Knowledge creation and management in the five LHC experiments at CERN: implications for technology innovation and transfer

B. Bressan
CERN, Geneva, Switzerland & Department of Physical Sciences, Helsinki University, Helsinki, Finland

K. Kurki-Suonio,
Department of Physical Sciences, Helsinki University, Helsinki, Finland

J. Lavonen,
Department of Applied Sciences of Education, Helsinki University, Helsinki, Finland

M. Nordberg,
CERN, Geneva, Switzerland

H. Saarikko
Department of Physical Sciences, Helsinki University, Helsinki, Finland

M. Streit-Bianchi,
CERN, Geneva, Switzerland

ATL-OREACH-PUB-2009-001
26 January 2009

GENEVA
2008

Abstract

The present study analyses knowledge creation, acquisition and transfer in the five LHC physics experiments at CERN: ALICE, ATLAS, CMS, LHCb, and TOTEM.

A questionnaire was provided during collaboration meetings and a total of 291 replies were obtained and analysed.

The results of this research study provide evidence that the social process of participation in meetings, acquisition of skills in different areas, and the development of interests by interaction with colleagues are key elements of the learning process. Furthermore, the results indicate that knowledge acquisition in a multicultural environment plays a mediating role in the interaction between social capital constructs (social interaction, relationship quality, and network ties) and competitive advantage outcomes (invention development and technological distinctiveness). Social interaction, relationship quality, and network ties are connected to greater knowledge acquisition, and also contribute to innovation and transfer of the knowledge to industry.

The fertile environment of the five LHC experiments building and managing multiple processes, involves a dynamic, interactive, and simultaneous exchange of knowledge both inside and outside their organization.

List of acronyms

ALICE	**A L**arge **I**on **C**ollider **E**xperiment (http://aliceinfo.cern.ch/)
ATLAS	**A T**oroidal **L**HC **A**pparatu**S** (http://atlas.ch/)
CERN	**C**onseil **E**uropéen pour la **R**echerche **N**ucléaire (www.cern.ch)
CMS	**C**ompact **M**uon **S**olenoid (http://cms.cern.ch/)
DELPHI	**DE**tector with **L**epton **P**hoton and **H**adron **I**dentification (http://delphiwww.cern.ch/)
HEP	**H**igh **E**nergy **P**hysics
ISR	**I**ntersecting **S**torage **R**ings
LEP	**L**arge **E**lectron **P**ositron collider
LHC	**L**arge **H**adron **C**ollider (http://lhc.web.cern.ch/lhc/)
LHCb	**L**arge **H**adron **C**ollider **b**eauty (http://lhcb.web.cern.ch/lhcb/)
MS	**M**ember **S**tate
OPAL	**O**mni-**P**urpose **A**pparatus at **L**EP (http://opal.web.cern.ch/Opal/)
R&D	**R**esearch **& D**evelopment
TOTEM	Total Cross Section, Elastic Scattering and Diffraction Dissociation (http://totem.web.cern.ch/Totem/)

List of figures

List of tables

Contents

1 Introduction

The purpose of scientific research, in general, is to find the laws to describe nature. It is pursued with the purpose of understanding phenomena and explaining the world in which we live. To understand phenomena, the comprehension of the scientific process is important, but in doing that to satisfy our needs, the technological process is essential. More and more often society asks physicists to explain what advantages society has gained from their research and which outcomes can be expected.

There are mainly three types of direct benefit to technology and society from physics research: first, entirely new fields of technology may be created and second, the pioneering technology created may solve technical or social problems. Thanks to the introduction of new scientific instruments, it is possible to improve knowledge acquisition as suggested by this study. This yields the third type of benefit, which is the most important: the transfer of acquired knowledge that may generate new innovation in many different fields. The lack of interaction among scientists and industry is the fundamental problem for science and technology transfer. It stems from a disparity of intent; between what is conceived to be the final goal of science on the one hand and the applicability of technology on the other.

Knowledge creation has become an interesting and relevant research topic for the impact it has for innovation and creation of new ideas. Big Science organizations such as CERN are a good place for such kinds of investigations as they train every year thousands of new researchers who constitute qualified people well trained both for academia and industry. The knowledge spillovers from fundamental science are also a source of beneficial outcome for the economy and for society. CERN also represents a good place to investigate how knowledge is created, acquired, and transferred by:

- providing and improving an introduction to other knowledge bases;
- expanding opportunities for the development of knowledge;
- improving competences;
- integrating skills and competences;

- providing and facilitating a variety of interactions possibly leading to technological innovation.

The knowledge acquired inside the organization catalyses and amplifies the knowledge created by individuals and is embedded at the group level through dialogue, discussion, experience sharing, and observation. It is a continuous and dynamic interaction between tacit and explicit knowledge, thanks to which innovations emerge. The nature of knowledge is represented by the individual's value system. This is a fundamental basis for explaining how innovation is realized. Furthermore, social interaction is built up according to the intensity, frequency, and breadth of information exchanged.

Stronger social interaction provides scientists and engineers with an insight into the specialized systems and structures of CERN and results in specialized information, language, and know-how. By intensifying the frequency, breadth, and depth of information exchange, social interaction increases relation-specific common knowledge especially in Big Science collaborations such as the CERN LHC experiments. Such diversity is necessary for new knowledge creation; it exposes the users to a greater range of knowledge acquisition opportunities and enhances the users' ability to value such opportunities. Common knowledge is required for learning to occur between two exchange partners; however, some diversity of knowledge is necessary for the transfer of new knowledge to occur. Indeed, exposure to many different external contacts is essential for learning in a competitive environment. The importance of social capital for technological distinctiveness and the input of the diversity and frequency of interactions in the innovation process have recently been assessed [Autio et al. 2003].

We now live in a ‘Knowledge Society’ [Drucker 1993], and in contrast to our former industrial society, where knowledge used to be just a resource, today *knowledge is the key factor* in innovation.

The educational impact of an intergovernmentally funded scientific centre such as CERN has been assessed in previous studies [Bressan 2004, Camporesi 1996]. These studies attempted to evaluate what competitive knowledge and core skills people develop and to determine the market value of their skills for CERN Member States’ industries.

For this purpose a knowledge creation, acquisition, and transfer framework model was created and verified.

The present study based on the five LHC experiments makes a detailed analysis of knowledge creation in the technological process as described by the model proposed in Fig. 1.1 [Bressan 2004].

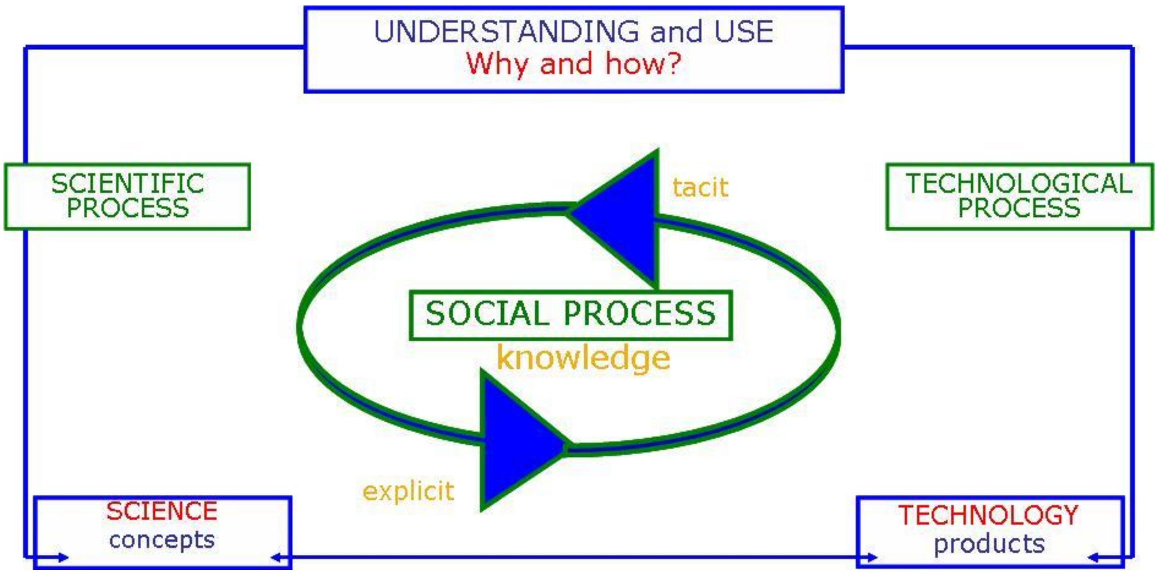

Fig. 1.1: The knowledge creation, acquisition, and transfer model.

Knowledge is created and expanded in a dynamic *human* process through *social interaction*, being converted through four different modes – socialization, externalization, combination, and internalization.

By introducing knowledge management concepts to science, this model helps to reduce the gap between the scientific and the technological worlds. These concepts have so far been limited to companies and information technology. The model also explains how technology transfer is closely related to and continuously fuelled by knowledge transfer. However, knowledge is highly related to an individual and organizational context and the tools available. Individuals are the key recipients when it comes to transferring, decoding, and utilizing existing knowledge. From individual perception, assessment, and analysis of context and tools in which the five LHC experiments evolved, it has been possible to track the various aspects of knowledge acquisition and transfer. Furthermore, routines and tools which are the media used to transfer knowledge have also been analysed by the present study.

In a quantitative and comparative assessment of the knowledge acquired by physicists and engineers who have worked at CERN, we have investigated how one's nationality, and therefore different academic curricula and cultural differences can affect knowledge perception, learning, and acquisition [Huuse and Nordahl 2004, da Cruz et al. 2004]. Furthermore, the environmental and multicultural aspects and interactions generated by a Big Science organization with scientific aims and high technological distinctiveness have been investigated among individuals sharing a strong common scientific identity. The study also aims at bridging the gap that exists between the industrial and scientific world, in the field of knowledge management. The study confirms, with quantitative data, and conceptualizes the role CERN has played over the past 50 years as a leading organization in creating knowledge, not only in the field of HEP but also in related technological fields. It also makes explicit the importance for individual and organizational knowledge creation in a multicultural scientific and technological environment. Many students, scientists, and engineers are embedded in a scientific atmosphere and are given the opportunity to confront and to interact with a vast array of technical and scientific specialists. CERN as an organization has its own epistemology, with its own tacit and explicit knowledge and creating entities (individuals, groups, and their organization).

At CERN, however, technology makes available to European physicists installations whose cost would be prohibitive for a single nation. Installations or equipment that are, at CERN, using cutting-edge technologies in many fields, from special materials to electronics, data acquisition and analysis.

The present project continues from the detailed analysis of knowledge creation in the technological process as described by the model proposed [Bressan 2004] to investigate the interaction patterns established in the five LHC experiments that lead to innovative product development, and the appropriate language and level of communication to manage huge endeavours in which more than 5000 physicists and technicians from all over the world participate.

A large part of the transfer of technology from CERN comes through the transfer of people's knowledge or know-how. Within CERN, and the institutes collaborating in the CERN physics programme, experts are needed in many fields of technology to perform the core business of fundamental research. This expertise is being continuously transferred to industry and external institutions in a number of ways through people. A study has shown that of the young researchers, who participated in two of CERN's LEP experiments some 40% from DELPHI, and about 46% from OPAL have gone to work in industry [Camporesi 1996, OPAL 2003].

Each year hundreds of young people join CERN as students, fellows, associates, or staff members on first employment. In summary, the continuous flow of people who come to CERN, who are trained by working with CERN's experts, and who then return to their home countries is a useful example of technology and knowledge transfer (TT & KT) through people. Experience shows that industry, universities, and other private and public employers value highly these people and the on-the-job training they receive at CERN [Bressan and Streit-Bianchi 2005, OPAL 2003].

The interface between the industrial and public research domains is multifaceted, and different research institutions may possess distinctive potentials for the knowledge creation for economic purposes. We hope that the analysis reported here will trigger further inquiries into the corollary learning and innovation impact of CERN and Big Science centres in innovation systems.

Previous research demonstrated that the potential of Big Science centres may well be currently under-utilized in industry [Autio et al. 2003]. Specifically, paying more explicit attention to technological learning could enhance the spectrum of technological impact. Economic returns have been monitored simply on industrial return to member countries. The total economic benefit resulting from technological learning in industry greatly outweighs this aspect [Autio et al. 2003, Nordberg 1997, Bianchi-Streit et al. 1984, and Schmied 1975]. It is to be noted that in LHC experiments almost 50% of the participants are not from CERN Member States. This means that spillovers of technological learning are worldwide.

2 Material and methods

The focus of the survey was on CERN-related learning, organizational, and other benefits. The survey questionnaire (Appendix) was designed according to normal survey practice and built up on experience based on previous questionnaires [Autio et al. 2003, Bressan 2004, and Huuse and Nordahl 2004]. Multi-item scales were used to measure both predictor and outcome variables, and the scales were derived from previously validated scales whenever possible. When CERN-specific scales were developed, this was done by paying attention to pertinent theoretical frameworks and research questions [Autio et al. 2003, Huuse and Nordahl 2004]. All scales were pre-tested in test interviews, and the feedback from these was used to iron out any inconsistencies and potential misunderstandings. A detailed analysis of the answers was used to finalize the questionnaire and make statistical analysis easier. However, after having collected the questionnaire from the ATLAS Collaboration, it was realized that information such as age and status was missing and this was added to the questionnaires for the ALICE, CMS, LHCb and TOTEM collaborations. In addition, question 9 was not clear enough, as illustrated by the various comments received, and had to be reformulated.

Descriptive statistical analysis, logistic regression, and multiple (OLS) regression analysis were employed as the primary statistical analysis methods to analyse the survey data. Colinearity was not a significant problem as proven by OLS regressions. The internal reliability coefficient of this scale was measured using Cronbach's α on a scale from 0 to 1. High value would suggest a high degree of internal reliability for the scale. We also employed a Likert-style scale to measure various parameters, with the scale ranging from 1 (disagree) to 7 (agree). This same scale was used for all outcome variables.

As a final step of our analysis, we examined bivariate correlations between relationship outcome variables and their predictors. We also examined how the various outcomes are related to one another. Finally, we examined what drives the creation of relation-specific assets that smoothes the relationship management as well as various aspects related to internal communication procedures. A high degree of inter-correlation between outcome variables was also looked at. Analysis was made both at single collaboration level and with all experiments confounded.

The questionnaires were distributed during collaboration meetings and accompanied by a covering letter. The respondents were informed of the aim of the study and that the questionnaire was kept anonymous. The questionnaires were also made available at the collaboration secretariats and in CMS, also advertised in the CMS newsletter. The ATLAS management was able to obtain a good response by the end of a collaboration meeting in Paris in November 2005. For the other experiments, individual contacts were necessary by going in offices to meet members of the collaboration during 2006. This was done in order to achieve a reasonable number of replies. Not all the questions were completed. This has been taken into account in the analysis. It explains why the number of answers does not always add up to the total number of questionnaires received.

The total number of questionnaires returned for the five LHC experiments is summarized in Table 2.1.

Table 2.1: Number of questionnaires returned for the five LHC Experiments.

ATLAS	ALICE	CMS	LHCb	TOTEM	TOTAL
116	51	62	52	10	291

Although the total number of questionnaires returned from ATLAS doubles that of ALICE, CMS, and LHCb, the responses did not differ significantly. When the distributions between respondents participating in different experiments were compared with a χ^2 test, no statistically significant difference between the distributions was observed. The data from the questionnaires were reported in Excel tables and the analysis of data was done after all the questionnaires had been collected using SPSS version 12.0.2 and analysing merged and individual collaboration data.

The sample of replies obtained represents a good cross-section of project managers, scientists, professors, and students participating in the collaborations.

The design of the questionnaire

The questionnaire was structured to determine what the respondents have learned from their experience at CERN in terms of acquired knowledge and know-how and how this has been transferred inside the groups and entire collaboration. Some questions have two scale items, one determining the frequency and the other determining the value attributed to the specific questions.

The structure of the questionnaire

The first part of the questionnaire is dedicated to personal information, asking for a description of the current position held by the respondents, as well as the position held while at CERN. The questionnaire then asks for specific information on scientific and technical functions and expertise, reasons for joining the collaboration, and technological developments performed (questions 1, 2, 3, 4, 5).

Communication and documentation barriers and enablers, and their impact in terms of efficiency and innovation are also assessed (questions 6, 7, 8, 9, 10, 11). The project network and management is addressed by questions 12, 13 and 14 whilst the importance of knowledge and industrial transfer is sought by questions 15, 16, 17 and 18.

The project was designed to answer the following research questions:

1. "What are the outcomes and dimensions of the knowledge transfer process in the LHC experiments?"
2. "To what extent does the scientific organizational and communication structure facilitate the knowledge transfer, technological outcomes and innovation?"

Other important aspects analysed are:

- The organizational and personal dimensions of knowledge transfer within each experiment and its sub-units and whether differences between the various experiments due to their size or interactions mechanisms allow for knowledge sharing.

- Whether the organizational structure takes into account mechanisms of knowledge transfer and innovation.
- Whether knowledge transfer depends on the domain of expertise, size of the collaboration, type of structure put in place, etc.

3 General analysis

To identify the outcomes, a similar approach to that used for projects aimed at technology transfer was used [Huuse and Nordahl 2004]. This has been challenging as different individuals may perceive them in a different way according to their role in the collaboration.

The number of individuals working on each experiment varies across the different participating organizations and institutes; so does the working time of each individual.

The number of institutes per experiment and the number of countries represented is reported in Table 3.1. The ATLAS Collaboration has about 1700 members, CMS 2000, whereas ALICE has around 1000 collaborators and LHCb around 650. TOTEM is the smallest collaboration, equivalent to 3% of the largest collaboration.

Table 3.1: Institutes and countries in the five LHC experiments.

	ATLAS	CMS	ALICE	LHCb	TOTEM
Number of Institutes	159	182	94	48	11
Number of Countries	37	38	28	13	8

The nationality distribution of the respondents is reported in Fig. 3.1. A total of 36 nationalities was represented in the sample. Physicists represent 75% of the respondents, whereas engineers and computer scientists account for 16% and 9%, respectively.

The sample of responses is truly representative of the collaborations and of its multicultural nature. The effect of the multicultural factors on the collaborations has also been assessed and analysed according to elements specific for the studied framework.

The demographic distribution of the LHC experiment project members is reported in Fig. 3.2. The maximum age of respondents was 71 years and the youngest was 21. It is interesting to note that the age range below 40 years is well represented in the respondent sample.

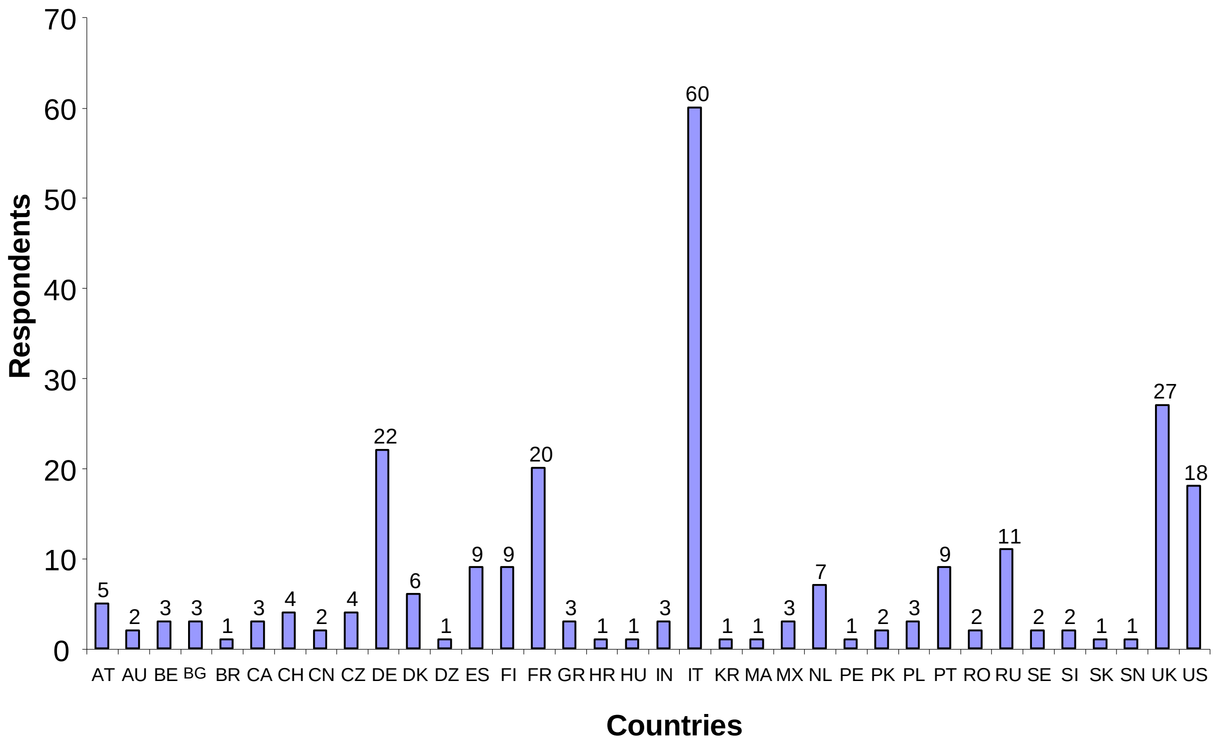

Fig. 3.1: Nationality distribution of respondents.

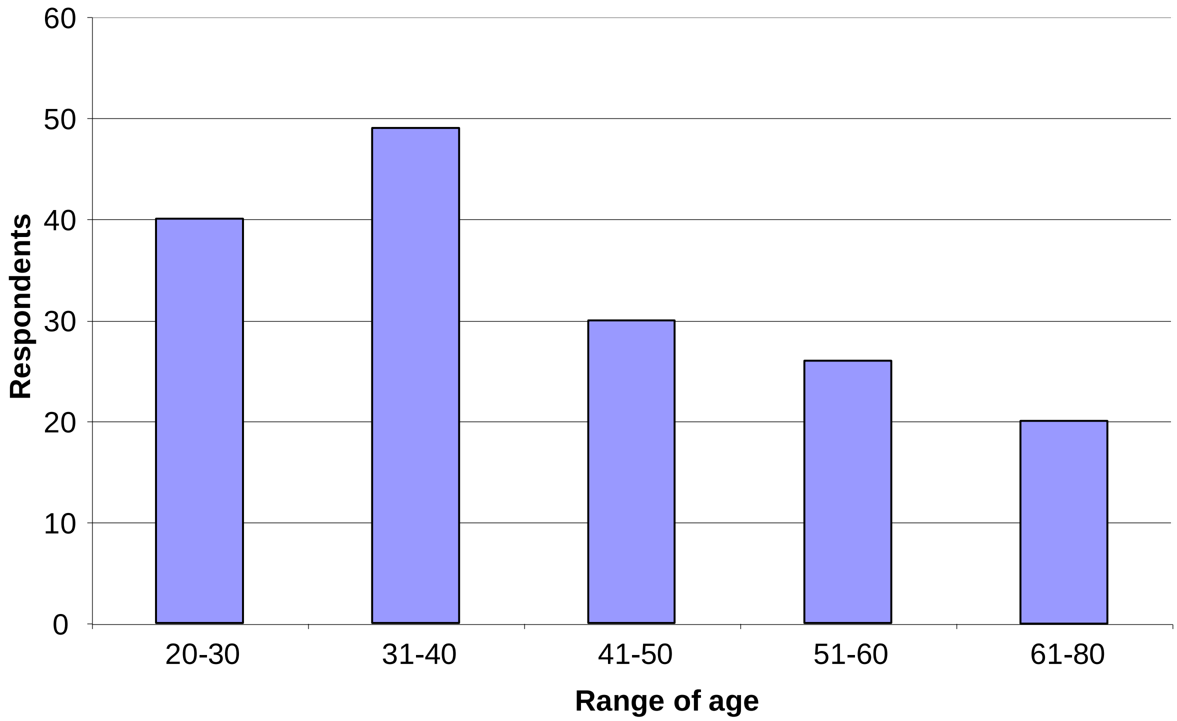

Fig. 3.2: Age distribution of respondents.

Table 3.2 reports the status distribution of personnel in ALICE, CMS, LHCb and TOTEM Collaborations. This information was not asked for from the ATLAS experiment. Table 3.3 considers the domain of expertise and function covered by the respondents in the five LHC experiments. Multiple replies were given for the domain of expertise and function by the respondents in most of the 291 questionnaires. Thirty-two per cent have managerial or coordination functions.

Table 3.2: Status of respondents from ALICE, CMS, LHCb, TOTEM Collaborations.

Student	**Ph.D. / Fellow**	**Assistant**	**Professor**	**CERN Staff**
17	53	24	46	30

Table 3.3a: Domain of expertise.

Domain of expertise	
Physics research	211
Software, engineering and analysis	130
Detector hardware	127
Electronics	57
Data acquisition	51
Administration	43
Other	29
Total questionnaires	**291**

Table 3.3b: Functions of the respondents.

Function / Role	
Physics researcher	219
Engineer	47
Computer scientist	55
Technician	15
Management / Coordination	94
Other	6
Total questionnaires	**291**

The working place where the respondents were spending more than 50% of their time is CERN for half of the sample, and universities all over the world for the other half. This means that a large fraction of university personnel is spending a large part of their time at CERN. More than 45% of the respondents spend 100% of their working time in the LHC experiments, as illustrated by Fig. 3.3.

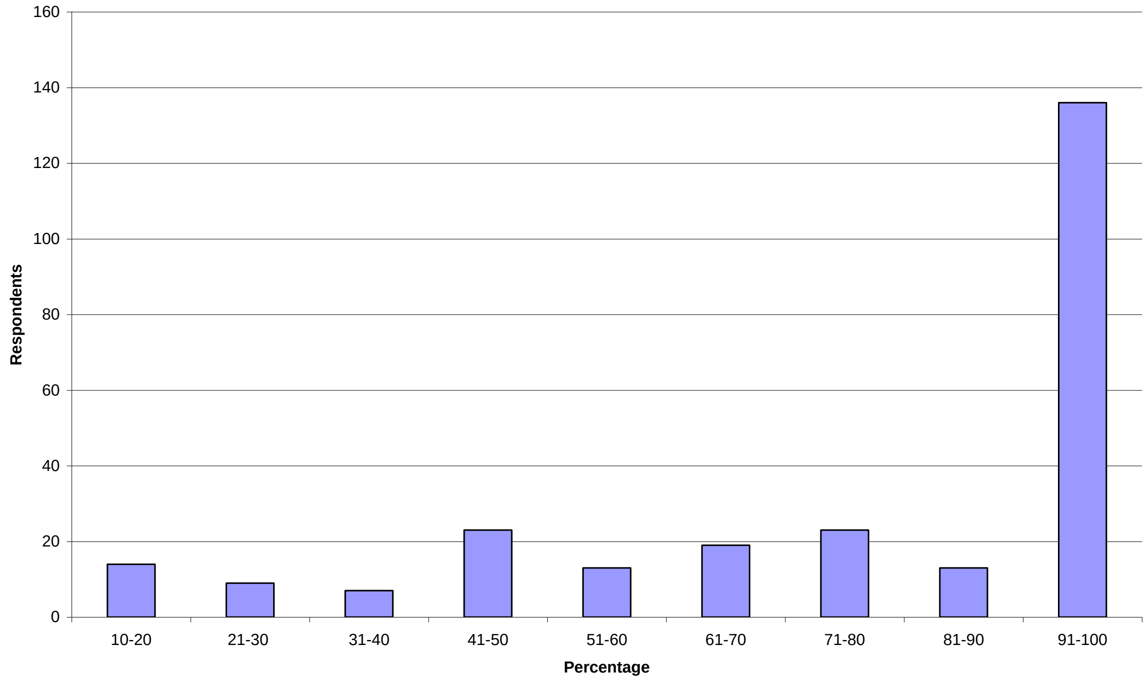

Fig. 3.3: Percentage of working hours spent during 2005 – 2006 in the LHC experiments (100% = full time).

Before joining the LHC project, 55% of the respondents had worked in some previous CERN collaboration (LEP, SPS, PS, ISOLDE, etc.), 44% worked in physics collaborations outside of CERN, 16% had previous work experience in physics. Multiple replies were given to these questions.

The analysis was done by considering and weighting each question by the total number of respondents (R) and the missing replies (M).

The institute and individual motivation for joining the LHC project (questions 1 and 2) is reported in Table 3.4. The respondents were asked to respond using a scale from 1 (disagreement) to 7 (agreement). The institute and the personal motivation show a very similar distribution with the technological motivation being more spread. This suggests that more importance is given to the scientific interest. About 10% of respondents consider the technological challenge as not being important.

As expected, owing to the size of the experiments and challenges represented by managing such big collaborations, about half of the respondents to question 3 consider, as indicated in Table 3.5, that the learning in terms of management and functioning of large collaborations will have a positive impact on their future careers. Because of the impact of the Grid on the analysis of the LHC data, Information Technology was indicated as a positive learning factor by 21% of the collaboration members.

Table 3.4: Institute and individual motivation for joining the LHC experiments.

Scale	**Institute motivation**		**Personal motivation**	
	Scientific	Technological	Scientific	Technological
	R = 267, M = 24	R = 263, M = 28	R = 281, M = 10	R = 275, M = 16
1	1	5	1	8
2	1	8	1	4
3	1	4	5	14
4	8	29	15	52
5	18	55	20	43
6	73	77	73	64
7	165	85	166	90

Do scientists move towards innovation with practical applications? This issue has been addressed directly or indirectly by questions 5, 14, and 17. The results are reported in Tables 3.5 and 3.6 and will be more thoroughly discussed in Section 4.

Table 3.5: Domain of technological learning useful for the career.

Domain of technological learning **R = 183, M = 108**	**Frequency**
Information Technology	39
Detector technology	12
Physics	18
Electronics	11
Management & Collaborations	86

Table 3.6: Innovative developments within the LHC experiments per domain.

Technological domain R = 194, M = 97	Frequency
Computing	64
Detector technology	79
Electronics	48
Mechanics	11
Other	8
Not known	6

As illustrated by Table 3.7 (question 4), the percentage of people that are thinking of starting an industrial company is about 6%. Seventy per cent of them are under 40 years of age and 80 % of them are physicists. Of those who consider going to work for a company, about half are below the age of 55. The percentage of respondents that are considering remaining in Academia is high (72%), as expected. Sixty-five per cent of the respondents consider that the development within the LHC experiments can be useful and applied in fields outside HEP, and 55% believe to have contributed to the developments of innovative technologies. This high percentage reflects a trend towards entrepreneurship and technology transfer which has been recently confirmed in a survey carried out at CERN in 2006 [Sessano, 2007].

Table 3.7: Career development inside and outside HEP.

Career development	Percentage
Start a company	6
Go to work for a company	19
Continue (or start in academia)	72
No reply	3

These developments have been categorized as reported in Table 3.6 (question 5). Computing, detector technology, and electronics represent 33%, 40% and 25% of the reported innovation, respectively.

Communication in Big Science collaborations is of paramount importance especially considering the worldwide distribution of the collaboration members.

The respondents in question 6 were asked to evaluate both the importance and frequency of tools used to communicate as well as to estimate the value of importance they give to communication, on a scale from 1 (low) to 7 (high). The results obtained are reported in Table 3.8a and 3.8b, respectively. For the Likert scale, Cronebach's α calculated value is 0.74.

Table 3.8a: Frequency of tools used in communication in the LHC experiments.

Frequency	**Same work place, same role R = 282, M = 9**	**Same work place, different role R = 283, M = 8**	**Different work place, same role R = 282, M = 9**	**Different work place, different role R = 281, M = 10**
Daily	4	1	4	12
Several times/week	3	11	44	106
Weekly	9	24	60	60
Several times/month	12	59	65	38
Monthly	59	84	69	42
Never	195	104	40	23

Table 3.8b: Importance given to communication.

Scale	**Same work place, same role R = 272, M =19**	**Same work place, different role R = 275, M = 16**	**Different work place, same role R = 271, M = 20**	**Different work place, different role R = 271, M = 20**
1	3	1	1	6
2	1	5	5	9
3	1	9	5	25
4	16	30	25	48
5	31	56	45	55
6	85	81	81	63
7	135	93	109	65

People working at different working places were having frequent contacts and this especially when they were assuming different roles in the experiment. This type of exchange is extremely important for knowledge transfer.

Table 3.9 shows frequency and importance of communication obtained for question 7. The mean and median are both measures of central tendency. The mean is the arithmetic average and median is the value above and below which half of the cases fall (the 50th percentile). The median is not sensitive to outlying values unlike the mean, which can be significantly affected by a few extremely high or low values.

Table 3.9: Communication, new knowledge and skills in terms of frequency and importance.

Statement	**Frequency (Median value) (1 = never, 6 = daily)**	**Importance (Average value) (1 = low, 7 = high)**
1. Telephone	5	6
2. Tele/video conference	2	5
3. E-mail	6	7
4. Newsgroup	2	4
5. Technical development meeting	3	5
6. Collaboration meetings	2	6
7. Taking part in the research activity: *planning activity*	3	6
8. Taking part in the research activity: *measuring*	2	6
9. Taking part in the research activity: *analysing data*	3	6
10. Taking part in the research activity: *writing a paper*	2	6
11. Taking part in the technology development: *planning activity*	2	6
12. Taking part in the technology development: *construction*	2	6
13. Taking part in the technology development: *evaluating*	2	6
14. Taking part in the technology development: *writing a paper*	2	5
15. Taking part in the problem-solving activity	3	6
16. Informal meeting space in cafeteria (lunch, coffee, etc.)	5	6
17. Informal meeting space in the evening (dinner, hostel)	2	5
18. Reading, writing and disseminating project documentation	3	6
19. Reading info from the general web pages	5	6
20. Reading info from the web pages (research article)	4	6
21. A course in particle physics (theory/experimental)	2	5
22. A course in particle instrumentation	2	5
23. A course in informatics	1	5
24. A course in material sciences; solid state physics	1	3
25. A course in engineering (mechanical, electrical)	1	4
26. A course in management of projects; innovation; finance	1	4
27. Other	0	0

Seven factors can be identified:

- media and communication (statements: 1, 2, 3, 4)
- technological activity (statements: 11, 12, 13, 14)
- research activity (statements: 7, 8, 9, 10, 15)
- reading (statements: 18, 19, 20)
- formal meeting (statements: 5, 6)
- informal meeting (statements: 16, 17)
- training (statements: 21, 22, 23, 24, 25, 26).

These seven factors represent 68% of the total variance of all the items. For the Likert scale, Cronebach's α calculated value is 0.91.

Question 8 refers to tools that could have made the project runs in a more efficient way. Twenty-seven per cent of respondents would have liked to have had more technical development meetings at CERN or in their home Institute, whereas the collaboration meetings have been assessed to be fully sufficient with fewer than 10% requesting more of these meetings. More than 25% would have liked to have had more informal meetings. A high percentage of people (60%) considered the project to be not efficient enough in terms of project documentation. Sixty per cent of them would have liked the documentation to be disseminated more frequently within the collaboration. The telephone, video and email were considered to be used sufficiently. Only 4% of respondents did not reply to this question.

Question 9 refers to the type of documentation that was to be produced in a large amount by the collaboration. The technical documentation and information provided by the participating members of the group was considered to be not sufficiently often (48% and 40%, respectively). It is interesting to note that 5% only did not reply to questions related to the experiment documentation whereas for information to the public and the records of individual contribution the amount of missing responses was 43%. This suggests that Outreach and public communication is not yet considered important by the collaboration members.

The information and documentation for members within the collaboration and to people outside the collaboration was addressed in question 10. Only 3% did not answer this question. Seventeen and a half per cent of respondents consider themselves to be poorly informed about the development of the project; 10% of them are students. Forty-nine per cent of the respondents consider that writing project documentation takes too much time. This reply is contradictory to the earlier assertion (question 8) that the respondents would have liked to have had more technical documentation. This could reflect the recognized importance of good project documentation but dislike of the amount of work it takes to achieve it. Only 15% of respondents complained of lack of information flow on the project development. It is interesting also to notice that, in spite of a good sharing of information within the participating institutions, 17% complain that R&D results are not shared with other LHC experiments.

The various aspects of networking within the collaboration are addressed by question 11, a question not answered by 2% of the respondents. To this question about 20% replied that it is difficult to find the right person to solve work-related problems; meaning that not enough effort is put in by the collaboration to inform about the available respective specific competences.

Good communication exists with persons within or outside sub-projects in each experiment. Eight-six per cent benefits from the expertise of other people. Furthermore 48% of respondents benefits from the expertise of people working on other LHC experiments. For the Likert scale, Cronebach's α calculated value is 0.78.

The multicultural environment on which the LHC experiments are building was addressed by question 12. This question was not replied to by 2%. The opinion that working in a multicultural environment is beneficial is shared by all participants in the LHC experiments and this amounted to 90% of positive responses. The positive aspects of multicultural/multifield interaction are a source of innovation and may benefit the fields outside HEP. Almost 84% of the respondents truly agree this statement. For the Likert scale, Cronebach's α calculated value is 0.60.

Various aspects of project management including scientific outcome, availability of resources and infrastructure, time pressure, etc. were addressed by question 13. In particular, only 9% of the respondents consider that the scientific outcome was not always kept in mind in the management of the project suggesting a strong sharing of common goals. Fifty-three per cent considered that inadequate resource and infrastructure support constitute an unnecessary obstacle to the development of the project. Although this question was not explored in more detail, the high response reflects a feeling of inadequate resource allocation by CERN as a host laboratory and/or by the participating home institutions. The missing responses to this question amount to 6%. For the Likert scale, Cronebach's α calculated value is 0.75.

Table 3.10 reports the values of frequency and importance obtained for question 14. The average missing response amounts to 7%. Four explanatory factors of importance were found:

- technical skills (statements 3, 5, 9, 10, 11, 12)
- scientific skills (statements 4, 6, 7, 8)
- social skills (statements 1, 2, 9, 13)
- labour market skills (statements 14, 15, 16).

These four factors represent 66% of the total variance of all the items. For the Likert scale, Cronebach's α calculated value is 0.88. In general, having worked for the LHC experiments increased the value for the labour market. Very important has been the impact of increased relations with and knowledge of industry; 26% of the respondents believe that it will be easy for them to find a job in industry.

Table 3.10: Outcome of knowledge transfer, skills, network and industry (frequency and importance of the statement).

Statement	**Frequency (Median value) (1 = never, 6 = daily)**	**Importance (Percentage) (5, 6, or 7)**
1. Improved and widened social network	5	70
2. Increased multidisciplinary insight	5	71
3. Improved management skills	5	67
4. Enhanced scientific knowledge	6	83
5. Enhanced scientific skills: *planning skills*	5	69
6. Enhanced scientific skills: *measuring skills*	5	53
7. Enhanced scientific skills: *data analysing skills*	5	62
8. Enhanced scientific skills: *paper writing skills*	5	54
9. New technical skills: *planning skills*	5	55
10. New technical skills: *construction skills*	5	52
11. New technical skills: *evaluating skills*	5	50
12. New technical skills: *paper writing skills*	4	40
13. Increased international network	6	79
14. Increased relation and knowledge of industry	5	50
15. New professional interests	5	51
16. Increased opportunity to find a job in industry	4	26

The importance of outcomes for the institutions and the nature of the interaction with companies were dealt with questions 15 and 16. For the institutions, participation in the LHC project has been very important in terms of R&D and motivation, deepening and widening the expertise of the collaborators. Forty-eight per cent of the respondents consider that company interaction has resulted in the application of cutting-edge technologies, large amounts of which can be applied outside LHC.

Table 3.11 reports the values of Frequency and Importance obtained for question 17. The interaction with industry reveals that on average the relation was monthly (only telephone and email) or several times a month (during planning and construction).

The response to point 8 clearly indicates that industry was involved more as a contractual supplier for the experiments rather than as an active partner. This finding is consistent with a study carried out on purchasing at CERN during the LHC machine construction [Autio et al. 2003].

Tab. 3.11: Type and value of communication in the collaboration with industry (frequency and importance of the statement).

Statement	**Frequency (Median value) (1 = never, 6 = daily)**	**Importance (Average value) (1 = low, 7 = high)**
1. Telephone	3	6
2. Tele/video conference	1	2
3. E-mail	3	6
4. Newsgroup	1	2
5. Technical development meetings	2	5
6. Taking part jointly to technical conferences: writing a paper	1	4
7. Taking part to the technology development: planning activity	2	4
8. Taking part to the technology development: construction	2	5

4 Discussion

A scientific centre such as CERN is an ideal place to test and evaluate theories and models on knowledge acquisition, and to carry out quantification of knowledge management in connection with enhanced innovation productivity [Autio et al. 2003, von Hippel et al. 2002, and Yli-Renko et al. 2001]. This is due to its multidisciplinary environment where R&D research and prototyping is carried out using cutting-edge technology. Existing knowledge transfer models, as applied in companies, do not take into account the scientific knowledge acquisition that is the primary role of a centre such as CERN. In contrast, the model applied in this study takes into account CERN's specific environment, where scientific knowledge is deeply bound to technological knowledge and is largely mediated by the social process occurring during the interaction of many physicists and engineers. At CERN, technology simply represents the way to make available to physicists a world-wide accelerator and detector facility using cutting-edge technologies to investigate the ultimate structure of matter.

The study based on the five LHC experiments makes a detailed analysis of knowledge creation in the technological process based on the model described in Fig. 1.1, as experienced by the participants.

The results of the present research show that social interaction, relationship quality, and network ties in the multicultural environment of LHC experiments are associated with knowledge acquisition (Table 3.9 and 3.10). Figure 4.1 stresses the importance of communication within and between members of the sub-projects.

Previous knowledge is also an important enabler within a shared framework where a community of practices is acting in facilitating knowledge transfer; this was addressed by asking whether the respondents had participated in other physics experiments (which was mostly the case). The participation in CERN collaborations amounted to 55% and the participation in collaborations outside CERN to 44%. The graphics presented in the present section report data from each LHC experiment. The distribution is very similar in all of them.

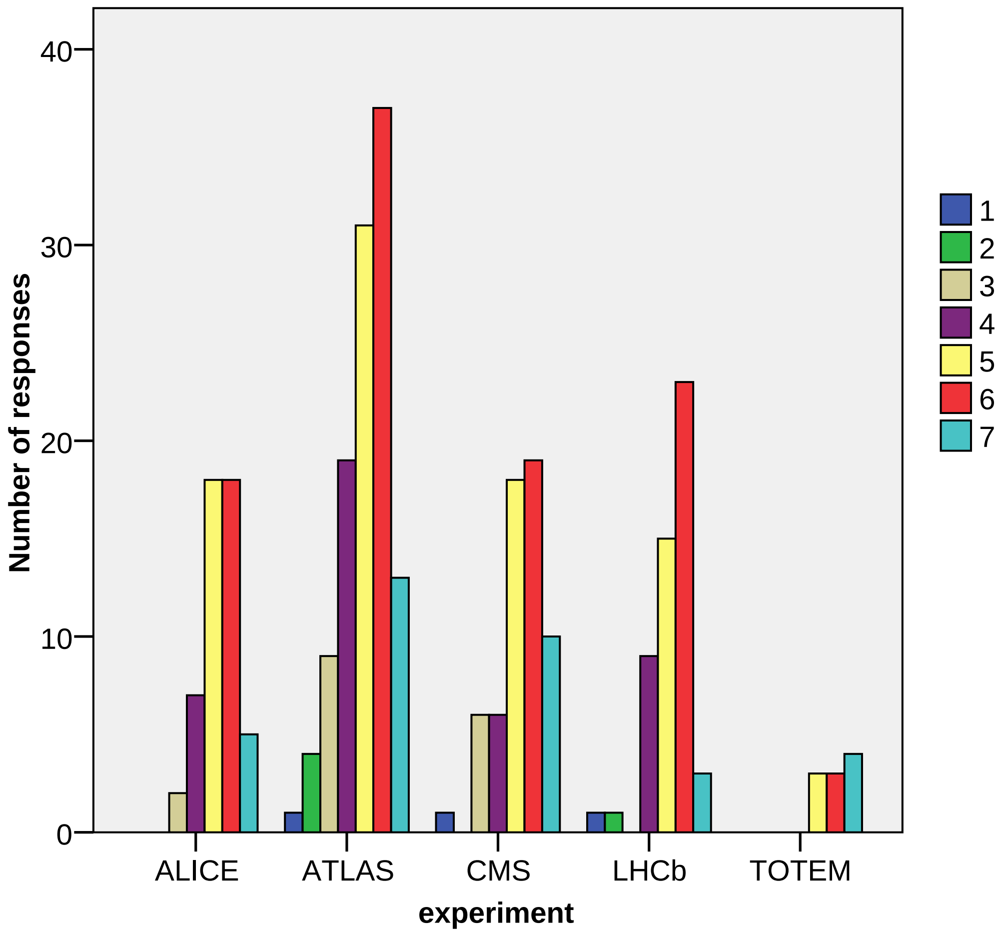

Fig. 4.1: I have good communication with persons inside or outside the sub-project of the project. (1 = disagree, 7 = agree).

Social interaction contributes to the development of the project and has beneficial cross-fertilization effects as illustrated in Figs. 4.1, 4.2 and 4.3.

Communication, interactions, and shared context are important both for knowledge acquisition and transfer [Autio et al. 2003]. These aspects have been, in general, well managed by the LHC experiments except for a minority of people that complained of not having been well enough informed (Fig. 4.2).

All respondents confirmed the importance of interacting with their colleagues both inside and outside their organization; the results obtained for the five individual LHC experiments are reported in Figs. 4.1 – 4.6 and Table 3.11.

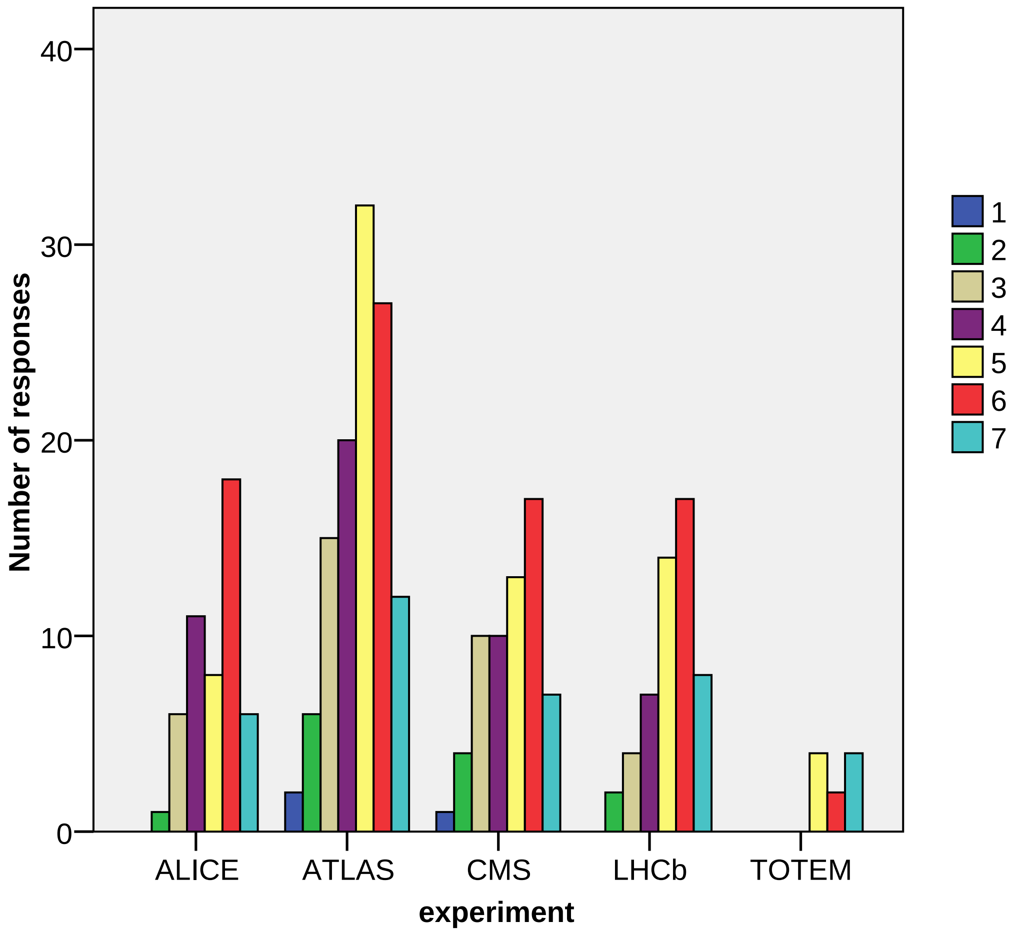

Fig.4.2: I am well enough informed about the development of the project.
(1 = disagree, 7 = agree).

Acquired knowledge appreciated by CERN LHC experimenters is a measure of the success of the social process in advancing the scientific and technological processes to create new knowledge and innovation.

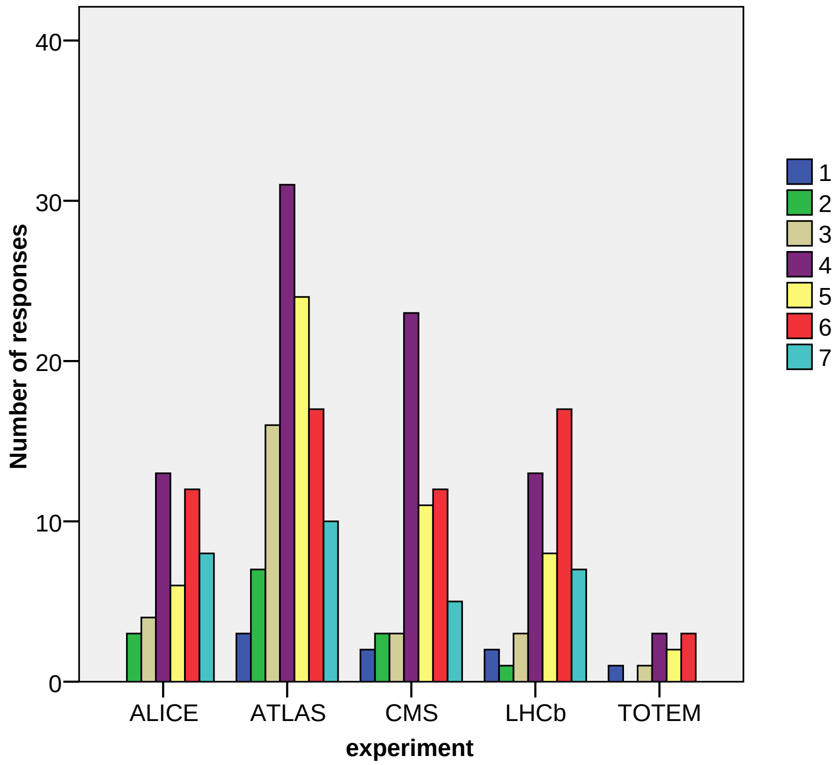

Fig.4.3: Results from R&D are shared with other LHC experiments. (1 = disagree, 7 = agree).

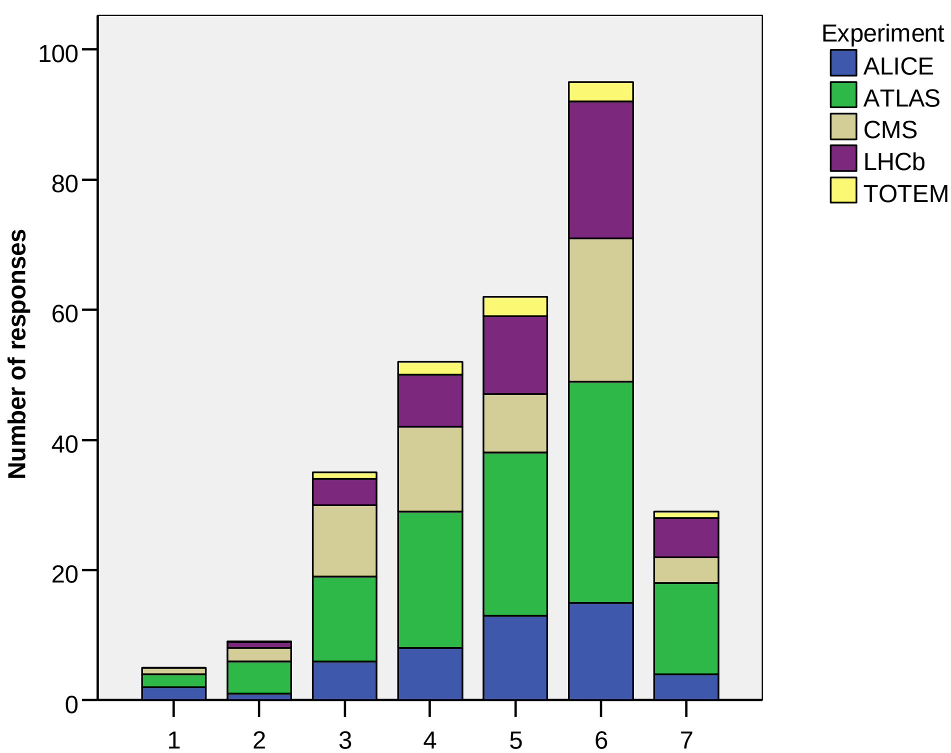

Fig.4.4: Project development flow of information in the team. (1 = disagree, 7 = agree).

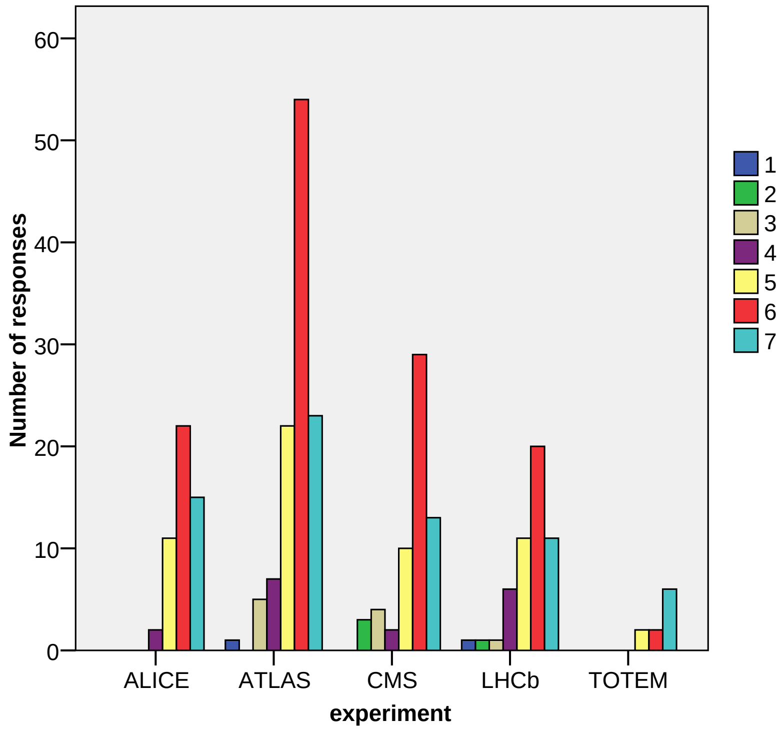

Fig.4.5: Knowledge transfer in the social process inside the project. (1 = disagree, 7 = agree).

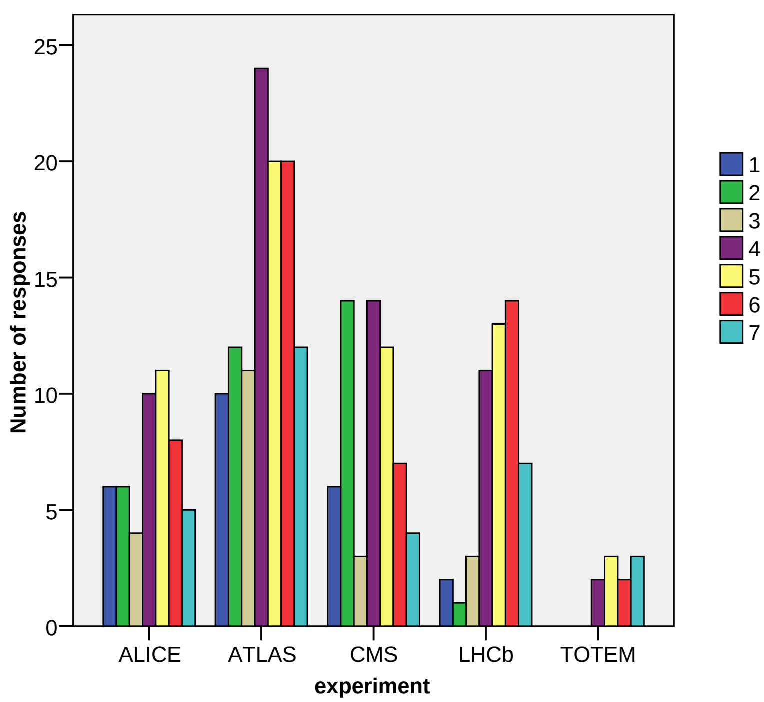

Fig. 4.6: Knowledge transfer in the social process from other LHC experiments.
(1 = disagree, 7 = agree).

Physicists and engineers had an equally favourable experience of the work benefit they got from the expertise of people of the other LHC experiments. There was no significant statistical difference ($F = 1.2^{ns}$) between these groups: (M = 5.7; S.D. = 1.2) and (M = 5.5; S.D. = 1.2) for physicists and engineers, respectively. A negative assessment (1–3) was provided by 28% of the respondents. This confirms a positive flow of knowledge transfer between experiments. Knowledge acquisition is positively associated with competitive advantage in terms of invention development and technological distinctiveness (Tables 3.7 and 3.10) and plays a mediating role between social capital constructs and competitive advantage outcomes. The respondents underline that their most important experience at CERN was the opportunity to work in an international environment and at a high-level research centre. In addition, they recognize the importance of the multicultural and multi-field interaction that can be beneficial also outside HEP (Fig. 4.7).

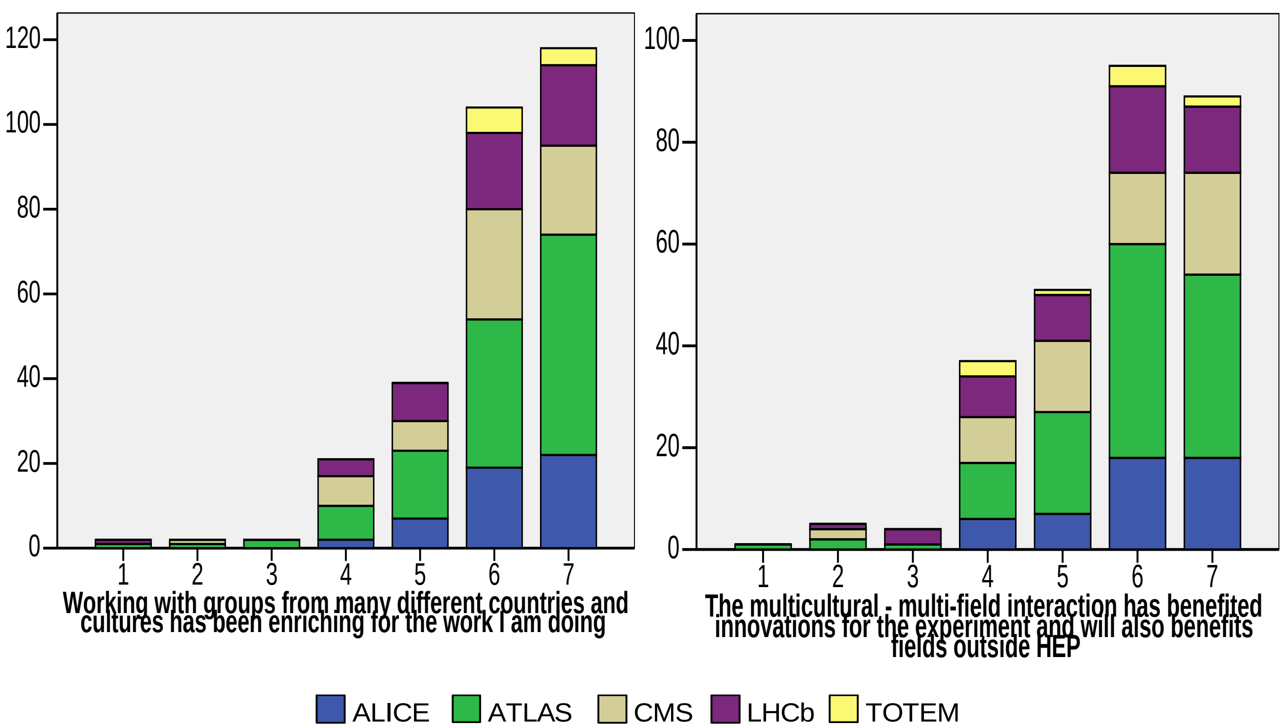

Fig. 4.7: Importance of multicultural and multi-field interaction. (1 = disagree, 7 = agree).

The organizational learning, i.e., the process where a group of people collectively enhance their capacities to produce the outcome, is a strong asset at CERN. This is specifically due to its multicultural, multi-field environment characteristics.

All these results indicate that social interaction, relationship quality, and network ties in a multicultural environment are associated with more efficient knowledge acquisition. Knowledge acquisition is, in turn, positively associated with competitive advantage in terms of invention development and technological distinctiveness. These results also show that knowledge acquisition plays a mediating role between social capital constructs and competitive advantage outcomes.

The acquired skills of the participants of the LHC experiments enable them to develop market value for industry (Fig. 4.8) as well as to motivate young researchers to work for industry or to start a company (Table 3.7).

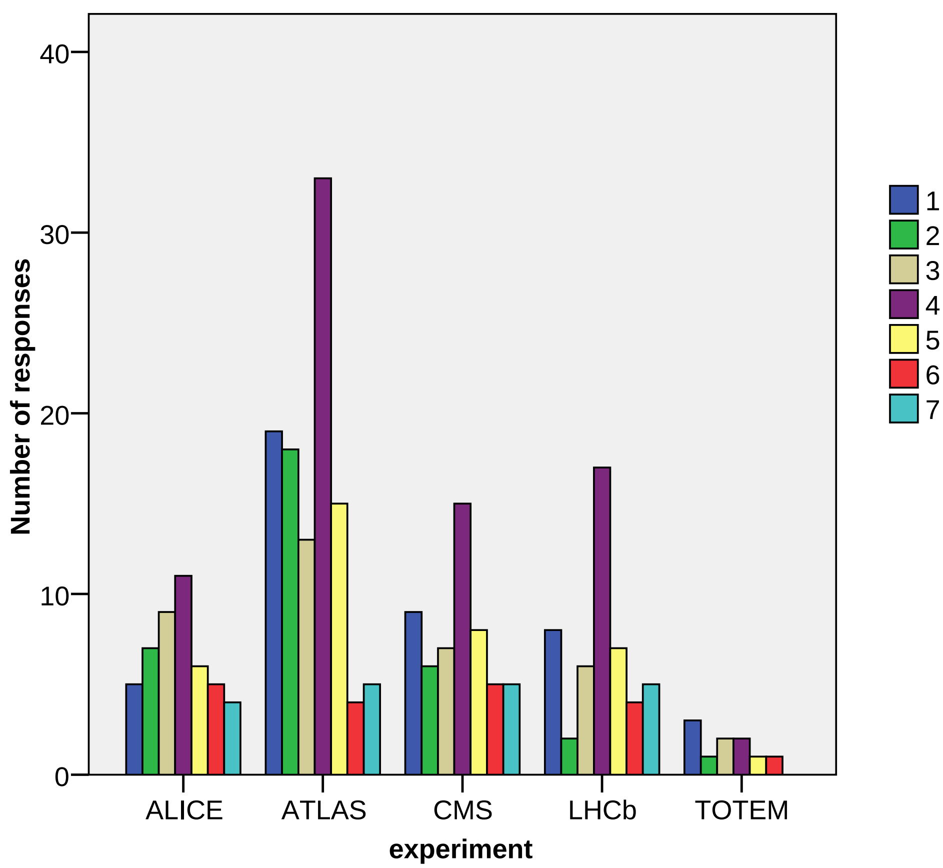

Fig. 4.8: Increased opportunity to find a job in industry. (1 = disagree, 7 = agree).

LHC experiments generated partnerships and interaction with the industrial world as shown by the answers to questions 16 and 17. The speed with which exchange and synthesis take place between scientists themselves and between scientists and industrial actors is a key factor for innovation. This was shown in the LHC experiments. It must be remembered that the questionnaire refers to relations with the industrial world at the period where most of the relations with industry were coming to an end. In fact, in 2006, at the time when the questionnaire was filled in, the LHC experiments were in their installation phases.

It is important to realise that HEP represents the most efficient way of transferring knowledge by transferring people, as demonstrated by previous studies carried out at CERN [Camporesi 1996, OPAL 2003, Bressan 2004, and da Cruz et al. 2004].

Among the barriers to knowledge transfer there is the insufficiency of money allocated to a project. The answers to question 13.6, reported in Fig. 4.9, indicate that some constraints resulted owing to lack of resources.

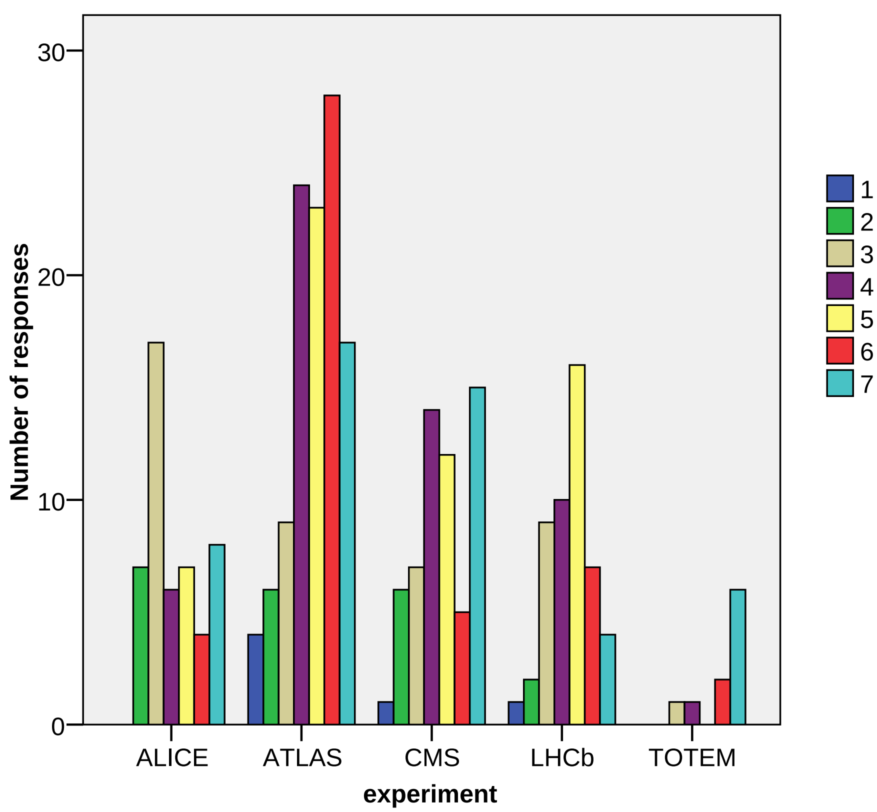

Fig. 4.9: Inadequate resources and infrastructure support has been an obstacle.
(1 = disagree, 7 = agree).

It should be recalled that the direct material costs of the experiments exceed one billion Swiss Francs of which only 20% comes from CERN, even though CERN hosts the experiments. On the basis of the replies received, it is difficult to draw any specific conclusions in this respect. It just suggests that the perceived lack of adequate infrastructure support has slowed down progress and possibly resulted in some unwanted technical compromises but that it has not jeopardized the outcome of the project.

In spite of the hindrance identified above, the scientific outcome was never put in question and has remained the main driving force in the project management. This conclusion is supported by Fig. 4.10.

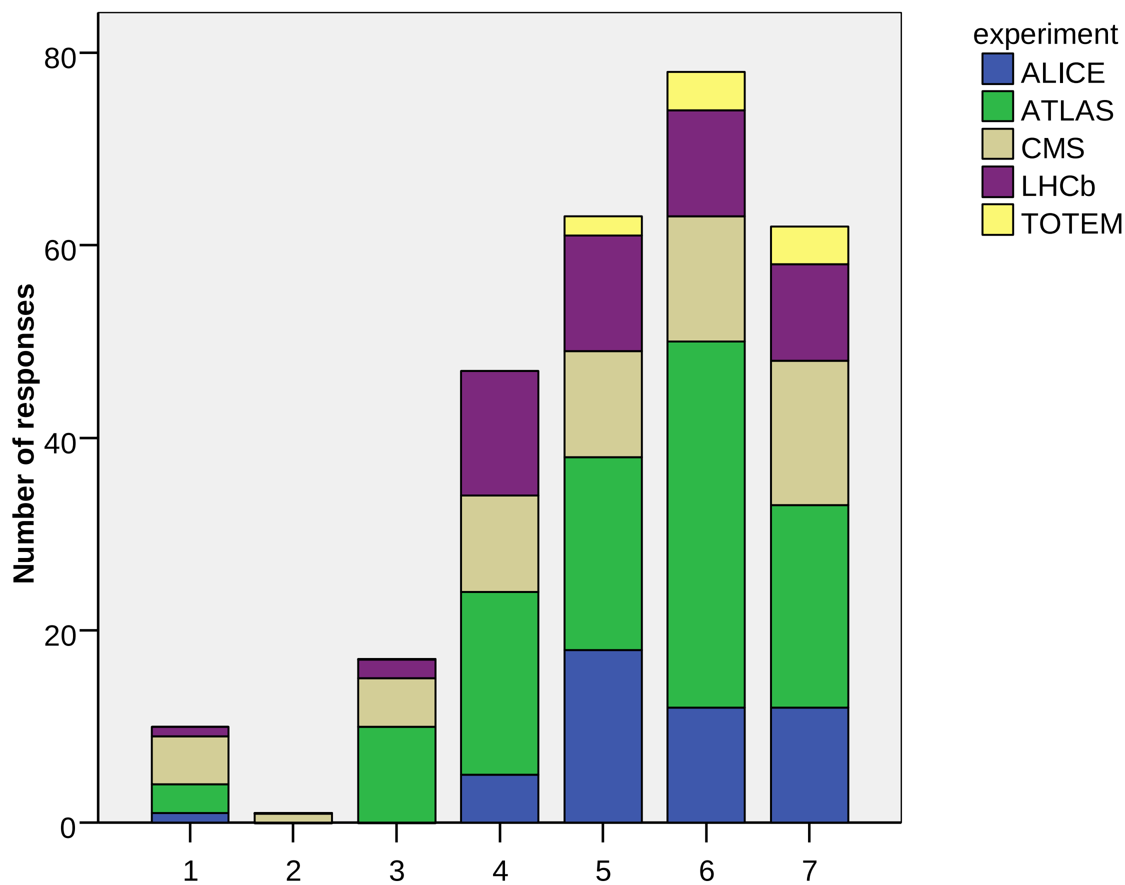

Fig. 4.10: The scientific outcome determined in the project management. (1 = disagree, 7 = agree).

Knowledge acquisition and the three constructs of social capital (social interaction, relationship quality, and network ties) are considered in the literature as independent variables. Knowledge acquisition is measured by statements reflecting the scientific and technological knowledge that a user may acquire from CERN. Social interaction is measured by statements reflecting the extent to which the relationship between CERN users is characterized by personal and social ties.

The extent of deepening and widening of scientific expertise has been assessed very positively by all five LHC experiments (Fig. 4.11). This is not surprising considering the fact that HEP research is at the forefront of scientific knowledge.

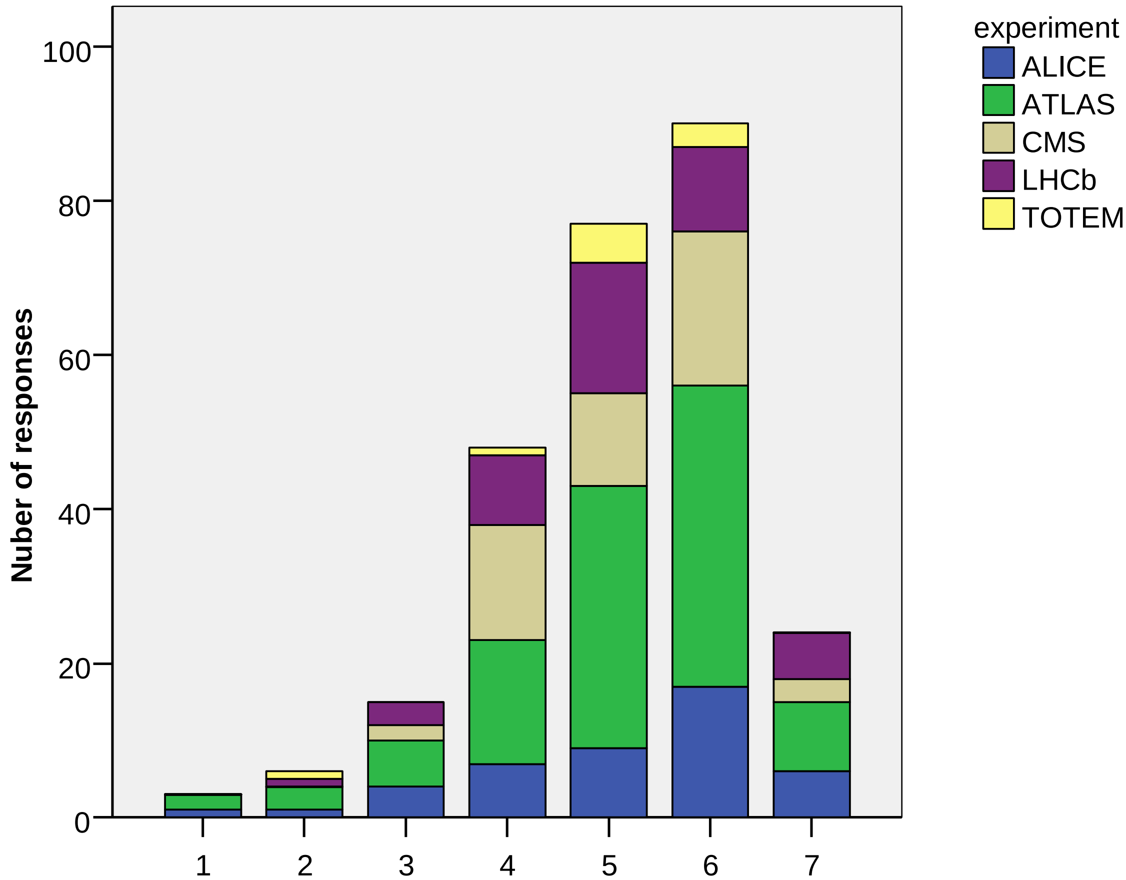

Fig. 4.11: Motivation due to increase in expertise. (1 = disagree, 7 = agree).

One important finding of the present study is that interaction amongst scientists and industry has been positive overall. This is due to the need to deal with high technology which has driven the close contact between industry and science. Both sides have learned from each other's goals and constraints (Fig. 4.12).

The most efficient factor in transferring knowledge is considered to be the mobility of people. CERN, and the LHC experiments in particular, have proved to be very instrumental to this end, as indicated by many results presented in various parts of the present study.

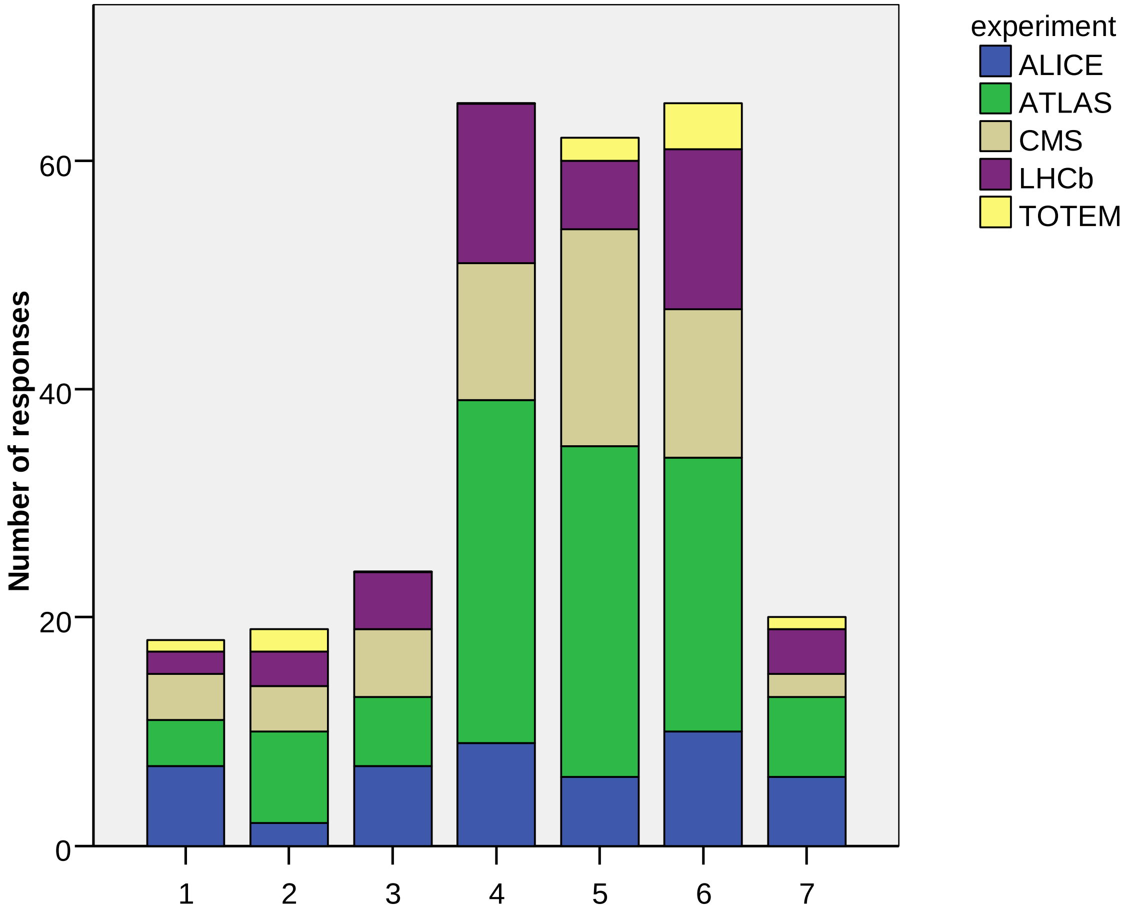

Fig. 4.12: Relation and knowledge of the industrial world. (1 = disagree, 7 = agree).

In order to better understand the nature of knowledge learning and technological transfer, it was decided to make an Exploratory Factor Analysis (EFA) to reduce the number of original variables related to personal outcomes of knowledge transfer. In the EFA analysis, principal component analysis was used as the extraction method, rotation being promax (K = 4) with Kaiser normalization. All factors whose eigenvalues exceed 1 before the rotation were accepted. This analysis yielded a clear four-factor solution:

1. Learning of technical skills.
2. Learning of science making skills.

3. Improvement of social network.
4. Increase of possibilities in the labour market.

This solution explained 66% of the extraction sums of squared loadings. The factors and loadings of single items, which measures the experts' personal outcomes of knowledge transfer, are presented in the Table 4.1. One conclusion from this simple factor structure is that the respondents have answered the questionnaire systematically.

Tab. 4.1: Loadings for factors measuring experts' personal outcomes of knowledge (reduced by the EFA on questionnaire items; the loadings <0.3 are not included).

Aspect	**Factor**			
	1	**2**	**3**	**4**
New technical skills: construction skills	0.919			
New technical skills: planning skills	0.904			
New technical skills: evaluating skills	0.852			
New technical skills: paper writing skills	0.591	0.307		
Improved management skills	0.536		0.414	
Enhanced scientific skills: planning skills	0.480		0.331	
Enhanced scientific skills: data analysing skills		0.952		
Enhanced scientific skills: paper writing skills		0.771		
Enhanced scientific skills: measuring skills	0.389	0.666		
Enhanced scientific knowledge		0.621	0.410	
Improved and widened social network			0.858	
Increased international network			0.779	
Increased multidisciplinary insight			0.540	
Increased opportunity to find a job in industry				0.828
New professional interests				0.718
Increased relation and knowledge of the industry			0.312	0.534

According to this result there are four principal dimensions of personal outcome from the research activity in CERN:

1. Learning of new technical skills, like construction skills, planning skills, evaluating skills and skills needed in management.
2. Learning of new scientific knowledge and science making skills, like data analysis skills, paper writing skills, and measuring skills.
3. Improvement and widening of social network.
4. Improvement and widening of labour market competence.

This solution helps us to analyse different dimensions of personal outcomes and will thus guide also the further development of programmes for visitors. When we were comparing, with the aid of ANOVA, the responses of those who were staff at CERN (N = 112) with the answers by visitors (N = 167), we found a statistically significant difference only in one item: “Most important outcome from the collaboration was improvement of social network” (F = 12.5***). The mean of the staff was 4.9 and of visitors 5.4 on the 7-point Likert-style scale. Therefore permanent staff and visitors were evaluating their personal outcomes rather similarly.

We have studied in detail the tools made available within the collaborations to ensure adequate sharing of information. The most modern tools of communications were requested by those physicists who were more familiar with the latest developments in information technology and e-mail together with the telephone. Communication was considered satisfactory except for a small minority. There were statistically significant differences in the value or importance of the communication type between young and old users in CERN. Nor was there any statistically significant difference between physicists and engineering in the value or importance of the communication type, except for the use of e-mail. The engineers (M = 6.3; S.D. = 1.0) find e-mail more valuable than physicists (M = 5.4; S.D. = 1.8) (F = 5.5*)

The fertile environment of the five LHC experiments building and managing multiple processes, involves a dynamic, interactive, and simultaneous exchange of knowledge both inside and outside their organization.

The present study assesses the dynamics of knowledge production and management within the LHC collaborations. It applies largely to the whole physics community from students to university professors and to CERN staff members involved in challenging high-technological developments. The acquired knowledge represents the most important type of direct benefit to society from CERN. It enables people to develop important academic assets and a market value for their acquired skills in the Member States’ industries.

5 Conclusion

While the fundamental science mission of Big Science centres should continue to dominate, greater attention should be paid to maximizing the technological impacts that scientific collaborations may potentially confer to industry and society. Big Science centres as well as the contributing member countries should encourage and prepare the terrain to make possible such kinds of collaboration with industrial companies and make better known the impact on society.

The present large physics collaborations have necessitated a change in approach with a much greater importance given to managerial aspects. This is confirmed by the results obtained in the present study where 94 of 291 respondents had a management and coordination role in addition to their physics or engineering functions. Furthermore, management is acknowledged to be important and useful for their career by almost 50% of the respondents.

Interactions between individuals in the project team who have common interests are important parameters for knowledge transfer which is extended to interactions between experiments. The interaction among the project members was facilitated by the organizational structure and by frequent use of available communication tools. Individuals were able to create and expand knowledge through the social process which also involved industry for many aspects in certain phases of the project development.

Personal outcomes of knowledge transfer have been substantial. These were assessed in terms of the widening of scientific knowledge and social networks, enhancement of scientific skills at different levels (planning, data analysis, paper writing), and acquisition of new technical skills. These positive outcomes, observed in a population of 79% users and 21% staff members, span over a wide age range, benefitting both young and experienced physicists.

The theoretical model, described in the introduction, allows the analysis of knowledge creation, acquisition and transfer, and underlines the importance of the scientific process. It also correlates how, what, and when the three processes (scientific, technological and social) interact at the individual and organizational level [Bressan 2004].

According to the factor analysis presented in this study, these processes appear clearly as three different dimensions. This was also acknowledged by the respondents. The analysis revealed also an additional fourth dimension related to labour market competencies acquisition.

In future, the development of personal skills, according to the four identified factors (learning of technical skills, learning of science making skills, improvement of social network, and increase of employment possibility in labour market) could be used to target individual development for improving opportunities for the labour market.

An organization such as CERN has its own epistemology where the mode of knowledge creation and innovation supersedes the national context. The conditions enabling the process are amplified by the wide multicultural environment. The researchers who responded to the study have shown a positive approach towards going to work for companies or to create their own company. The financial constraints within the LHC experiments resulted in some slowdowns of technical progress but have not jeopardized the final outcome.

6 References

Autio E., Bianchi-Streit M., Hameri A.P. 2003. Technology transfer and technological learning through CERN's procurement activity. CERN Report, CERN-2003-005, *ISBN 92-9083-214-2*.

Bianchi-Streit M., Blackburne N., Budde R., Reitz H., Sagnell B., Schmied H., Schorr B. 1984. Economic utility resulting from CERN contracts (Second Utility). CERN Report CERN 84/14.

Bressan B. 2004. A study of the research and development benefits to society from an international research centre: CERN. *Ph.D. thesis*, University of Helsinki, Finland, (*Report Series in Physics HU-P-D112. ISBN 952-10-1653-1).*

Bressan B., Streit-Bianchi M. 2005. CERN technology transfer to industry and society. *ISBN 92-9083-240-1*.

Drucker P.F. 1993. Post-capitalist society. Oxford: Butterworth-Heinemann.

Camporesi T. 1996. Statistic and follow-up of DELPHI Student Careers, CERN/PE, and 2000 Physics acts as a career stepping stone, CERN Courier, October 8.

da Cruz E., Herzog R., Sirage E. K. 2004. From purchasing goods and services to proactive Technology transfer and partnerships. *Master of Technology (MOT) thesis*, Ecole Polytechnique Fédérale de Lausanne, Switzerland.

von Hippel E., von Krogh G. 2003. Open source software and the private-collective innovation model: issue for organization science. *Organization Science* **14**: 209-223

Huuse H., Nordahl O.P. 2003. Knowledge transfer between projects. Master's thesis, Norwegian University of Science and Technology (NTNU), Trondheim, Norway.

Nordberg M. 1997. Transaction costs and core competence implications of buyer-supplier linkages; the case of CERN. *Ph.D. thesis*, Katholieke Univeriteit Brabant *(Tilburg University. ISBN 92-9083-117-0)*.

OPAL private communication. 2003 (from OPAL management collaboration).

Schmied H. 1975. A study of economic utility resulting from CERN contracts. CERN Report CERN 75-5.

Sessano D. 2007. Entrepreneurial Behaviour of researchers in basic research centres: the CERN example. *Ph.D. thesis*, University of Turin, Italy.

Yli-Renko H., Autio E., Sapienza H. J. 2001. Social capital, knowledge acquisition, and knowledge exploitation in young technology-based firms. *Strategic Management Journal* **21**(Summer Special issue): 587–613.

Appendix: Questionnaire for an LHC Experiment

The aim of this enquiry is to assess the knowledge transfer and technological learning which occurs in a large collaboration such as LHC. The purpose of this questionnaire is to capture the learning benefits and evaluate how to enhance the innovation and knowledge transfer to industry and society.
The answer you will provide to this questionnaire will be used for statistical purposes only. No quotes or references to individual replies will be made.

Age____________________

Status: student □, Ph.D./fellow □, assistant □, professor □

Your present domain of expertise you may fill more than one of the given options, number them in order of importance

- ☐ Physics research
- ☐ Software engineering and analysis
- ☐ Detector hardware
- ☐ Electronics
- ☐ Data acquisition
- ☐ Administration
- ☐ Other_______________

Your main function / role in the LHC sub-systems, you may fill more than one of the given options, number them in order of importance

- ☐ Physics researcher
- ☐ Engineer
- ☐ Computer scientist
- ☐ Technician
- ☐ Management and/or coordination
- ☐ Other____

Nationality __________

Main work place (geographically and where you are spending >50% of time):

- ☐ CERN, Geneva
- ☐ University of …………………., Town………………..Country……….(specify)
- ☐ Other ____

Employer (if different from above) ___________

Percentage of working hours last year used on the collaboration _____%

Before joining the current project you had previous experience in working in:

- ☐ CERN Collaborations (LEP, SPS, PS, ISOLDE, other)
- ☐ Other physics collaborations outside CERN
- ☐ Other

1. <u>Institute</u> motivation for joining the LHC project?	
Statements (please circle a number)	disagree ←← agree →→
1. Scientific challenge	1 2 3 4 5 6 7
2. Technological challenge	1 2 3 4 5 6 7

2. <u>Your</u> motivation for joining the LHC project?	
Statements (please circle a number)	disagree ←← agree →→
1. Scientific challenge	1 2 3 4 5 6 7
2. Technological challenge	1 2 3 4 5 6 7

3. What have you learned in the project that you think will be most useful to your career?

4. Development of management skills

a) Has the participation to the LHC project or the discussion with your colleagues contributed to develop management skills

- ☐ Yes
- ☐ No

b) During my career I have considered to (tick one option only)

- ☐ Start a Company
- ☐ Go to work for a Company
- ☐ Continue (or start) in Academia

c) I believe the development made in my project domain will most likely be useful in fields outside HEP

- ☐ Yes
- ☐ No

d) I have contributed to developing innovative technologies in LHC:

- ☐ Yes
- ☐ No

5. List below what you consider the most innovative or technologically most challenging development in LHC in your project domain:

6. How often do you communicate with Collaboration members? (function/role as defined in b at page 1)							
	Mean and frequency of tools used in communication						Value or importance of the communication
Statements	Daily	Several times a week	Weekly	Several times a month	Monthly or less	never	low ←← high →→
1. .. at the same work place with people of same function / role	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
2. .. at the same work place with people of different function / role	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
3. .. at different work place with people of same function / role	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
4. .. at different work place with people of different function / role	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7

7. Mean and frequency of different type of communication in the Collaboration and value or importance of the communication type from the point of view of learning new knowledge and skills (or innovation or technology)

	Mean and frequency of tools used in communication						Value or importance of the communication
Statements	Daily	Several times a week	Weekly	Several times a month	Monthly or less	never	low ←← high →→
1. Telephone	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
2. Tele/video conference	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
3. E-mail	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
4. Newsgroup	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
5. Technical development meetings	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
6. Collaboration meetings	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
7. Taking part to the research activity: planning activity	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
8. Taking part to the research activity: measuring	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
9. Taking part to the research activity: analyzing data	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
10. Taking part to the research activity: writing a paper	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
11. Taking part to the technology development: planning activity	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
12. Taking part to the technology development: construction	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
13. Taking part to the technology development: evaluating	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
14. Taking part to the technology development: writing a paper	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
15. Taking part to the problem-solving activity	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
16. Informal meeting space in cafeteria (lunch, coffee,…)	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
17. Informal meeting space in the evening (dinner, hostel,…)	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
18. Reading, writing and disseminating project documentation	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
19. Reading info from general Web pages	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
20. Reading info from Web pages (research articles)	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
21. A course in Particle Physics (theory/experimental)	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
22. A course in Particle Instrumentation	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
23. A course in Informatics	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
24. A course in material sciences; solid state physics	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
25. A course in Engineering (mechanical, electrical)	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
26. A course in Management of Project; Innovation; finance.	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
27, Other___________(specify)	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7

8. To make the project more efficient, one would have needed:					
	Much less	Less	Unchanged	More	Much More
1. Technical development meetings at CERN or in home institute	☐	☐	☐	☐	☐
2. Collaboration meetings	☐	☐	☐	☐	☐
3. Informal meeting space (e.g. in cafeteria)	☐	☐	☐	☐	☐
4. To read and write documentation	☐	☐	☐	☐	☐
5. To disseminate project documentation (e.g. via Web)	☐	☐	☐	☐	☐
6. Telephone calls	☐	☐	☐	☐	☐
7. Tele/video conference	☐	☐	☐	☐	☐
8. E-mail	☐	☐	☐	☐	☐
9. Other________________(specify)	☐	☐	☐	☐	☐

9. What kind of documents do you feel there have been made too many or too few of:					
	Much less	Less	Unchanged	More	Much More
1. Project plans	☐	☐	☐	☐	☐
2. Status reports	☐	☐	☐	☐	☐
3. Technical documentation	☐	☐	☐	☐	☐
4. Formal documents for external bodies or funding agencies	☐	☐	☐	☐	☐
5. Information from the participating members or groups	☐	☐	☐	☐	☐
6. Information to the public	☐	☐	☐	☐	☐
7. Records of individual contribution	☐	☐	☐	☐	☐

10. Information and documentation	
Statements (Please circle a number)	disagree agree ←← →→
1. I am well enough informed about the development of LHC	1 2 3 4 5 6 7
2. People in other experiments have easy access to LHC related information (if they wanted to)	1 2 3 4 5 6 7
3. Writing - project documentation takes too much valuable time	1 2 3 4 5 6 7
4. In my team there is a good flow of information on the project development	1 2 3 4 5 6 7
5. Results from R&D are freely shared with the participating institutions	1 2 3 4 5 6 7
6. Results from R&D are freely shared with other LHC experiments	1 2 3 4 5 6 7

11. Networking	
Statements (Please circle a number)	disagree agree ←← →→
1. It is easy to find the right persons to solve a work-related problem	1 2 3 4 5 6 7
2. I find the answers I need through other LHC members	1 2 3 4 5 6 7
3. I know who knows what in LHC	1 2 3 4 5 6 7
4. During the project I have gained insight in other disciplines	1 2 3 4 5 6 7
5. I consider myself as an important contact point for other persons in LHC or in the project domain I am working in	1 2 3 4 5 6 7
6. I have good communication with persons inside or outside the sub-project of LHC	1 2 3 4 5 6 7
7. I have benefited from other people's expertise to do my tasks in the project (inside LHC)	1 2 3 4 5 6 7
8. I have benefited from other people's expertise for my work in the project (other LHC experiments)	1 2 3 4 5 6 7

12. Culture	
Statements (Please circle a number)	disagree agree ←← →→
1. Working with groups from many different countries and cultures has been enriching for the work I am doing	1 2 3 4 5 6 7
2. Working from my institution in a distributed project structure has been a challenge	1 2 3 4 5 6 7
3. To work with people from different disciplines has been challenging and has had an impact on my way of approaching problems	1 2 3 4 5 6 7
4. To cooperate with people with different native languages has been no problem	1 2 3 4 5 6 7
5. The multicultural – multi-field interaction has benefited innovations for the experiment and will also benefit fields outside HEP	1 2 3 4 5 6 7

13. Project management (in my own project domain)	
Statements (Please circle a number)	disagree agree ←← →→
1. The scientific outcome has been always kept in mind in the management of the project	1 2 3 4 5 6 7
2. The scientific outcome has been always kept in mind in the management of my project domain	1 2 3 4 5 6 7
3. The changes in priority have been well managed	1 2 3 4 5 6 7
4. The objectives of the project have been clearly communicated	1 2 3 4 5 6 7
5. All participant strive to achieve the same goal in time and in competition with others LHC experiments	1 2 3 4 5 6 7
6. Inadequate resources and infrastructure support has been an obstacle	1 2 3 4 5 6 7
7. The functionality of the detectors have been kept in spite of financial constraint however further and more interesting high-tech development could not be done	1 2 3 4 5 6 7
8. Unnecessary time pressure has limited the development of more effective detector technologies	1 2 3 4 5 6 7

14. Personal Outcomes of knowledge transfer:							
Most important outcomes from the collaboration and interactions with colleagues	disagree ←←						agree →→
1. Improved and widened social network	1	2	3	4	5	6	7
2. Increased multidisciplinary insight	1	2	3	4	5	6	7
3. Improved management skills	1	2	3	4	5	6	7
4. Enhanced scientific knowledge	1	2	3	4	5	6	7
5. Enhanced scientific skills: *planning skills*	1	2	3	4	5	6	7
6. Enhanced scientific skills: *measuring skills*	1	2	3	4	5	6	7
7. Enhanced scientific skills: *data analyzing skills*	1	2	3	4	5	6	7
8. Enhanced scientific skills: *paper writing skills*	1	2	3	4	5	6	7
9. New technical skills: *planning skills*	1	2	3	4	5	6	7
10. New technical skills: *construction skills*	1	2	3	4	5	6	7
11. New technical skills: *evaluating skills*	1	2	3	4	5	6	7
12. New technical skills: *paper writing skills*	1	2	3	4	5	6	7
13. Increased international network	1	2	3	4	5	6	7
14. Increased relation and knowledge of the industry	1	2	3	4	5	6	7
15. New professional interests	1	2	3	4	5	6	7
16. Increased opportunity to find a job in industry	1	2	3	4	5	6	7

15. What has been the important outcome for your institution:	irrelevant ←←						important →→
1. Improved network	1	2	3	4	5	6	7
2. Increased international exposure	1	2	3	4	5	6	7
3. New R&D projects	1	2	3	4	5	6	7
4. Motivated employees by deepening and widening expertise	1	2	3	4	5	6	7
5. New knowledge	1	2	3	4	5	6	7

16. Interactions with Suppliers							
How you would describe the interactions with Companies in your project domain	disagree ←←						agree →→
1. Supply of out of shelves products	1	2	3	4	5	6	7
2. Non standard delivery with major modifications	1	2	3	4	5	6	7
3. R&D project with development of new products/services	1	2	3	4	5	6	7
4. Cutting edge technologies to be applied for LHC	1	2	3	4	5	6	7
5. Cutting edge technologies to be applied outside LHC	1	2	3	4	5	6	7
6. Frequent interactions required	1	2	3	4	5	6	7
7. Neither the companies or us try to cheat each other	1	2	3	4	5	6	7

17. Mean and frequency of different type of communication in the Collaboration with Industry and value or importance of the communication type from the point of view of knowledge and skills (or innovation or technology) transfer							
	Mean and frequency of tools used in communication						Value or importance of the communication
Statements	Daily	Several times a week	Weekly	Several times a month	Monthly or less	never	low ←← high →→
1. Telephone	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
2. Tele/video conference	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
3. E-mail	☐	☐	☐	☐	☐	☐	
4. Newsgroup	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
5. Technical development meetings	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
6. Taking part jointly to technical conferences: writing a paper	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
7. Taking part to the technology development: planning activity	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7
8. Taking part to the technology development: construction	☐	☐	☐	☐	☐	☐	1 2 3 4 5 6 7

We kindly appreciated your contribution and the effort made to answer to our questions.
If you have suggestions for:

- questions not asked , but relevant
- ways of increasing knowledge transfer and innovation in big experiments

please comment on the back of this page.