knowledge, which is the desired deliverable of scientific and research projects.

The increasing complexity of scientific projects and limited access to tangible and intangible resources makes it necessary to create partnerships and cooperate to achieve scientific goals. This kind of cooperation often goes beyond organizational boundaries and functional dependencies. Coopetition is a new phenomenon in the history of science development. The situation when rival scientific units start cooperating happens is nowadays common in this domain.

This work aims at verifying the research hypothesis which claims that both cooperation and competition between teams have positive effects on the quality of knowledge created by scientific projects. The aim was to conduct research on the nature of factors that influence the cooperation relations in scientific projects. The research task was to analyze factors facilitating cooperation and competition relationships in scientific projects and their significance.

The study revealed that the collaborations are stratified into the core part involved in all strategic discussions and the peripheral part that often stays out of them. Nevertheless, effective cross-functional cooperation does not always require discussions of the project goals and results with all involved participants. Also, we have observed that competition for shared equipment between collaboration members is able to improve the research outcome because compliant behavior in the situations of competition for equipment was found to negatively affect cross-functional cooperation. These results confirm our hypothesis that competition is required for success of scientific projects and has to complement cooperation between members of project teams.

The analyses have indicated a number of factors which affect positively quality of the created knowledge. They clearly indicate the specificity of research and scientific projects. These are the projects realized by the selected teams of top scientists. A significant part of the project team members are people at the beginning of their science career. These are people with a master's degree or doctorate. These individuals are willing to cooperate with others in the implementation of large scientific projects. It is often an opportunity for them to gain access to specialized equipment and measuring tools. It is also an opportunity to demonstrate their skills and to develop their careers.

Career interests also explain collaborators' strong motivation to compete. The scientific collaboration members who have already achieved statuses of full professors are not so much in need of rivalry. They prefer to take the role of mentors to junior scientists. They are eager to establish cooperation, and they would also accept the role of a co-author of publication. This scenario is typical for the traditional university system and its organizational culture. Another conclusion which can be identified as a result of the study is the predominance of the task-oriented managerial style in projects. The criterion for selection of team members in scientific research projects are their knowledge and competence. Therefore, project managers have no need to interfere in the way in which activities are carried out. Project tasks are delegated to the team members and it depends on them how to achieve them. One of their aims is to create always high-quality knowledge. However, observed in this study balance of cooperation and competition suggests that scientists' epistemic interests are often intertwined with non-epistemic ones.

The results of the study point out to the necessity of simultaneous relationship of cooperation and competition in teams implementing projects of scientific research. The results that have been presented in the earlier part of this work confirm the hypothesis of the necessity of cooperation in order to achieve high-quality knowledge. Additional insight is an indication of the importance of simultaneously maintained relations of rivalry. In the research hypotheses, we assumed the coopetition relationship as a strategy for implementing projects of a scientific nature. Our analyses underline that for the production of high-quality knowledge, it is complementary to cooperation, harmonizes interactions within the project, and represents itself an important determinant of success. The results indicate that the effectiveness is achieved as a result of the synergy of two conflicting relationships in the process of creating high-quality knowledge in the processes of a scientific nature. We have also revealed the stratification of the collaboration into the core part (composed of decision-makers) and the peripheral part (composed of subordinate experimentalists).

The study has a few limitations that need to be noted. Firstly, it is a relatively small sample size. The research was targeted at project members and project leaders. The survey was addressed only to the participants of 3 projects which were limited to only 2 science disciplines: physics and management. Secondly, projects, that have been analyzed, have a strictly scientific character. The study does not include aspects related to industrial implementations of the product (knowledge), neither did it include market's verification of created knowledge (implementation, utility, effectiveness). The quality of knowledge, created as a result of the project was assessed only by the respondents. As a result, the knowledge quality was evaluated by its creators. Nevertheless, it can be assumed that the limitations in objective assessment could be offset by the great experience of the participating scientists.

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