Summary report and final evaluation

Photonics and Modern Imaging Techniques

Research Programme

ACADEMY OF FINLAND

Contents

1. Introduction

This report documents the evaluation of the Academy of Finland's research programme Photonics and Modern Imaging Techniques. The results of the report will be made public for further possible use by the Academy of Finland, academia and Finnish society at large. The results can support decisions on research policy.

1.1. General information about Academy of Finland research programmes

The Academy of Finland is a leading public funding agency for cutting-edge scientific research in Finland. It finances high-quality and innovative research that is targeted at scientific breakthroughs, acts as a science policy expert and strengthens the position of science and research.

The Academy allocates research funding to fields that are considered important in terms of science and society. Particularly the Academy's research programmes are designed to raise scientific standards, create new scientific knowledge and know-how, and increase international cooperation.

At a given time, the Academy funds about twelve research programmes, each with a funding volume of about 10–15 million euros for about 4–6 years. Examples of currently ongoing programmes are available athttp://www.aka.fi/en/research-and-science-policy/academy-programmes/current-programmes/.

The research programmes are managed by a steering group and programme managers. The steering group consists of representatives of the Academy's research councils and other experts. The programme managers are employees of the Academy and hence government officials.

1.2. Photonics and Modern Imaging Techniques

1.2.1. Objectives and programme memorandum

The Academy of Finland decided to launch a research programme in the field of photonics and modern imaging techniques in 2008. The objectives and the focus areas of the programme are described in the programme memorandum (see http://www.aka.fi/en/research-and-science-policy/academy-programmes/completed-programmes/photonics-and-modern-imaging-techniques).

1.2.2. Funding calls

The first call, which was a national call, was launched in 2009, and the funding decisions on this call were made on 14 October 2009. In total, 13 projects with 33 participating research groups were funded, starting on 1 January 2010 and running until the end of 2013. The funding for this national call was 9 million euros.

International calls with three organisations were launched to strengthen the international dimension of the programme. The foreign funding organisations were the National Council for Scientific and Technological Development of Brazil (CNPq), the Japan Science and Technology Agency (JST), and the Russian Foundation for Basic Research (RFBR). In total, 13 projects from these international calls were funded with an overall funding of 4.2 million euros. Some basic information about the calls is summarised below.

National call:

- 13 research projects, funding 9 million euros
- Funding period 1 Jan 2010–31 Dec 2013

International calls:

Call with National Council for Scientific and Technological Development (CNPq):

- 4 research projects, funding 1.7 million euros
- Funding period 1 June 2010–31 Dec 2013

Call with Japan Science and Technology Agency (JST)

- 4 projects, funding 1.4 million euros
- Funding period 1 May 2010–31 July 2013

Call with Russian Foundation for Basic Research (RFBR):

- 5 projects, funding 1.1 million euros
- Funding period 1 May 2010–30 Apr 2013

Please note that the amounts above comprise only the funding of the Academy of Finland for the Finnish parties of the projects.

1.2.3. Programme coordination

The coordination activities of the programme consisted of annual seminars, seminars for early-career researchers, foresight exercises and a final evaluation. The activities of the programme are listed below:

2010 Opening seminar
2011 Spring seminar (topic: Materials in Photonics)
2011 Autumn seminar (topic: Imaging)
2012 Seminar for early-career researchers
2012 Annual seminar
2012 Intermediate reports from the projects. The programme coordination summarised the main results.
2013 Closing seminar
2013 Seminar for early-career researchers
2014 Foresight exercise (topic: Photonics Materials)

1.3. Evaluation process

The steering group of the programme decided the focus of the evaluation based on the objectives of the programme, as described in the programme memorandum. The focus of the evaluation was set to be the following three themes:

● Has the programme managed to increase the level of the Finnish research and technology expertise?

● Has the programme fostered the evolvement of national and international networks?

● What have been the success stories and breakthroughs within the programme?

The evaluation is based on the data from the final reports of the projects and the answers of the Webropol online questionnaire submitted by the project leaders. The questionnaire is presented in Appendix I, showing the questions that mapped the opinions of the projects leaders on the above three questions.

Three external experts (names shown in Appendix 3) were invited to perform the final external evaluation of the programme. They were asked to evaluate the programme from the perspective of the guiding questions presented in Appendix II. The final evaluation was performed in Autumn 2016. This evaluation is presented in Appendix III.

2. Statistics

The data obtained from the final reports of the all 26 projects has been compiled in this chapter.

2.1. Participating universities and research organisations

There were a total of nine universities and research organisations participating in the programme. Figure 1 shows the funding proportions in percentages and the number of subprojects per university or research organisation.

Approximately 70% of the funding was granted to projects from three universities: Aalto University, the University of Eastern Finland and Tampere University of Technology. The number of subprojects for these three universities was also the greatest.

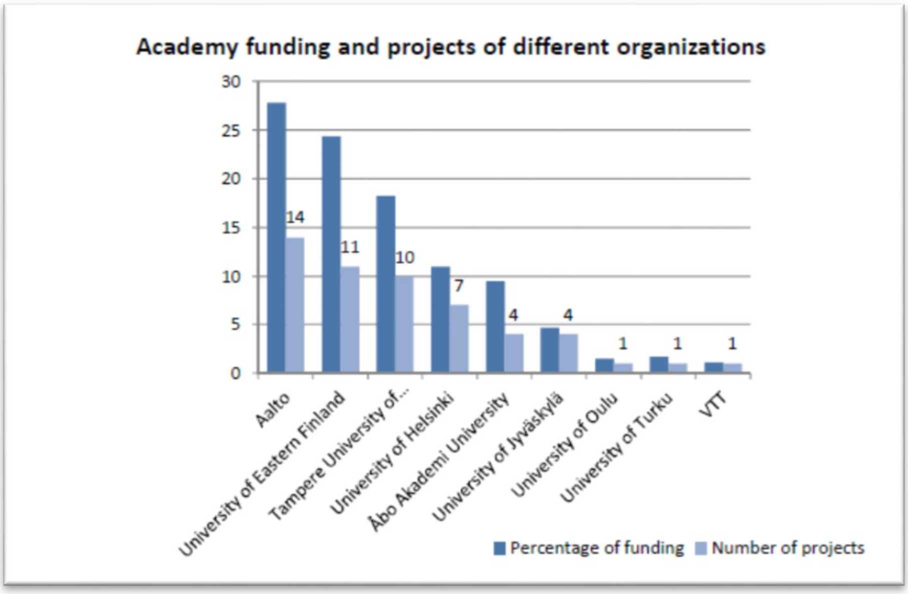

Figure 1. The funding proportions in percentages and the number of subprojects per university or research organisation.

2.2. Personnel of the projects

According to the final reports, there were in total 311 people involved in the 26 projects of the programme. The personnel was divided into different personnel categories as follows: 97 (about 31%) were postgraduate students, 118 (about 38%) were postdoctoral researchers or researchers, 83 (about 27%) were assisting personnel and 13 (about 4%) were professors. Figure 2 illustrates the division of the project personnel into different personnel categories. Figure 3 in turn shows the proportions of the full-time equivalent (FTE) research personnel in the different personnel categories. In absolute terms, postgraduate students, researchers, assisting personnel and professors represented approximately 84, 69, 25 and 2 person-years of research, respectively, by assuming eleven effective working months per year.

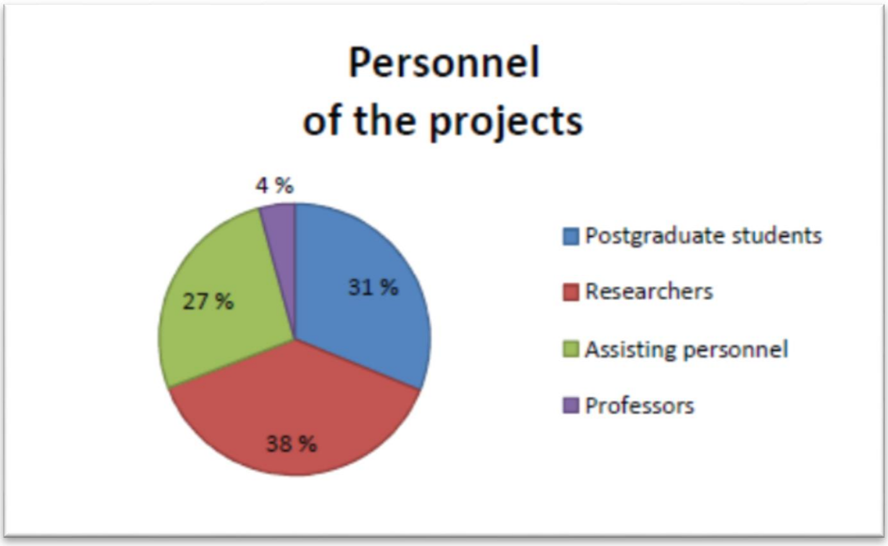

Figure 2. Division of project personnel into different personnel categories.

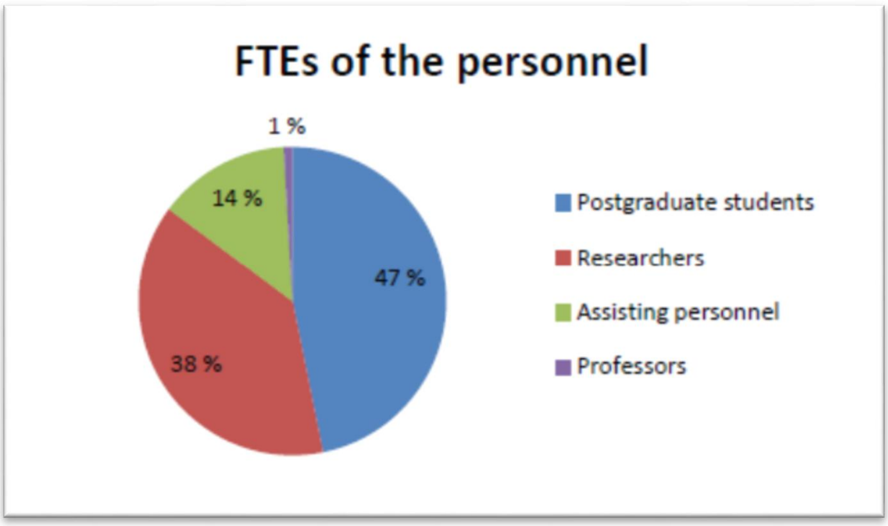

Figure 3. FTEs of research personnel in the different personnel categories.

The numbers for these two figures have been picked from the financial reports obtained by the Academy of Finland from the research groups. The numbers may not fully reflect the truth, but they describe, for example, the ratio of the postdoctoral (= researchers) to doctoral student workload in the projects.

2.3. National and international mobility

From project to project, the amount of mobility varied significantly. There was a considerable amount of mobility in some projects, whereas it did not occur at all in other projects. About 30% (8 projects) did not have any mobility. On average, the research mobility was 17.6 months per project among the projects that included mobility. The average mobility for the national and international projects was 28.2 and 7.1 months, respectively. The mobility in months and the mobility adjusted by the granted funding in national and international projects are presented in Table 1.

Table 1. Mobility and funding in national and international projects (both from and to Finland).

	International projects		**National projects**	
Project	**Mobility in months**	**Mobility per funding of 0.1 million euros**	**Mobility in months**	**Mobility per funding of 0.1 million euros**
1	4	1.75	2	0.24
2	0	0	0	0
3	2	0.44	48	5.13
4	0	0	6	1.15
5	0	0	71	8.41
6	2.3	0.64	75	8.76
7	27.7	7.8	31.5	3.31
8	15	4.18	2.5	0.85
9	2	0.67	0	0
10	0.5	0.32	0	0
11	8	3.01	0	0
12	0	0	12	3.40
13	2.5	1.44	5.6	0.59
Average	**4.92**	**1.56**	**19.51**	**2.45**

The amount of mobility was greater both in absolute terms and also when adjusted to the amount of project funding within the national projects as compared to the international ones. On average, the national and international projects had 2.45 and 1.56 months of mobility, respectively, per 0.1 million euros in funding.

The national mobility was 54.5 months in total, which accounts for approximately 17% of the overall mobility of some 317 months. Hence, the figures shown in Table 1 reflect mostly the international mobility, although they include the national mobility as well.

Within the national projects, the division between the mobility from and to Finland is close-run. Approximately 46% of the total of 253.6 months of the mobility was inward mobility to Finland while 54% was outward mobility. The international projects included 64 months of mobility, and the division between the mobility from and to Finland was again quite equal: 46% outward and 54% inward. The national mobility was included in the inward mobility to Finland.

2.4. Publications

The total number of scientific publications from the programme was 446. Most of them, about 71% (317 publications), were original scientific articles (A1). About 11% (49) were articles in conference publications (A4) and 10% (45) were articles in conference proceedings (B3). This information is shown in Table 2. Type A publications were peer-reviewed scientific articles, while type B publications were non-refereed scientific articles. In addition to these, there were also dissertations, master's theses or diploma work and reviewed articles and publications in scientific books. Communication to other than scientific community occurred, too. Project leaders also reported two television/radio interviews, articles/interviews in newspapers or magazines and one other communication of information. The classification is based on the Ministry of Education, Science and Culture's publication type classification. Learn more on the Academy of Finland's website http://www.aka.fi/Tiedostot/Tiedostot/Liitetiedostot/OKM_julkaisutyyppiluettelo_2010_en.pdf

Table 2. Publications

A1	A2	A3	A4	B1	B2	B3	TOTAL
Journal article, original research	Review article, Literature review, Systematic review	Book section, chapters in research, bookresearch	Conference proceedings	Non-refereed journal article	Book section	Non-refereed conference proceedings	
317	7	2	49	6	1	45	427

Table 3 presents the number of publications and the number of publications per granted funding of 0.1 million euros. The results show that the number of publications as compared to the granted funding is approximately the same for the national and international projects, that is, 3–4 publications per 0.1 million euros of funding on average.

Table 3. Publications and publications per amount of funding in national and international projects.

	International projects		National projects	
Project	Number of publicationspublications	Publications per 0.1 million euros of funding	Number of publications	Publications per 0.1 million euros of funding
1	10	4.4	6	0.7
2	9	2.6	8	1.1
3	9	2.0	27	2.9
4	13	2.0	15	2.9
5	10	2.8	23	2.7
6	13	3.6	40	4.7
7	22	6.2	53	5.7
8	7	2.0	6	2.0
9	5	1.7	32	4.2
10	4	2.5	9	1.6
11	14	5.3	13	3.2
12	11	6.1	12	3.4
13	11	6.9	65	6.8
Average	**10.6**	**3.7**	**23.8**	**3.2**

2.5. Degrees

Approximately 88% of the projects produced degrees for the research personnel. The total number of degrees was 73. About 56% of these (41 degrees) were doctoral degrees, 42% (31) were master's degrees and 1% (1) was a licentiate degree.

Only twelve degrees (16%) were fully financed by the project it was part of: one doctoral degree and eleven master's degrees. Most of the degrees were mainly funded from sources outside the programme: only ten doctoral degrees received more than half of their funding from the programme, the average funding percentage being 33.0%. Therefore, the programme can be said to have produced about 13.5 full doctoral degrees. As for master's degrees, their funding percentage was significantly higher at 58.6%. In the final reports, there was no information on three master's degrees' funding percentages, so they have naturally been left out from the calculation.

Section 2.2 showed that the FTE working time of postgraduate students was 84 years. Dividing this with the 13.5 full doctoral degrees, we can say that, on average, it took approximately 6.2 years for a postgraduate student to write a doctoral thesis.

2.6. Inventions and patents

The respondents were asked to report the number of inventions (a notification of invention) and the number of patents (or patent notifications) they have generated from their projects involved in the programme. According to the reports, 7 out of 27 respondents had produced either inventions or patents. The total number of inventions and patents was 7 and 4, respectively.

Considering that the funding from the Academy of Finland for the programme was 13.2 million euros, the nominal cost per one invention or patent was 1.2 million euros.
3 Photonics in Finland and impacts of the programme

This chapter concentrates on the results of the Webropol online questionnaire presented in Appendix I. The data is mostly presented in verbal way but there are numeric/statistical figures, too. The direct citations from the questionnaire are italicised. The questionnaire was sent to 41 people and 27 responded. The response rate was approximately 66%. Those that did not respond were approached multiple times without success.

3.1 Links to strategy of host institute and image of photonics research
Most of the respondents said that photonics research is linked to the strategy of their host institute (Question 4). Only one respondent said that the link was weak; the absence of a consolidated strategy in photonics was seen as a reason for this.

The respondents found (Question 5) that the image of photonics research in general is good at their host institute, giving an average score of 4.04. No one found the general image to be poor. The image of photonics research in Finland gained a slightly lower average value of 3.81. All of the answers are shown in Table 4.

Table 4. The image of photonics research.

The image of photonics research	Poor	Inadequate	Fair	Good	Excellent
At your host institute	0	1	5	13	8
In Finland	0	1	8	13	5

2.7. Perceived changes in the field of photonics research

It was said (Questions 6 and 7) that the biggest changes in the field of photonics during the past five years were multidisciplinarity (73%), new topics 65%), internationalisation (35%), infrastructure (27%), change of focus (19%), doctoral education (15%) and resources (12%). These percentages are presented in Figure 4 below.

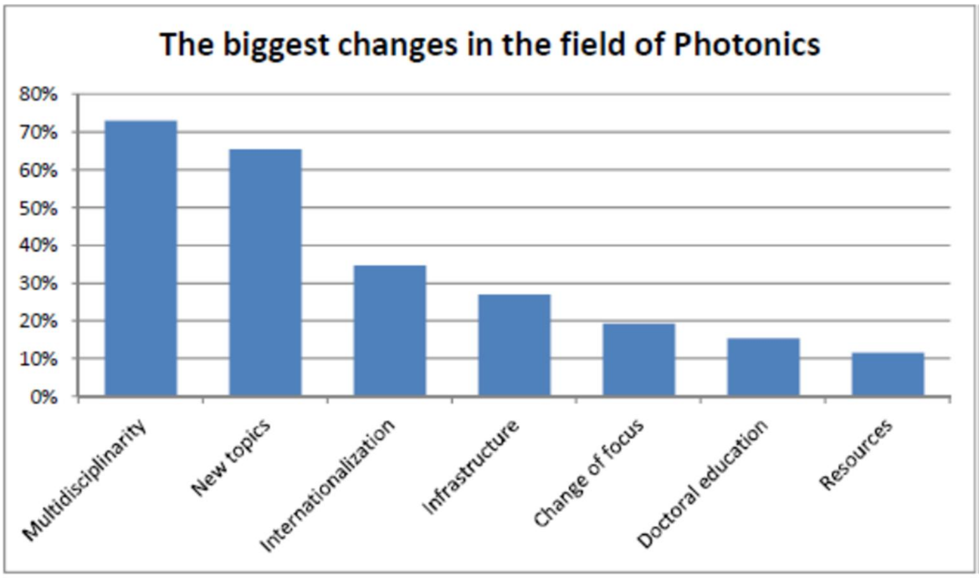

Figure 4. Perceived biggest changes in the field of photonics.

The respondents explained their choices in the following ways:

- International collaboration is all the time more important, many international calls are open and EU has big investments in photonics. New topics e.g. quantum optics, plasmonics and metamaterials have merged interdisciplinary fields in Finland including radio science, chemistry and mathematics. Resources in doctoral education have diminished due to the end of graduate schools funded from the Academy of Finland.

- Increasing use of new materials and materials developed specifically for photonics applications are changing focus and making photonics multidisciplinary in its nature.

- The amount of international staff has been increased remarkably. Also, international degree programmes have been developed. At the same time, new research topics are emerging, like 3D printing of photonics or random lasers.

- Photonics research has always been very internationals, but now researcher visits and postdoc periods abroad are common, and also Finnish research groups have a lot of foreign postdocs and PhD students.

- Photonics has changed quite drastically with the possibility of nanotechnology and new manufacturing possibilities of photonic structures

- Increasing use of new materials and materials developed specifically for photonics applications are changing focus and making photonics multidisciplinary in its nature.

2.8. Funding

The Academy of Finland was the most important source of external funding for the research groups involved in the programme. The biggest funders of research after the Academy of Finland (excl. own university funding) were Tekes – the Finnish Funding Agency for Innovation, the European Union or the European commission, and doctoral programmes (Question 8).

Among the research groups involved in the programme, the ratio between the funding from the Photonics research programme (Question 9) and the overall external funding for photonics-related research varied from 3% to 60% on average during 2009–2014. This is illustrated in Figure 5. For most of the research groups, the funding from the Photonics programme accounted for less than 20% of all external funding. However, for quite a few research groups, the funding from the programme accounted for up to 50% (or more) of all external funding.

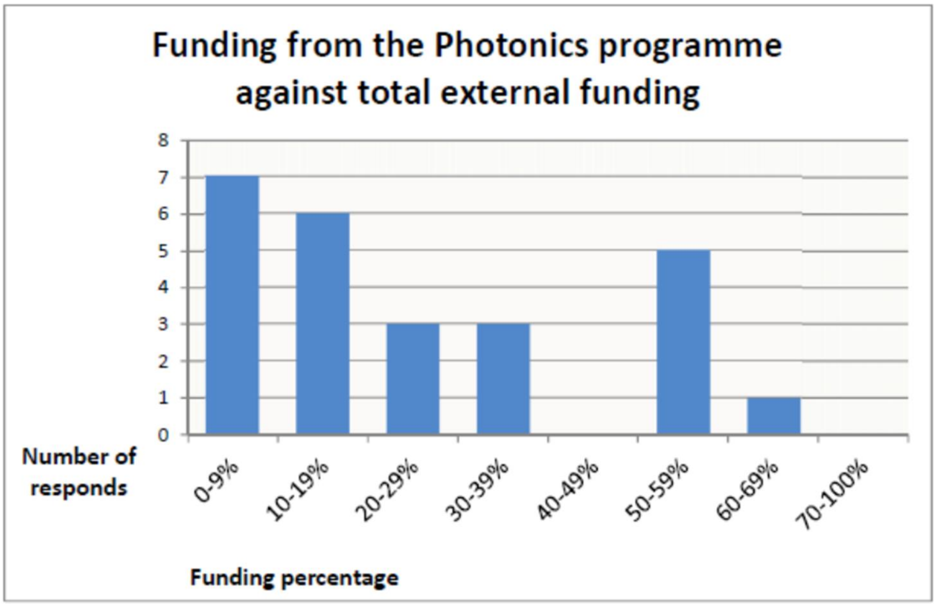

Figure 5. Funding (in percentages) from the Photonics programme as compared to overall external funding on average during 2009–2014.

2.9. Impacts of the programme

This section summarises some of the data that can provide indications of the impacts of the programme. It should be noted that these are mainly, if not exclusively, only indications.

2.9.1. Knowledge transfer

According to the answers (Question 10), the most important knowledge transfer mechanisms included the following:

- Journal papers, conference talks, including few invited ones, posters, invited reports on the seminars.
- Bilateral commercialization activity with a company, scientific publications.
- Further experimental demonstrations
- Transferring patents to the industry, attending photonics Finland networking.
- International and national seminars, workshops and summer schools.
- Student training, participation of international researchers.
- Collaboration with companies.

Most respondents (56%) said that the publications they produced were the most important mechanisms for knowledge transfer.

2.9.2. Benefits of being part of the programme

The respondents described (Question 11) how their research benefitted from being part of the Photonics programme. According to the answers, the programme has helped researchers in increasing the level of national and international networking and cooperation. Also new research topics were pursued. Interdisciplinary was found to produce added value for the projects, too.

2.9.3. Impacts of the programme in Finland

The researchers also estimated the positive impacts of the Photonics programme in Finland (Question 12). The visibility of photonics research has improved and the programme has managed to strengthen the communication, multidisciplinarity and cooperation between research groups. The programme was said to have given possibilities to conduct innovative research and to deliver the know-how of the field nationally. It was also said that it improved the quality of the academic research.

2.9.4. Effects on public image, research partners and industrial partners

On average, the respondents thought (Question 13) that the Photonics programme has been useful in affecting the public image of the research groups and in gaining new research partners. The respondents did not see a strong influence of the programme on new industrial relations. Yet, three respondents thought that the programme's influence on their group's new industrial partners was excellent. According to the final reports, one of these respondents (who saw the influence as being excellent) was a member of a research group that was able to develop two inventions and one patent.

The respondents who (Question 14) thought the industrial partners had benefitted from the programme (25%) provided, for example, the following comments:

- The industrial partners were very actively involved in following the progress.
- Better business (on international level) was made.
- The invention was transferred, and the industrial partner got a highly educated researcher.

The ones who found that industrial partners did not benefit from the programme (75%) had, for example, the following to say:

- There were no industrial partners.
- Industrial partners were not directly involved.
- There was only one industrial connection during the program, and it existed only in the level of discussions.

2.9.5. How the programme's multidisciplinarity affected the research

Approximately 85% (23 respondents) thought (Question 15) that the programme had benefitted their research. The benefits for the research groups were, for instance:

- Interdisciplinary research
- Interaction with people from other fields
- Fruitful new research collaborations

The rest, that is, approximately 15%, found that the multidisciplinarity of the programme did not benefit their research:

- More multidisciplinary consortium would have been needed.
- They already had multidisciplinary research.
- There were not any new (benefits) for the research group.

2.9.6. New professorships, postdoctoral researchers and postgraduate students

The increase in the number of professorships in the field of photonics was in the range of approximately 5 to 10 during the programme period (Question 17). The increase was concentrated mainly to those organisations that already had a significant position in the field of photonics in Finland. The number of granted FiDiPro professorships in the field of photonics was three during the programme period (Question 18). Similarly as with the new professorships, the new FiDiPro professorships were also concentrated to those organisations that already had a significant position in the field of photonics in Finland.

The change in the number of postdocs and PhD students goes hand in hand, and is reportedly ranged from a decrease of two to an increase of six during the programme period (Questions 19 and 20). This evidently reflects the fact that the total funding for photonics research has increased during the programme period.

2.9.7. Start-ups

There were no direct new start-ups from any of the projects in the programme (Question 22). According to one answer, there was a partial start-up that resulted from a project in the programme. There were two comments that start-ups have not occurred yet, but may develop later.

3. National and international cooperation and networking

One of the aims of the programme was to strengthen networking, both national and international. National and international collaboration is dealt with in this chapter. Section 3.1 deals with national aspects and sections 3.2 and 3.3 with international aspects in international projects (those funded by one of the international joint calls) and national projects, respectively. In section 3.4, the importance of international collaboration for the host institutions is discussed. Section 3.5 presents figures showing the relations between the quality and number of publications and the extent of mobility in national and international projects.

3.1. National collaboration and networking

The respondents felt that the national cooperation and networking took place mainly in seminars, by invited talks, workshops and through interaction between researchers. In general, the respondents estimated that the level of networking has increased nationally. The respondents described their networking and collaborations as follows (Question 24):

- A strong collaboration with VTT. Also, improved collaboration with Aalto University.
- New collaborators in national and international level (Kuopio).
- A hope that the cooperation will continue informally after the program. New informal contacts were established in particular with the University of Jyväskylä.
- Co-operation and common teaching of Ph.D. students in the field.
- Collaboration with three other research groups in different universities.

- Increased the number of connections.
- New collaboration with Professors. Göery Genty's group at Tampere University of Technology.
- Project consortium enabled new close cooperation of six Finnish groups.
- Networking with Tampere University.
- The photonics programme meetings have led to new contacts with researchers from the physics side of photonics and led to a joint project application.
- Active collaboration and networking within the consortium was something that we have not had before in national level.

3.2. International collaboration and networking: projects funded in international calls

In total, 30% of the international joint call projects had had earlier collaboration with their international partners (Question 26), and 70% did not have any earlier collaboration. The collaborations had lasted 7–15 years (Question 27). The international partners were found by networking on different occasions, such as workshops, conferences, delegate trip to target country, working abroad, etc. (Question 28). Some mentioned that they had been contacted by their research partner.

The main attractions for the collaboration were for example the following (Question 29):

- Overlapping interests and needs
- Complementarity of activities and skills
- Skilful workforce, including our own one (mine and the leader of the Russian team)
- In Japan especially the intensity of the work
- Excellent researchers
- Excellent international reputation of the Japanese partner
- Interesting research field
- The facilities
- Knowledge

The international collaboration was important (Question 30) in creating new scientific methods (average score 4.36) and better scientific results (average score 4.09). The importance in creating new forms of collaboration and new training methods was also found to be on a relatively high level. There was some variation though; some people found that the understanding of differences in research cultures and organisations was not a relevant issue. The figures are presented in Table 5.

Table 5. Importance of international collaboration (Question 30).

What was the importance of international collabora-tion in creating…?	1 Poor	2 Inadequate	3 Fair	4 Good	5 Excellent
New scientific methods	0	0	1	5	5
Better scientific results through access to re-search facilities in project partner`s organisation	0	1	1	5	4
New forms of collabora-tion	0	0	2	8	1
New training methods (for students)	0	1	3	5	2
Insigts for cross-cultural differences in general	1	0	4	4	3
Understanding of differ-ences in research organi-sations and cultures	1	1	3	4	2
Other, please specify:	0	0	0	0	0
Total	2	3	14	31	17

Some respondents found that other than providing funding, the Academy of Finland did not have an important role in fostering international research collaboration (Question 31). Those who said the role of the Academy was important briefly explained why. According to them, the seminars were interesting, the programme had supported the research and found new forums for scientific cooperation, the framework of the programme had provided a solid platform for fostering international collaboration and the first contacts obtained via the Academy of Finland had been fruitful when researchers networked for EU projects.

3.3. International collaboration and networking: projects funded in national calls

Approximately 77% of the project leaders involved in the national call (Question 32) estimated that they had a significant international partner involved in their research project. Slightly more than 50% of the project leaders had earlier research collaboration with their significant international partner (Question 33). The research partners were mostly found through networking in workshops, conferences, etc. or with the help of earlier contacts (Question 35). The earlier collaboration (if any) with the international project partner had lasted on average nearly seven years (Question 34).

Approximately 28% of the project leaders (Question 36) found that the main attractions for the international research collaboration were the expertise of their research group and the excellent researchers. Other important issues mentioned were research facilities, publications and common research visions and a well-planned research plan.

3.4. Importance of international collaboration for host institution

The project leaders evaluated the importance of the international collaboration in the Photonics programme for their host institution from various perspectives: importance for postgraduate students, teachers, etc. The programme was found to be important in particular for postgraduate and postdoctoral students, for mobility and for creating new research topics and research collaboration (Question 37). The lowest scores were given to the importance of agreements between universities and organisations (1.71), new posts (2.05) and teachers (2.25). The total average of all evaluated themes was 3.21. These figures are listed in Table 6.

Table 6. Importance of international collaboration for host institution.

	1 Poor	2 Inade-quate	3 Fair	4 good	5 Excel-lent
Postgraduate or postdoctoral students	0	1	5	9	10
Teachers	10	5	4	3	2
Researcher mobility	1	1	8	6	9
Agreements between universities and research organisations	15	3	5	0	1
New research topic(s)	0	0	8	7	10
New research collaboration with the same international partner	2	4	5	9	5
New research collaboration with other (national or international) partners	1	2	5	6	11
Conferences	2	2	8	8	5
New posts	10	5	4	2	1
Other, please specify	0	0	0	0	0

3.5. Publications and mobility in national and international projects

The relationship between international joint publications and mobility and the relationship between international joint publications and other published material are presented in Figures 6, 7, 8 and 9. International and national projects are presented in separate figures.

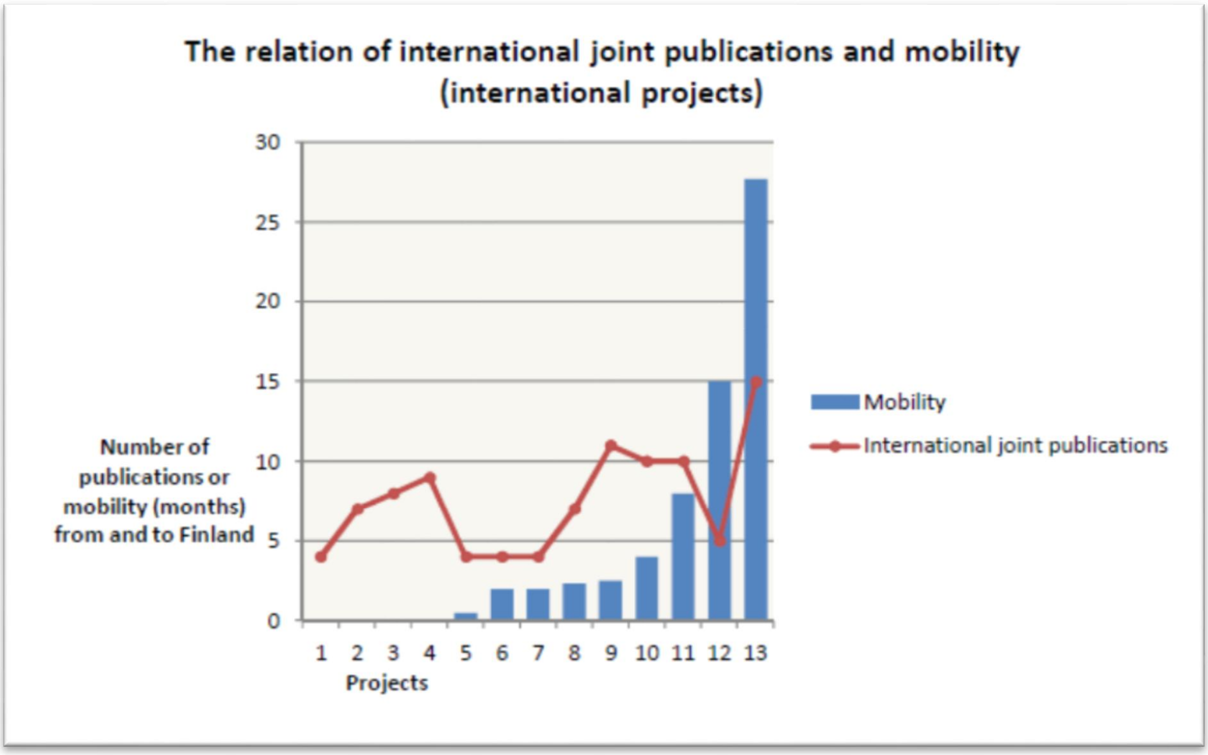

Figure 6. International joint publications and mobility in international projects.

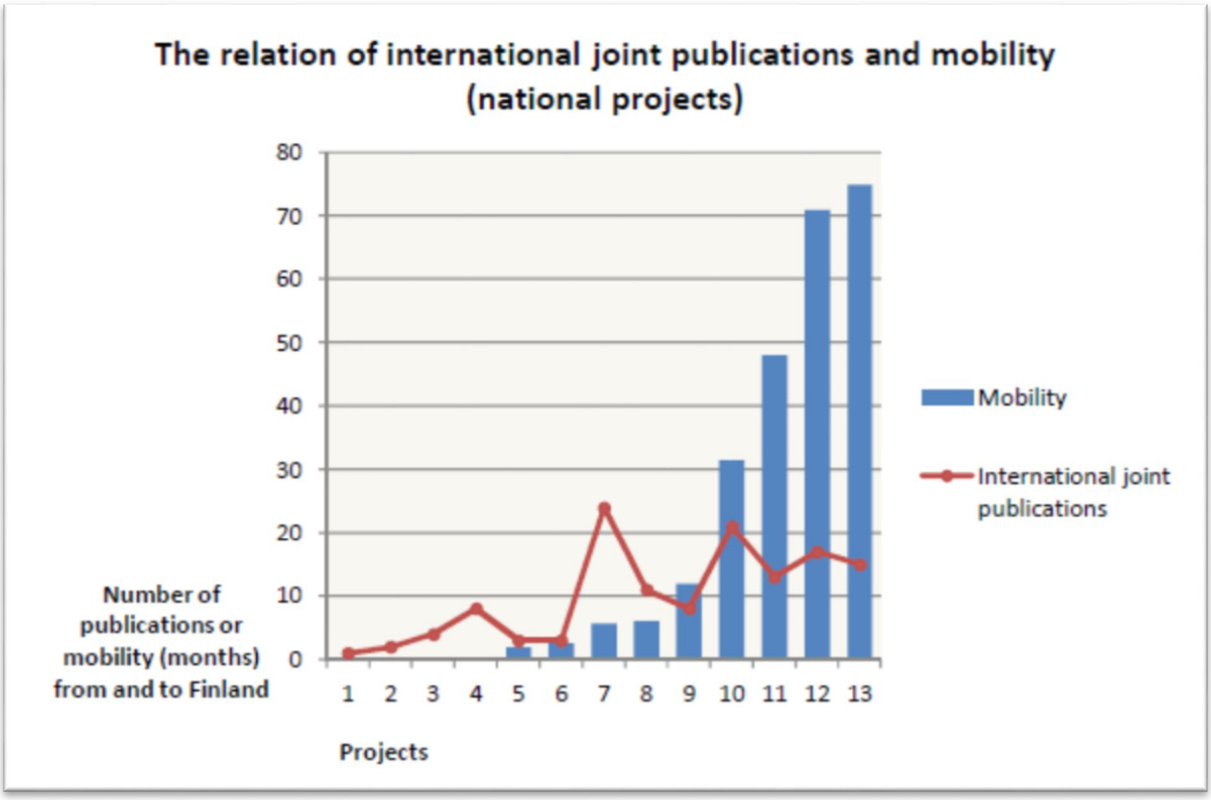

Figure 7. Mobility and international joint publications in national projects.

Figures 6 and 7 indicate that – in both national and international projects – there is only a weak correlation between the number of joint international publications and the mobility. The international projects did not include any national mobility. In the national projects, as compared to the international projects, the number of joint international publications is only on a slightly higher level, but the number of mobile research months is in general significantly higher.

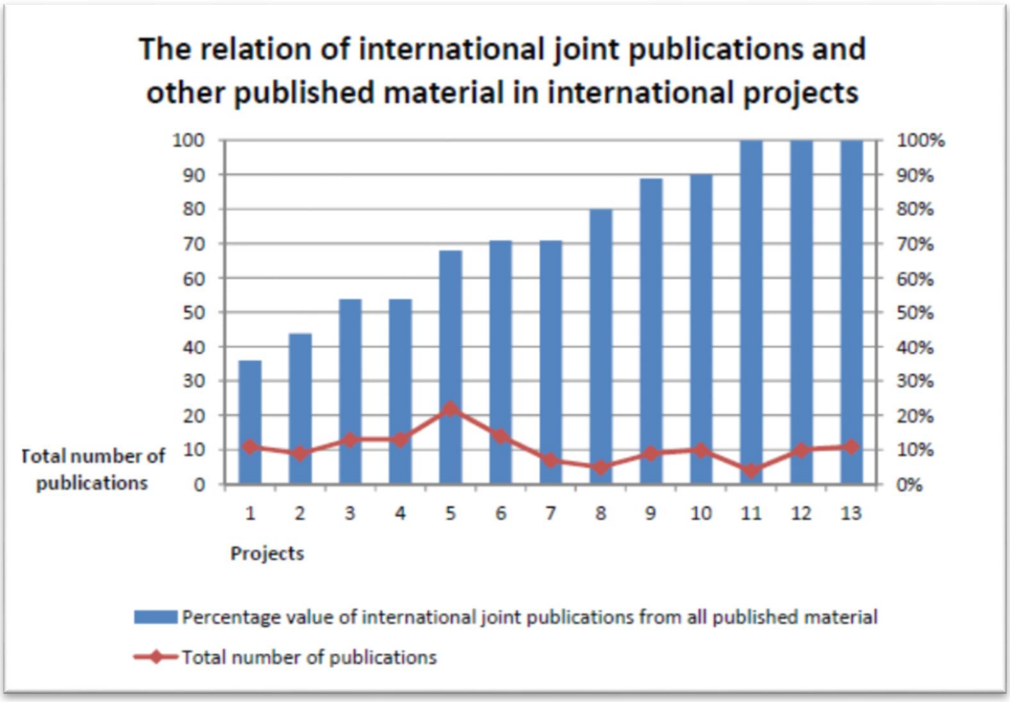

Figure 8. International joint publications and other published material in international projects.

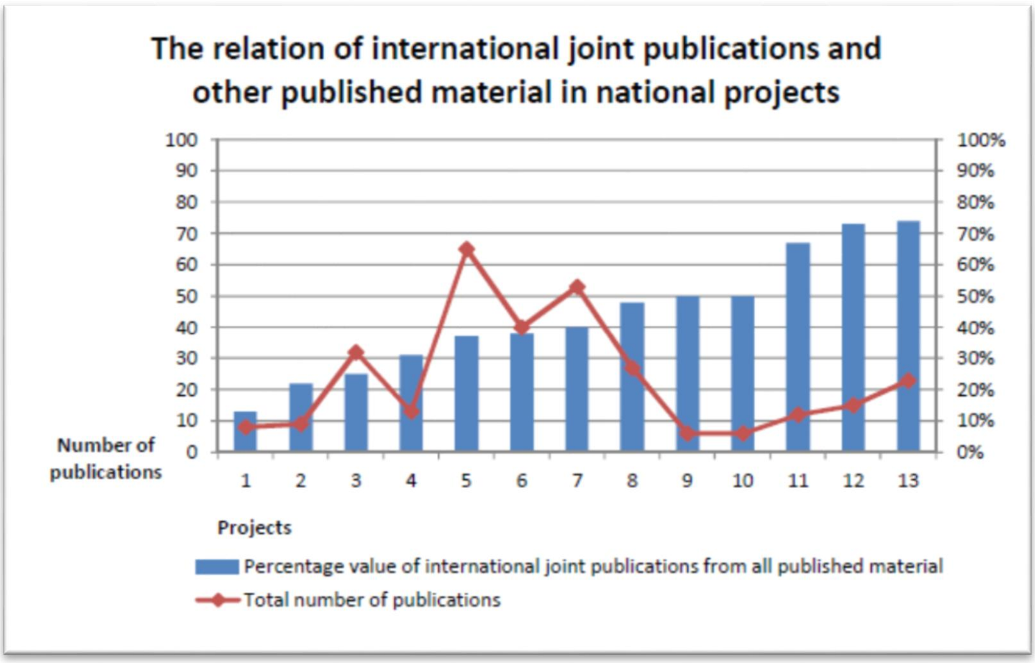

Figure 9. International joint publications and other published material in national projects.

Figures 8 and 9 show that a clear majority of the publications produced in international projects are joint international publications, but the share of joint internationalpublications from national projects is also relatively high. The other observation is that the total number of produced publications is higher for national compared to international projects.

4. Success stories in more detail

One aim for the programme was to produce success stories and (scientific) breakthroughs. The success stories named by the respondents are presented in this section.

4.1. Highlights and breakthroughs

Almost every respondent found that they had made a (scientific) breakthrough during their project. Over 81% briefly explained their breakthroughs (Question 21). The breakthroughs varied; some of them were new theories, successful experiments, development of techniques, publications, inventions etc.

The scientific breakthrough stories mentioned were:

- New fabrication process for metallic nanocones. The process enabled several high-profile research papers and even industrial collaboration. A nanostructure was developed that has simultaneous plasmonic and wave guide resonances.
- Chlorophyll-based molecular design for optical anion sensors, supramolecular approach to assemble donor-acceptor dyads, which can be used in solar cell applications.
- Replicated nanoslot waveguides for visible light, the improved quality of nano-slot waveguides.
- Producing a photonics-based NEMS/MEMS device characterization tool.
- We could experimentally 22 years after the invention of the DSCs show how the oxidised dye receives its lost charge from the commonly used I-/I3- electrolyte.
- Assessment and characterization (quantification) of supercontinuum coherence, novel dispersion-cancelled spectral-intensity optical coherence technique.
- Developing new tools suitable for long-term ratiometric ROS imaging.
- IRC-MEMS project has produced a photonics-based NEMS/MEMS device characterization tool. The developed stroboscopic near infrared (NIR) scanning white light interferometer (SWLI) can characterize single and multi-layer micro- and nanostructures in static and dynamic mode.
- Our work on polarization-based nonlinear microscopy (ANIMOS project) started as an idea.

However, its potential has already been demonstrated in different contexts (plasmonics, lipids, carbon nanotubes, semiconductors, collagen...). However, this is just a beginning and more results will follow. Another interesting case is that amorphous silicon nitride has an unexpected second-order response (REDMETA project). Again, more results will follow.

- The whole research field related to utilizing nanodiamonds in biomedical applications experienced a considerable upswing during this time, and through the programme we have been enabled to be an active part of this.
- Observation of strong coupling between surface lattice modes and molecular excitations in a system comprising of metal nanoparticle arrays and a molecular film. Proving the spatial coherence of such light-matter hybrids. Strong coupling is behind many important coherence phenomena and the results may enable e.g. threshold less lasing in the nanoscale.
- The highest efficiency in the world for black silicon photovoltaic cell was obtained.
- Our results push the performance of stroboscopic white-light interferometer vibration analysis to new limits.
- We invented a lithography technique that allows large-area nanostructures to be fabricated in an effective way. This technique has been adopted by other research groups in Finland and abroad.
- Blood Pulsation Imaging system was invented.
- Polymeric slot waveguides as well as tight bends in Si photonics
- For the first time, we were able to write fluorescent structures into polymer by utilizing silver nanocluster formation under laser irradiation. The fabrication method opens new opportunities for applications in nanophotonics like imaging, labelling, and metal ion sensing.
- The paper in Mater.Horiz. 2014 presents a facile and scalable route for the preparation of periodic arrays of unique three-dimensional subwavelength-sized structures on large sample areas, which is very cumbersome to achieve by other methods. The results have provoked wide interest abroad, leading to new international collaboration.
- We have been able to develop a new generation of optogenetic regulators of specific major cell signalling proteins. These tools bring optogenetic control beyond the typical cell activation, allowing highly localised changes in activity of individual biochemical pathways. Ongoing work on these pathways we can now manipulate revealed new insights into mechanisms of neuronal development and neurodegeneration. The main findings were published in Nature neurosci and J Neurosci.
- Invention of the new passivation method for nanostructured silicon and consequently the world record solar cell efficiency in this material.
- Non-linear spectroscopy (four wave mixing, second harmonic generation) of individual carbon nanotubes. These are pioneering experiments of non-linear spectroscopy of individual carbon nanotubes.

4.2. Acknowledgements

This chapter presents the award-winning achievements mentioned in the Project impacts sections of the final reports. The names and achievements listed here are only examples and do not represent a complete list.

Some of the people involved in the projects have been rewarded for their work. For example, in 2011, Technology Academy Finland presented Millennium Distinction Awards to two Finnish researchers, Professor Jouko Korppi-Tommola and Professor Helge Lemmetyinen. They were recognised for their pioneering development work in solar energy. The World Economic Forum (WEF) awarded Hele Savin as a Young Scientist 2013 for her nanotechnology-based innovations in solar energy. Savin received the national “Future of Electricity” award as recognition of her work in developing solar energy conversion efficiency.

Also other principal investigators were noticed. Professor Rashid Giniatulli was selected as a representative of Finland in the EU ROS-Cost Action, and Professor Martti Kauranen was invited to join a new COST Action on Nanospectroscopy. Nowadays he represents Finland in the management committee of the Action.

Dr Alexei Kamshilin was invited as an international expert to evaluate the research projects submitted to the National Scientific Committees of Austria (2013) and Qatar (2011); the principal investigator Jessica Rosenholm was called as invited speaker to the JSAP-MRS. A PhD student from the same project, Eva von Haartman, attended the International Conference on Diamond and Carbon Materials in Spain and gave one out of three Young Scientist Award presentations. The honorary professorship at the Polish Academy of Sciences (Wroclaw) in 2013 was awarded to Jorma Hölsä thanks to the expertise gained in the project with which he worked.

Examples of particular success stories in science and education are the FiDiPro Professorships. Two new FiDiPro Professors were appointed (Question 18). One was Nasser Peyghambarian and the other was Gaetano Assanto. Peyghambarian was appointed as FiDiPro Professor of Photonics at two universities (Aalto University, University of Eastern Finland), and Assanto at Tampere University of Technology.

According to the online questionnaire, one highlight in the field of Finnish photonics was the launch of an MSc programme at the University of Eastern Finland. The programme is the only one in the country, and it has offered opportunities to hire high-level professors to the university (Question 23).

5. Future visions

The respondents were asked to evaluate the future of photonics. It seems that this branch of science will be a central area of scientific development. The future visions were evaluated at institutional, national and global levels.

5.1. Institutional views

About 38% of the respondents thought that the future of their host institute looks bright (Question 38a). Most of the project leaders also gave suggestions for forthcoming research. These included:

- Synthesis of photonic particles and their use.
- Solar energy in various forms, quantum optics and materials science.
- 3D printing in photonics, spectral imaging techniques of biological samples, new light sources.
- Chemical dynamics using non-linear multidimensional femtosecond spectroscopy, nano- and bioimaging by using femtosecond CARS techniques and plasmonics.
- Nanostructured materials, new methods for imaging, spatiotemporal control of ultrafast pulses, novel techniques for optical measurements, spectroscopy.
- Development in Bio-medicine of imaging.
- Nanophotonics, quantum plasmonics.
- Collaboration within material research, nano-optics and quantum physics.
- Novel light sources, nonlinear optics and imaging and (remote) molecular sensing/imaging.

5.2. National aspects

The benefits of photonics are nowadays recognised, and the field has become more nationally visible (Question 38b). According to these visions, Finnish research in the field of photonics will:

- Concentrate to a few but strong research institutes.
- Be put in the area of development of new more efficient light sources and its application in real life.
- Exploit more the existing knowledge in special fields in various places (Joensuu, Tampere, Oulu, Helsinki/Espoo, etc.).
- Support the industry with educated employees and create new knowhow on what the industry can build their future products.

Approximately 19% of the respondents evaluated that multidisciplinary research and collaborations and cooperation will be part of the future. The themes and research area suggestions included:

- Solar energy, biophotonics and materials processing.
- More efficient light sources and its application in real life.
- Coherence theory, quantum optics, new materials.
- Nanofabrication, soft materials.

- Sensing systems
- Imaging technology, radiation detectors.

The project leaders estimated how the research of Finnish Photonics could be improved (Question 39). Many researchers made several suggestions. These visions included various themes:

- The research programmes of the future (33%)
- Socialization, collaboration or networking (29%)
- Funding (29%)
- Internationalization (24%)
- Industrial impacts (14%)
- Units, multidisciplinarity and education (9.5% each).

The percentages describe how many times the theme was mentioned (21 answers overall).

5.3. Global perspectives

The future of global photonics research is bright. Approximately 42% of the respondents described the future positively (Question 38c). In all, 9.5% considered that Europe, in particular, will be an important part of the global field of photonics in the future. It was also stated that solar energy will be an important part of the global research area: over 19% of the project leaders mentioned having considered it. Other future research topics that emerged included:

- Lighting, photonics integration
- Photovoltaics, solar cells
- Optical connectivity
- Energy consumption in lighting
- Nano-optics, plasmonics

6. Feedback

The project leaders had a chance to give feedback about the programme (Question 40). Most of the feedback was considered positive, but there were also some suggestions for changes. The researchers of the Photonics programme commented on the programme in the following ways, for instance:

- Very nice programme with interesting seminars and a good platform for networking. We are very happy and proud to have been part of this programme and would like to thank all coordinators and other "organizers" (whom all have been extremely helpful throughout the whole programme also) from the Academy of Finland side!

- Photonics program was really well coordinated. Several common seminars with interesting speakers were really eye opening and also created some collaboration. Also young scientists' events were very welcome.

- Programme meetings inevitably focus on the funded researchers. However, it is clear that some researchers in the field, particularly on the biology side, were not funded (while others were funded but did not attend perhaps because of the emphasis on physics). It would have been beneficial to all for programme meetings to be more inclusive.

- I think the Program must keep supporting basic research; they are not very expensive and ensure the resonance in the scientific community. The orientation to applied research, more applied research interesting only to Finnish industry will lead to the degradation of existing scientific teams and will hinder the rising of new teams.

- Photonics program was a welcomed action by the Academy of Finland (again, considering for instance Photonics21 in EU). The coordination was very good, especially in the beginning. Similar programs are needed from the Academy of Finland and also from Tekes, with support from optics and photonics industry.

APPENDIX I

Questionnaire: Photonics and Modern Imaging Techniques Research Programme

Part 1: Basic information about the researcher and research organization

1. What is your home instutute?
2. How many professorships does your home institute have in the field of Photonics?
3. What is the overall number of professorships in your home institute?
4. How did the PHOTONICS programme link to the strategy of your home institute?
5. How do you see the image of the Photonics research in general (1 poor, 5 excellent):
    a. In your home institute?
    b. In Finland?
6. Name 2-4 biggest changes in the field of Photonics research during the past 5 years from among the topics:
7. Please provide brief explanations for the previous choices. You may also name other changes apart from the list above:
8. What have been the two main external funders of your research?

Part 2: Wider influences of the PHOTONICS research programme

9. Estimate in percentages how large has been your funding from the PHOTONICS programme compared to the overall external funding of your organization for photonics-related research on average since 2009? You may include Tekes funding to external funding.
10. What are the most important knowledge transfer mechanisms with which the research results and know-how of your research have been incorporated into practice? Please give examples.
11. Describe briefly how did your research benefit from being a part of the PHOTONICS research programme (new networks, research topics, etc.)?
12. What kind of a positive impact has the PHOTONICS programme had in Finland?

13. How has the PHOTONICS research programme influenced your research group's:

(1=not at all, 5=very much)

1 2 3 4 5

a. Public image?

b. New research partners?

c. New industrial partners?

14. Has your industrial partner gained benefit from the PHOTONICS programme? Please comment:

Yes_________________________________

No_________________________________

15. Did the multidisciplinarity of the PHOTONICS programme benefit your research? Please comment:

Yes_________________________________

No_________________________________

16. Name the key publication of your PHOTONICS project and its number of citations?

____

____

17. Has the number of professorships changed since 2009 in the field of photonics in your organization?

- The number has increased since 2009 by

____

- The number has decreased since 2009 by

____

If there have been new recruits, provide the following details: field of the professorship(s), year of recruit(s), age of recruit(s):

____

____

18. Have you received FiDiPro-professorship(s) in the field of photonics since 2009? If yes, provide name:

Yes________________________________

No_________________________________

19. Post-doctoral researchers:

What has been the number of post-doctoral researchers (excluding professors) a year (on average) since 2009 in the field of photonics in your organization?

____

- The number has increased since 2009 by ______________________
- The number has decreased since 2009 by ______________________

20. PhD students:

What has been the number of PhD students a year (on average) since 2009 in the field of photonics in your organization? ___________________________

- The number has increased since 2009 by ___________________________
- The number has decreased since 2009 by ___________________________

Part 3: Success stories in more detail

21. Scientific breakthroughs in the PHOTONICS programme:

____

____

22. Start-ups from your PHOTONICS project research:

____

____

23. Other highlights:

____

____

Part 4: National and international research networks

24. How has the PHOTONICS programme influenced networking of your research group nationally?

____

____

The following questions (25-31) are for those who were involved in PHOTONICS international joint calls with Brazil, Japan or Russia

25. Were you funded through Academy's international joint call with

Brazil

Japan

Russia

26. Did you have any earlier research collaboration with your international joint project partner?

Yes

No

27. If yes, for how many years has the collaboration lasted?

____

28. How did you find your international project partner?

____

____

29. What was the main attraction for research collaboration (facilities, excellent re-searchers …)?

____

____

30. What was the importance of the international collaboration in creating

(1=not important; 5=very important)

1 2 3 4 5

a. New scientific methods

b. Better scientific results through access to the research facilities in the project partner's organization

c. New forms of collaboration

d. New training methods (for students)

e. Insights for cross-cultural differences in general

f.Understanding of differences in research organisations and cultures

Other, specify: ________________________________

31. Did the Academy have any important role in fostering international research collaboration (other than providing funding)? If yes, what was it?

No________________________________

Yes ________________________________

The following questions (32-36) are for those who were NOT involved in PHOTONICS international joint calls with Brazil, Japan or Russia

32. Did you have any significant international partner involved in your project in some way? If yes, please answer questions 33-36.

Yes

No

33. Did you have any earlier research collaboration with your international project partner?

Yes

No

34. If yes, for how many years has the collaboration lasted?

____

35. How did you find your international project partner?

____

____

36. What was the main attraction for research collaboration (facilities, excellent researchers …)?

____

____

The following questions are for all project leaders:

37. What was the importance of the international collaboration in PHOTONICS programme for your home institution:

(1=not important; 5=very important)

	1	2	3	4	5
Post-graduate and/or post-doctoral students					
Teachers					
Researcher mobility					
Agreements between universities and research organizations					
New research topic(s)					
New research collaboration with the same international partner					
New research collaboration with other (national or international) partners					
Conferences					
New posts					
Other, specify ___________________________________					

Part 5: Future visions

38. Evaluate briefly the future of Photonics research. Consider what are the future thematic, rising fields of the Photonics research

a) in your home institute

---

b) in Finland

---

c) globally

---

39. How can the quality and impact of Finnish photonics research be improved?

---

40. General comments and feedback to PHOTONICS programme coordination:

APPENDIX II

Guiding questions to reviewers:

What is/has been the impact of the photonics programme on the raise in the technological expertise level in photonics in Finland?

You may consider this question with the help of (all or some of) the following questions:

How has the technological expertise level raised?

Has the programme been timely?

Has the focus of the programme been appropriate?

Would you have focused the research programme more on something else?

How important has been the role of international research collaboration?

Have the research collaboratory countries been "the right ones"?

You may also mention any concrete examples of impacts of the programme if you may have.

APPENDIX III

External final evaluation of the Research Programme “Photonics and Modern Imaging Techniques” (2010-2013) of the Academy of Finland

The Research Programme memorandum is very well written with clear and appropriate objectives and precisely defined research themes. The evaluation text highlights the outcome of the Programme with some statistics of, e.g., publications, mobility, patents, and examinations along with feedback from the participating researchers. However, only 2/3 responded. So, probably, this does not provide the full picture. A suggestion to improve this may be to require this input, only after which final project payment will be made.

Mostly, the discussion in the Research Programme memorandum is quantitative, with the exception of the reported “success stories”. We consider these the more important outcomes, albeit it is difficult for an outsider to assess the magnitude and impact of these in an objective way without more details being provided (e.g. citation records, albeit this will only emerge over time).

The majority of funding was awarded mostly to the three leading universities with already strong research in this area. This is natural, but as seen in Fig. 5 this funding represents less than 20% of the funding for these groups. This makes it somewhat unclear to determine the impact of the funds from this specific call for these groups. Other groups, on the other hand, have relied much more (over 50%) on this call.

In our opinion the expertise of national research teams in the selected photonics topics have increased significantly as the result of the Programme. The main areas in which the technological expertise level raised are photovoltaic materials, plasmonic effects and their applications, nanoparticle and subwavelength structures based materials. Also several novel imaging methods (nonlinear spectroscopy, nonlinear microscopy, and scanning white light interferometry with supercontinuum sources) have been developed and implemented mainly for biomedical applications including cutting edge research aimed at tackling of neurodegenerative diseases.

Publication rates and personnel distributions are reasonable. The number of patents and reported contacts with industry (and created spin-offs/outs) is perhaps small, but this does not necessarily represent a good measure of the technological expertise. Also we have the impression that the TRL of the materials/technologies/instruments is relatively low. All this can be, at least partly, explained by the different roles that, e.g., the Academy of Finland and Tekes have for funding basic and applied research, respectively, in Finland. The low number of patents and lack of spin-offs/outs also proves the challenges that Finnish universities have in motivating their researchers in commercializing their research.

The research had been timely and well correlated with the European and international activities devoted to similar topics (e.g., ERA-NET, JPND, and green technology programs: nanotechnology-based innovation in solar energy).

The selected themes seem highly relevant for the Finnish context. It is positive that the topics had been well focused and selected in such a way that they did not compete with the world players at the market of laser manufacturing, LED or CCD/CMOS production etc., but they concentrate at the hot topics in material science (nanotechnology), enhanced imaging, and their applications, as these achievements might be turned in future into competitive products.

The Programme has as one objective to increase multidisciplinary research through mobility both nationally and internationally. The evaluation shows, however, poor correlation between mobility and joint publication. Thus, this is not a very useful measure – cross-disciplinary research can also happen within a single department, so other measures of this objective could be developed. In general, in cases where new collaboration has been initiated through this Programme, it could be expected that the pay-off from this will likely take place a few years after the end of the project, and maybe should be evaluated at a later stage.

Mobility was not higher among the international projects, which is a bit surprising. International and national collaboration have different purposes and this Programme may have helped enable new such collaboration in some projects, while in other helped sustain already previously established ones. This distinction is not so clear in the evaluation. Therefore, the result from this can vary considerably among the projects.

In most of the national projects the cooperation with international research groups had played important role. However, we cannot judge whether Japan, Brazil, and Russia were the best nations for international partners for this call. Anyway, we are sure that this activity has built a strong fundament for applying for EU projects, especially, in Horizon2020 program (the cooperation with, e.g., Poland, Germany, and the UK).

The non-EU partners had been in the case of Japan (strong expertise and technology in material science, e.g., excellent cooperation with prof. Kobyashi) and Russia (strong theoretical background, especially, in St. Petersburg and natural source of human capital from neighborhood) well selected. The results of this cooperation are significant and most of the links should maintain. However, in the case of some of the projects with Japan the spendings and mobilities are somehow decoupled with the reported achievements (2 PhDs founded from some projects are not co-authors of any reported publications, the mobilities to Germany & India but no mobilities to Japan etc.). Brazil (which, in general, has not strong photonics background) was not so obvious partner. In the case of two projects, that is Tuomisto (Aalto Univ.) and

Vahimaa (UEF), the initiated co-operation resulted in significant achievements and increased mobility. In the other two cases the impact of the project for increasing the international co-operation has been small or the description is insufficient.

The joint, correlated efforts of groups located at different universities and representing complementary knowledge have increased, in many cases, the efficiency of the research and provided full technology paths from materials/technology up to applications. The multidisciplinary approach in the joint teams had been a strong driver in pushing the novel concepts/technologies toward applications, especially, in functional materials, solar energy and medical sciences. As Fig. 4 shows, the researchers themselves also perceived “multidisciplinarity” and “new topics” as the biggest changes in the field of photonics during the past five years.

In general, the internationalization of the research in Finland has increased significantly due to the Programme (even more through “national” but bilateral projects). Our evaluation of the total Programme is very positive, although sometimes it is difficult to judge what is the direct influence of the Programme, as parallel photonics topics had been founded from other national and international sources. Based on the responses, it is clear that the Programme has had a positive impact of the research within these themes in Finland.

In Joensuu (Finland), Gothenburg (Sweden), and Warsaw (Poland) on January 2, 2017

Prof. Jyrki Saarinen, University of Eastern Finland, Finland (Chair)

Prof. Peter Andrekson, Chalmers University of Technology

Prof. Malgorzata Kujawinska, Warsaw University of Technology