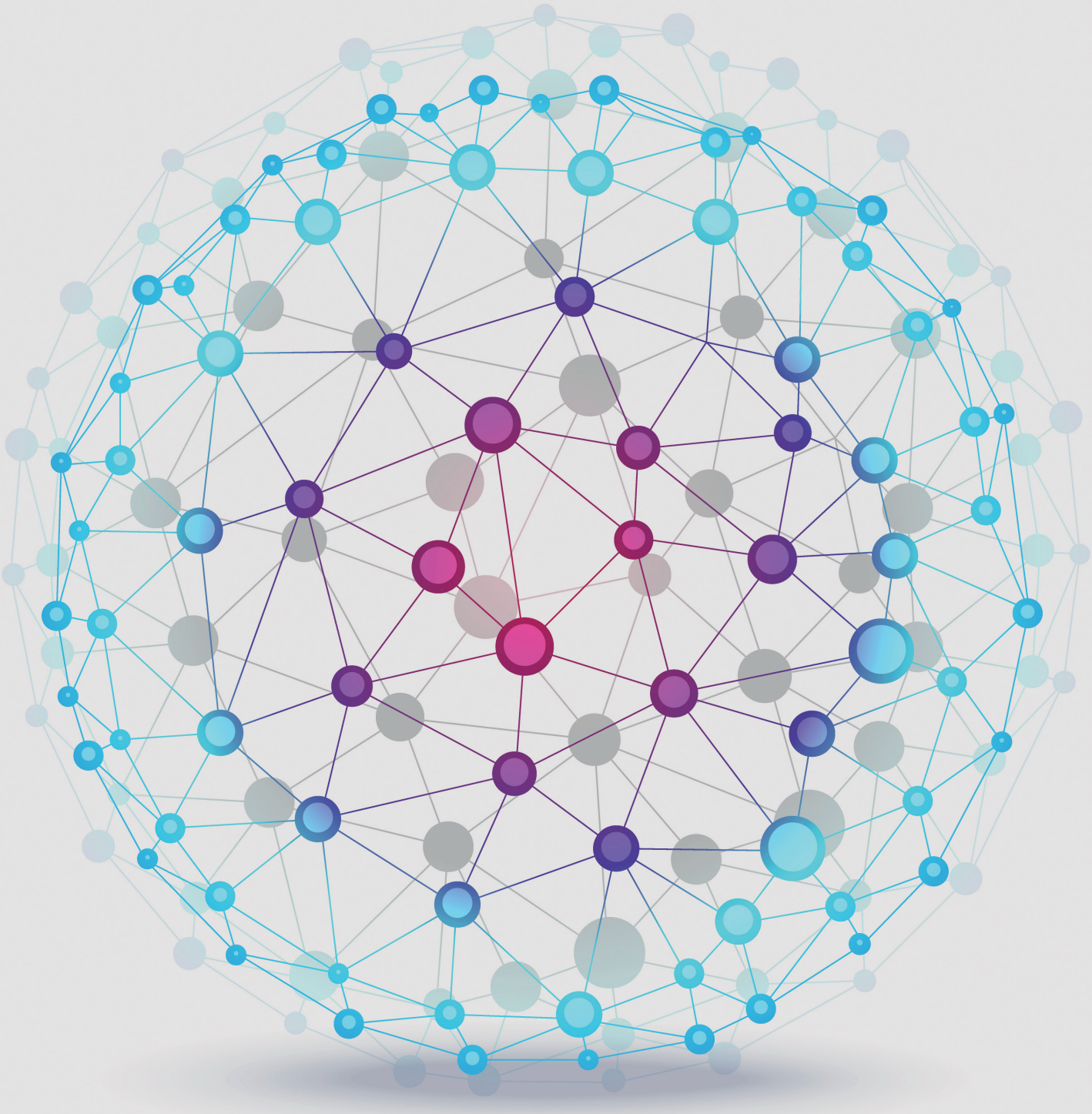
Collaborations

A physicist's guide to working in partnership



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Introduction

This guide has been written to equip doctoral students and postdoctoral researchers with an understanding of collaboration and its value to their careers.

The guide will illustrate that collaboration comes in many different forms. A number of established physicists have been interviewed for this guide and they explain what collaboration looks like for them. In their profiles, they explain what they enjoy and gain by working in collaboration with others, whilst they are honest about the challenges to overcome.

Some areas of physics have a long history of collaborative working because of the scale and complexity of the questions being considered. It would be impossible and meaningless for many of these ideas to be considered in isolation by lone researchers. This model of cooperative working is now increasingly attractive to research funders who are encouraging all researchers to look beyond their own work and consider how they could work with others to have greater impact. This means that an increasing proportion of research funding will be focused on collaborative activities.

Developing a collaborative element to your research interests isn't just about positioning yourself for funding. As you read the profiles and advice in this guide you will see that these researchers have enjoyed the stimulation of working with other experts. You will also see the wider benefits in terms of employability and broadened expertise.

Through the profiles in this guide and key lessons extracted from them we hope to enable you to develop a more collaborative mindset, to understand the support available and to begin your own collaborations with confidence. The successful collaborators also talk about why they work in partnership – something that was considered in The Dowling Review of Business-University Research Collaborations of 2015. Although this focused on commercial research, the summary of motivations set out the benefits of collaboration.

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MOTIVATIONS TO COLLABORATE

Section 1
Getting it right

This section looks at various stages in the development of a collaboration, starting with the steps to understand other disciplines, researchers and sectors and how to meet people who may share your interests and be interested in working with you. There is also advice on how to look and act like a researcher who would be a good collaborative partner.

The call for written evidence for the recent The Dowling Review of Business-University Research Collaborations included the question: "What are the key success factors for building productive, long-term research partnerships between business and academia?" This generated a top 10 factors for success, and we are grateful to Professor Dame Ann Dowling and her team for permission to reproduce the following figure, which summarises these responses.

Rank	Top 10 key success factors for a successful collaboration
1	Strong and trusting personal relationships
2	Shared vision, goals and objectives defined, setting in place clear expectations
3	Mutual understanding between partners
4	Ability of – and opportunities for – staff to work across institutional boundaries
5	Collaboration brings about mutual benefits
6	Funding available
7	Processes for agreeing contracts and intellectual property are in place
8	Clear and effective communication between partners
9	Organisational support, including senior management buy-in and championing
10	Willingness to devote time and resources from both parties

Learn enough about other disciplines to recognise the meaning of their contributions.

Understanding other disciplines, researchers and sectors

Collaboration with others inevitably exposes you to different approaches. Some of these emerge from the sectors, countries and disciplines that people are based in. Others are down to differences in working style. Managing and understanding people is an important skill for a collaborative researcher.

Although there is great variation around the world in terms of education systems, there always comes a point at which you will stop studying most academic subjects. Although there are steps being taken to educate doctoral researchers in multi- and interdisciplinary environments (the Centres of Doctoral Training and Innovative Training Networks being two current approaches), the fact remains that most physicists' understanding of other academic areas is limited.

The academic and business worlds also have very different cultures and approaches. Although collaborations emerge because of a shared interest in an area of science, the difference in motivations to pursue the study and the outcomes from it can create tensions.

These factors create barriers when researchers come together and can only be overcome if everyone is willing to invest time in understanding enough about the other field, sector or person to be able to interact and co-produce new ideas in a meaningful way. It is easy to say that you intend to do this, but rather harder to do. It requires you to admit the gaps in your knowledge, ask basic questions and learn enough about other disciplines to recognise the meaning of their contributions.

Ask questions

These questions were used in a workshop with a group of researchers (including physicists) who were keen to collaborate across disciplines. They found that they led to useful conversations and helped them to really listen to and understand the different perspectives around them.

Understanding the disciplines

- Tell me about some of the challenges associated with your research approach?
- What is missing from your disciplinary approach?
- Are there any common misconceptions about your research that you've faced?

Understanding another's viewpoint and preferences

- What is your view of the world?
- What do you need from other collaborators so that you can deliver your contribution to the best effect?
- What will you take responsibility for?

Being honest about the project

- What worries you about the project?
- Can you describe the roles and responsibilities of all the other collaborators?
- Why are you doing this/what inspires you?

Minimising communication problems

- Are there any words that you use that might not mean what I think they mean?
- Are there any words I use that aren't clear to you?

James Dracott
We have a wide portfolio and want to see the maximum value from advances in each field – these often come by talking to people in other fields who may be trying to overcome similar problems. Of course, in these cases the researchers have to overcome language barriers – each discipline has its own vocabulary but also distinctly different approaches to research. It's important to invest time in learning these different languages because the proposal must reflect the strengths and opportunities across the whole range of people involved.

Tim Bodley-Scott
Collaborations bring challenges for instance, with business-university interactions these include novelty, intellectual property and publishing. We overcome a lot of potential problems by being clear about the values of our institutions and the demands of academic research – this means that the projects must be novel so they can count towards the students' PhDs and the companies must understand how important publications are for academic career progression.

Sally Day
To meet potential collaborators from academia and industry, look for events and meetings. The IOP special-interest groups are brilliant for bringing together people with a common area of interest and I'd encourage any early career researcher to join the groups that overlap with their research pursuits. Similarly, Knowledge Transfer Networks will run events in your region – talk to your institution's business development team for advice on where to meet people and how to prepare for these events.

Dick James
You need to be interested enough in other people's work to start conversations with them, having invested time in understanding their field. Although enthusiasm is important, there must be solid foundations to any initial conversations and this can only happen if you are willing to learn about other disciplines and become familiar with their terminology and scientific approach. Collaboration with other disciplines is a little like foreign travel – you get a lot more out of it if you read the phrasebook before you go.

Darran Milne
There are differences, of course, as our motivations are different. We are trying to develop a commercial product and must therefore be careful about intellectual property. The academics are keen to disseminate their findings to build their research reputations. The common ground lies in the interest we have in the science, and this has enabled us to find solutions.

Loretta Dunne
There will also inevitably be personality clashes, particularly over access to data, so we have set up carefully worded memoranda of understanding between teams. This can take a lot of effort and you need to have team members who are diplomatic and able to manage some of the bigger personalities you can get in science. I've learned that the best team has a range of personalities at the top level to cover all these angles. Our collaborations with other teams have proved to be immensely rewarding to both parties.

Tom McLeish
If you are interested in collaboration with industry you need to understand that they have different motivations. Their timescales are different and they define success in different ways, so although the win-wins are still there you must understand each other. Take time to get to know them because the potential benefits are significant. My industrial collaborations have been intellectually satisfying as well as scientifically valuable. By being open to accepting their ideas I've taken my core research in really interesting directions and gained access to data and resources that I could never have generated within academia. We've worked together to find interesting questions in overlapping domains of interest and we've all benefited. These projects have produced several key papers, much commercially useful knowledge, improved manufacturing and stimulating science.

Finding collaborators

The first stepping-stones towards a collaboration may not involve research. It may be that you sit on a committee with someone, or help them to organise an event. These are situations in which they can judge your reliability, communication skills and learn more about your interests.

Look for funding to support a research visit, either for you to visit another lab to do research or to invite someone to yours. This is a fairly low-risk way of seeing someone in action as the visits are usually short and if things don't go well, you can walk away without any longer-term implications. If things go well, you have an ideal opportunity to develop and possibly test ideas during the visit and to explore funding options.

Involvement as a junior in a new collaboration is mentioned above, but you can also build up the role you have in existing collaborations if you are a PhD student or postdoc, offer to attend management meetings or write project updates if your supervisor is busy. Get involved in the reporting process back to the funder (this can be very demanding for some funders so your supervisor will welcome your offer of help) and take time to read and understand the wider project, not just the part you are working on. Investigate the final grant agreement looking for opportunities to develop an understanding of the collaboration and to play a greater role in it. Take the initiative.

If your research interests draw you towards commercial and industrial partners, the early steps to these projects could be through offering consultancy services. These will rarely lead to research outputs but they will start to develop the relationship and give you a platform for discussing your ideas and explaining where you think there might be common ground and potential interactions. You may be able to develop these relationships and your ideas further through a short secondment or research trip. This model of training researchers is integrated into some doctoral programmes, such as the Centre for Doctoral Training (CDT) model described on p36, but can be a wider opportunity for other early-career researchers. Researchers can arrange their own placements/visits using funding from a range of sources, and there is an increasing amount of support to arrange short projects with industrial research groups.

This support often builds on the success of existing partnerships. Tim Bodley-Smith, the Integrated Photonic and Electronic Systems CDT administrator, is involved in a wider programme at University College London to give early-career researchers a more commercial perspective. This scheme, called BITE (Breakthrough Information Technology Exchange) facilitates and funds placements in industry for early-career researchers. This enables them to develop their skills and strengthen links with companies through direct knowledge transfer. Additionally, the hub runs a three-day residential course aimed at encompassing business and entrepreneurship into doctoral training. This scheme is partly funded through the Impact Acceleration Account mentioned earlier, so similar opportunities may be available in your institution.

Navigating the Funding Landscape, the IOP's funding guide, contains more information on the schemes that support initial contacts with commercial partners, but it is worth repeating here that this is among the strategic aims in the government's science strategy. They are very keen for the complementary skills, expertise and approaches of academic and industrial scientists to come together, and are keen to simplify and facilitate greater interactions. You can learn more about this from The Dowling Review of Business-University Research Collaborations published in July 2015, but also by talking to the business-development people in your university's research office.

Anne Crean

If you are keen to collaborate with others, the best place to start is one of our 48 special-interest groups. Of these, 44 have a technology focus, and the membership is a mixture of physicists from academia, industry and other sectors. We strongly encourage early-career researchers to join these groups as they enable you to personalise your IOP membership to suit your career goals and interests.

Penny Gowland

My collaborations have grown in a number of ways. There's always an element of luck involved, because even if you identify a person who you think has the right skills and interests to be your perfect collaborative partner, they may not see it, or be too busy to be involved. Projects flourish when you and the other scientists (and clinicians in my case) involved are interested in each other's specialisms and respectful about what other disciplines they can (and can't) do.

Rob Martin

You can start becoming a more collaborative researcher at the next conference you attend. Go to a wide range of talks and think about what has inspired you and what fits with your own interests. Approach people and have open conversations about what might be possible. Collaborations often start with these kinds of conversations. If someone is interested in you or your work, and if your discussions quickly lead to ideas that you wouldn't have had in isolation, the seeds of a potential project could start to grow.

Tara Shears

There are many first steps towards collaboration, particularly in a community like CERN, but it's important to start with your own work. Take a step back from the detail and think about whether anything could be done differently, then look around for people who seem to have the skills that might help you do it. Do some initial research into their work and see if your first thoughts stand up as you learn more. If so, you should approach the person and explain what you are thinking. Don't be shy about approaching people, even if they are the world expert and you are a PhD student; fresh ideas are always stimulating and impressive to physicists, so if you have spotted a new possibility, that person should want to work with you. Collaborations tend to start with conversations and if you've found the right person the idea will develop and grow in directions that neither of you could have found independently.

Sally Day

Collaborations start and grow in different ways. In some cases I've been approached through people in my network who know my interests and my work, so it's important to talk to your colleagues and research peers about your skills, achievements and future interests. I'm also an active member of the Society for Information Displays with members from both academic and industrial organisations. Being involved in such an interlinked society has helped me develop a broader profile as I've published in the society's conference proceedings. Although these articles haven't had the same academic impact, they are great for building awareness of my work with potential industrial partners.

Sheila McBreen

My network has been building since my PhD days and some of the people I work with now have known me since then. A great way to build these relationships is to go to summer schools in your field. These are organised around the world and give you a week or more focused study on a topic and the chance to meet an international community of people interested in the same area. I can't stress enough how important these were to me, so, if you are serious about building a strong network for future alliances, seek out the ones in your area.

Tom McLeish

After an initial meeting, follow up as soon as you can with a telephone call or email. You should exchange published work but also demonstrate your trust by sharing pre-prints and work in progress. If this leads to interesting conversations and they are motivated to take these further, invite them over for a seminar and take your discussions further or visit them for a little longer. You want to get to know them well enough to decide if you want to take the substantial step of writing a grant with them.

Being an attractive collaborator

People meet and are connected under all kinds of circumstances, so there is no single model for meeting potential collaborators. It is important however to be visible to these collaborators so that they are aware of your existence, the contribution you could make and feel that they could trust you to be part of their team.

You can build a stronger research profile using traditional methods – talking at conferences, writing good papers that people benefit from reading, talking to people who visit your department and visiting other departments and groups. If you are taking advantage of these opportunities to build peoples' awareness of you, make sure that you are making your collaborative ambitions clear. Where possible, inform people of your work to generate interest and engagement. Highlight successful partnerships that you've been involved in and ask former research collaborators, supervisors or co-workers to bear you in mind if they become aware of interesting opportunities. Approach people with complementary interests and invite them to visit your group or meet at conferences. Many collaborations start because shared enthusiasms and interests emerge during conversations.

You can also make it easier for people to find you by making sure that you have an up-to-date online presence and that this highlights your collaborative interests and suitability.

Highlight the projects that have led to your publications, rather than just having a list. Talk about your research vision in your profile as well as your past achievements. Use online networks such as Twitter, ResearchGate and LinkedIn to follow and connect with people doing interesting work. To those new to collaborations it may seem impossible that these virtual actions will lead to anything as substantial as a research project, but these are all ways of getting to know someone and putting yourself on their radar.

Once you have a strong profile and have begun to network with potential collaborators more seriously, it is important to be reliable. Be prompt when following up on initial meetings. Share resources that you have offered. Act and speak with integrity so people feel comfortable developing novel ideas with you.

The importance of mentors cannot be overstated. If more senior people are aware of your ambitions and are impressed by your skills they may connect you with potential collaborators. Leading researchers are approached with more opportunities than they can ever be involved in, so they may be willing to delegate some of these to a more junior colleague. Being involved in a larger project as a work package leader is a fantastic way to understand how collaborations work (and sometimes to observe ones that aren't working). These insights will be really useful as you start to develop your own ideas and proposals.

Once you have a strong profile and have begun to network with potential collaborators more seriously, it is important to be reliable.

Penny Gowland

I'm careful with new collaborators to look for evidence that they deliver of projects; so for instance I may take a look at their publication track record using Web of Science. This is particularly important where the collaborator will be providing more than intellectual input, so that you will be relying on them to deliver tangible inputs without which a project cannot be completed. Generating pilot data is a good starting point – you can see if people have time to commit to the idea and to start to get a feel for how they work.

Sheila McBreen

A good way to tell if a collaboration is going to lead to something is to reflect on how interested the other people are in your work. It's a little like the early stages of your career when you might be applying for funding to spend time in a research group, either on a postdoctoral contract or for a visit. If the hosting department aren't very interested in you and don't do much to support your application, then it probably isn't going to go anywhere. Look for the signs that people are really interested in your work and that there is a strong mutual benefit for everyone who is involved. You should also demonstrate this interest by following up quickly on any conversations – send an email and start looking into funding to enable you to visit their labs or bring them over to yours. Don't let things lie as it creates the impression that you either aren't interested or don't tend to make things happen.

Tom McLeish

I have two ground rules for a good collaboration. First: there are no stupid questions. Second: trespassers will not be prosecuted. This means that I welcome discussions about my science and expertise with people from other fields. Everyone has to be comfortable talking about each others' work and it's a sign of a healthy collaboration when this happens. You must be committed to all aspects of the project and willing to offer perspectives on anything that you have an opinion on. You also need to exercise academic hospitality and to welcome people and their perspectives. Always avoid any master–servant hierarchies because they greatly reduce the chances of achieving the win-win that you are looking for. This means being careful with your language and respectful of other disciplines.

Turning an idea into a plan

Once you've met the right people and identified a common goal that you all feel motivated to work towards, the next step is to identify a funding call that will suit the aims of the project and the discipline base in the team. Many large-scale funds, which would fund ambitious collaborative research goals, have an annual cycle so this should allow you plenty of time to develop your ideas, work them up into a robust plan and secure the letters of support that you'll need to convince the funder. Ideally, in the run up to writing the proposal you will have had time to work with the other researchers in the team and get to know them, to understand their work and to know where there might be a difference in approach or tensions (and to talk about these).

In this case, it can sometimes be difficult to have conversations about authorship, responsibilities and risk strategies because they feel like they are assuming things will go wrong and people won't deliver. It's a little like being presented with a pre-nuptial agreement on the eve of your wedding – despite being told it's something that you won't ever need and it's just a formality, it still feels rather uncomfortable.

This is one reason that funders are so explicit in their demands for detail in the project plan. They understand that no one sets out with an expectation of failure or difficulty in a collaborative venture, but that, unless the risks and tasks are identified and discussed in advance, this is likely to happen. We've talked earlier about the differences in approach between disciplines, sectors, cultures and individuals – you can't ever assume that your attitudes and work style are automatically shared by everyone.

In the box are examples of the areas that you will need to have agreement on before you commit to a collaboration. In many cases, the funder will expect you to explicitly address these in your proposal, so they are a critical stage in the planning of the project. Some of them might be rather uncomfortable to discuss, but nowhere near as uncomfortable as they would be to deal with during the project – always assuming that you spot problems in time to deal with them.

Areas of agreement

Structure and roles

- Are there common goals understood by everyone, that we can all explain and are committed to achieving?
- Does everyone have a clear role and set of responsibilities in the collaboration?
- Are these motivating for them and are they equipped (with the skills, resources and time) to fulfill them?

Managing information

- How will data be shared?
- Are there any intellectual property concerns arising from the project?
- If there is confidential or commercially sensitive information involved in the project, does this impact on our data-sharing or dissemination strategy?

Communication and management

- What mechanisms will ensure that team members are up-to-date with each other's progress?
- Are the meetings scheduled for sensible times in the project lifespan?
- What are the project milestones and have we taken into account any local reasons why these might not be achieved?

Risk

- Have we looked at each part of the plan and identified the weaknesses?
- What will we do if deadlines are missed?
- How will we handle conflict or disagreement in the team?

Dissemination and networking

- When and where do we anticipate publishing and disseminating the outcomes of the project?
- Will every partner benefit from a useful output?
- How will we decide on authorship credits for collaboratively produced results?

These questions will lead your discussions into the realm of the worst-case scenario, so it could make for a difficult discussion, but it is based on the experiences of people who've worked in successful and failed partnerships. Each question represents something that has gone wrong – usually not because of a deliberate decision to undermine the project but because there were assumptions, misunderstandings, or failures to ensure that all partners felt that they were being treated fairly or cultural differences.

You should enter collaboration with the belief that the people around you are completely committed, engaged and keen to deliver. But you shouldn't commit to collaboration until everyone has contributed and committed to an agreement that explores the risks and potential difficulties.

Suzanne Foley

Funding decisions are made by panels acting on expert reviewer reports. They look for evidence in proposals that the collaboration is real, rather than a series of individual projects stitched together to be eligible for the funding. Each partner must be fully engaged, and the letters of support from any non-academic partners must describe the place they have in the research programme and the benefits of their involvement. There needs to be a clear plan that sets out what everyone will do and justifies why a collaborative approach is needed.

We conduct mid-term reviews on many of our grants, so we are familiar with the signs of potential weakness. Some examples are a poorly thought-out communication plan that suggests that people aren't interested in the wider activity in the project, letters of support from general managers in companies rather than senior people in research or technical roles, and a failure to describe the agreements about intellectual property and publishing with commercial partners.

Rob Martin

As well as fostering a collaborative culture, we are also making sure that the tools that measure research activity are fair and reflect more accurately the contributions that people make. This is an important thing to get right as it plays a part in appraisals, workloads and promotion. It's deeply frustrating to have played a critical role in a collaboration only to see this counting for little if you weren't the principal investigator.

Tara Shears

Healthy collaborations need to have strong mechanisms for management, communication and credit, particularly ensuring that postdocs and research students are building their CVs. From the outside it isn't always easy to see who has done what in our publications, as names are listed alphabetically, so we use other indicators. Conference papers and seminars are given by the main researcher whatever their career stage. This meritocratic approach is really important as we need these researchers to be motivated and fully engaged in the success of the work.

Sally Day

You should feel able to talk to people in the project. Set up the lines of communication and make sure they aren't restricted to the formal meetings. Encourage more junior researchers to talk to each other as they probably have more need to interact with their peers across the collaboration. Some funding for larger collaborations comes with demanding project management structures and reporting expectations. Although these can be helpful in that they provide lots of internal deadlines to keep people on track and talking to each other about progress, they can sometimes take over projects. Make sure that conversations about science still happen and that meetings aren't just about deadlines and reports.

Dick James
The level of complexity and noise in biological data means that clarity about experimental or field design is critical. As a physicist and the person who aims to draw out meaning in the data, I will only collaborate with people who have really thought about this and designed their observation process to minimise any clouding. This understanding of the complexity of the data creates common ground between us and is the foundation of our collaborative work. There is also a good argument for running small pilots in the early stages so you have something to discuss and you can get a good feel for how a larger project may develop. Apart from the science, this also helps to build trust as you get to know the other people and can see how they work.

Tom McLeish
If the project is interdisciplinary, start the planning and evaluation process with this mindset – always think about how you will manage the project, the funding process and the publications to bring interdisciplinary benefits. You'll find it relatively easy to identify disciplinary approaches once this is done, but it is almost impossible to go back and embed interdisciplinary thinking into a disciplinary project. This is particularly important because of the difficulty in reviewing interdisiciplinary proposals. It's a bit like the old Indian myth about the blind men and the elephant. Disciplinary reviewers only look at the bit they understand, so you need someone who can see that it is greater than the sum of its parts. You need to write the proposal so these benefits are explicit.

Balancing risks and advantages

Loretta Dunne: Early-career researchers involved in large collaborations experience both benefits and drawbacks. Benefits are of course access to wonderful data-sets and many possible science projects. The cost is the loss of the spontaneous creative process, as any idea for a new project has to be approved and checked against other projects for conflicts. Sometimes a researcher has to be restricted in their analysis because of overlaps with other people's work. It can be much harder to demonstrate independence in this environment. Before starting an collaborations you must first consider whether the potential benefits outweigh the risks.

Loretta Dunne's insights summarise the risks involved in very large collaborations for early-career researchers. You must consider carefully whether the potential benefits outweigh the risks, and accept that sometimes collaborations will go badly for reasons outside of your control. Having acknowledged the risks, there are steps you can take to minimise the impact of failed projects.

Have a career plan

Sally Day: As with any collaboration, when you're working with industrial partners you must think about how the projects fit with your own career strategy and goals. Without these, there's a danger of letting the company's interests take precedence, but if you have a clear career vision, it's usually possible to discuss this with your potential partners and find a win-win point as you develop the idea.

Tara Shears: You also need to think about how the collaborations you are involved in will form part of the narrative in your CV. Although these research strategies are often written retrospectively, you must make sure that there are developing themes and that each project has led to tangible outcomes that will improve your prospects.

Don't rely on one person as your only collaborator

Penny Gowland: There are more rewards with collaborative research, particularly if, like me, you are motivated by applications and interested in broad topics. However, there are also risks. I'd strongly encourage any young researcher to find a more senior colleague with whom they can discuss these – a mentor is important and valuable. The main problem that I've had has been with collaborators who come and go – academic careers can be very international and mobile, so it's important not to build your career on one project or person. If they move away and become ineligible for funding or find new interests, your career could be set back.

Ensure that you will benefit from the collaboration and that reward and recognition systems are fair

Loretta Dunne: The reason that fairness and reward was such an important part of our systems is that a lot of the work in managing the survey data can be difficult and isn't always very exciting, and mostly lays foundations for others. I wanted to try to ensure that the researchers (who tend to be PhD students and postdocs) who were involved in the grunt work were rewarded for the services that they were providing to the wider community. We continue to tweak our system as the core data people are absolutely critical and the work they do should benefit them as well as others.

Rob Martin: There is always a tension in the early stages of a career, particularly in academia, between developing an identity based on individual expertise and growing partnerships with others. I think it is possible to find a balance here and also to demonstrate independence within a collaborative research profile. You must ensure that any role you play in a joint project is recognised, either in terms of having responsibility for a particular element, then leading up to managing a work package. Try to avoid being one name in a long list.

Penny Gowland: It's important that early in a research career, you don't end up as a handmaiden on projects. You should get recognition for your contribution and be sure that you are benefiting intellectually from the partnership right from the start. Early in a collaboration, your contributions may inevitably be quite functional, but you should aim to work with people who are either interested in the deeper potential of your work or willing to let you explore it in the project.

Make sure that publications will include you

Dick James: Publishing interdisciplinary work can also present challenges and is something that you should be aware of early and start discussing at the early stages of project development. As an early-career researcher you need to work with people who are generous and will acknowledge your contribution with shared authorship rather than an acknowledgement in the text.

It's important that early in a research career, you don't end up as a handmaiden on projects.

Acknowledge the importance of good relationships with partners

Sheila McBreen: The people side of collaboration is important. There are lots of different personalities in science and you won't find it easy to work with everyone. My best advice is to maintain a broad network within any collaboration. Don't confuse personal disagreements with differences over the science, which should be discussed and debated openly – particularly by early-career researchers as this a great way to build your profile in larger groups. Also, learn not to take criticism personally.

Tara Shears: It's impossible to separate the science in a collaboration from the people doing it, so it's important to be able to work with people effectively. There needs to be mutual respect and interest between the collaborative partners. At the start of a career it can be difficult to know how people work so I'd encourage you to talk to people (face-to-face ideally) who have worked with the person you are interested in about their experiences. They will usually be polite, but will also be honest if there are particular things to be aware of.

All the established researchers who contributed to this guide were keen to share their experiences so that early-career researchers might benefit from them. Seek out a mentor who can do the same for you.

Section 2
Collaboration in physics

There is a recognition that many problems require broader skills and knowledge than any individual can draw on. A range of connected experts can address these problems, but the nature of the connectivity between them is key. This section sets out what collaboration looks like for the physicists that we've interviewed. You'll see that it comes in many shapes and sizes.

The experiences of the researchers interviewed here are mostly very positive and they are all enthusiastic about the benefits of collaboration. However, they also explain that the positive experiences they have had are often because of hard work and constant effort in managing collaborations, particularly communication between partners.

In this section, each physicist explains a little about their work and shares important points about collaboration.

These include advice on:

- understanding other people – how to overcome the barriers between disciplines and sectors
- growing collaborations – what they recommend as the first steps, particularly for early-career researchers
- managing collaborations – examples of the processes and approaches that have worked in their projects

Collaboration comes in many shapes and sizes.

Professor Tara Shears

Professor of experimental particle physics and the Liverpool LHCb group lead at the University of Liverpool

As an experimental particle physicist working on one of the experiments at the Large Hadron Collider, collaboration is everything in my research. There are 700 researchers working on the same experiment as me from around Europe and beyond. Working in a team on this scale brings challenges, particularly in keeping people engaged and in giving fair credit for individuals' effort, but the experimental physics community tries to get this right and I think that we have developed some good models for other big science projects.

There are two reasons why more senior staff should support junior researchers – we were all early-career researchers once, and we were given the same support and recognition in the early stages of our career. Second, we need to constantly develop early-career researchers within collaborations so that they can take on increasing leadership and continue the work. Our experiments last for years and the LHC is likely to have a 50-year lifespan – there needs to be highly skilled generations following us to ensure that our ambitious plans are realised.

Our early-career researchers take responsibility for their own career development and have organised a mentoring network at CERN, which meets four times a year and runs events themed around the challenges that they face. They have built up a list of senior people who are willing to mentor them and they constantly add to this. I'd encourage other researchers to look for ways to be proactive and creative – this is how you do your science, so apply the same approach to your careers.

The best of your ideas should be pursued with funding. Collaborations are attractive to funders because they will yield much broader outcomes and deliver more than the combined efforts of the individuals involved. Any case for funding should demonstrate that the proposal is novel, that the experimental approach you propose will measure what you need and that you are able to carry out the work – in fact, that you are uniquely positioned to do it. You should also emphasise that the work is timely and will yield important publications. Writing a grant proposal is another collaborative endeavor, even if it is for a fellowship. You must have a network of people with whom you can discuss your idea, develop your case for support and who will review your proposal. I've worked on the Science and Technology Facilities Council's Mid-Career Fellowship panel and it is always obvious where people have received support and feedback from their institutions and networks. It makes a huge difference to the quality of their applications.

It's impossible to separate the science in a collaboration from the people doing it, so it's important to be able to work with people effectively. At the start of a career it can be difficult to know how people work, so I'd encourage you to talk to people (face to face ideally) who have worked with the person you are interested in about their experiences. They will usually be polite, but will also be honest if there are particular things to be aware of.

CERN is a hugely international community, which brings challenges, particularly in communicating with people in different time zones. We all have to be flexible because communication is so critical to success. Even in a collaboration on the scale of LHC, which involved thousands of researchers, we've developed a culture of discussing and developing ideas through consensus and feedback. It can be slow as ideas are reworked and discussed repeatedly but it has been critical to the success of the whole project.

Given the importance of communication, I'd encourage all early-career researchers to take up opportunities to engage the public in your work. Everything that helps you to collaborate effectively – being able to stand back from your work, think about different perspectives, be open to new ideas and able to communicate in an open and engaging way, is developed through public engagement. I can't emphasise enough how valuable these skills are – they will help you write stronger grants, develop better collaborative relationships and working with people who are amazed by your work is a great way to maintain your enthusiasm for your subject.

Dr Sally Day

Senior lecturer in the Department of Electronic and Electrical Engineering at University College London

My research focuses on the applications of liquid crystals, principally in displays. This field of physics naturally interacts with the many industry sectors that use displays, so there are many opportunities to collaborate. The majority of my research has a collaborative element, driven both by the opportunities and also my own working style. I really enjoy talking to people and seeing the applications of my work.

Although there are many opportunities to collaborate with companies, it isn't always easy to find the right people to start with. There are fewer larger companies with central research labs compared to a decade ago, but there are now many technology-based spin-outs and small businesses. Most universities have adapted to this by creating business-development roles. I'm also interested in collaboration with other academics as there are lots of interesting possibilities at the interfaces between disciplines. Many universities have research institutes located inside existing departments that independently runs events and hold talks, which I try to attend to learn more about new areas and to meet people.

As with any collaboration, when you're working with industrial partners you must think about how the projects fit with your own career strategy and goals. Without these, there's a danger of letting the company's interests take precedence, but if you have a clear career vision, it's usually possible to discuss this with your potential partners and find a win-win situation as you develop the idea.

Although this longer-term career vision is important, you should also view business collaborations as a useful tool in broadening your employability. Excellent options may become apparent as any project proceeds, so you may decide that you prefer this to an academic post, so time spent working with a company could yield far more than research experience – it could be a route into a new career. As a postdoc, time spent initiating small projects with industry is always worthwhile. These projects can develop into Knowledge Transfer Network projects whereby a researcher is employed by the company on a collaborative project and sometimes kept on in a permanent role afterwards.

Another advantage of the industrial projects is that the company will be able to articulate the business case for the work, which is very compelling in any applications for research funding. There are many different schemes to support industrial collaboration, but you need to understand what is expected in the applications and to write in the style of the call; they are often very different in style to research proposals. An application vary in terms of the detail in which the research is described, and the balance between ambition and outcomes. Generally, a traditional research proposal is more ambitious and focused on the idea. Commercially focused research is more grounded and funders focus on outcomes and delivery. This makes the business/commercial case for the work, provided by the company, a significant part of the proposal and assessment criterion. The proposal may also need contingency plans to account for the possibility of the research not developing as planned (thus ensuring that the commercial partner still benefits).

Intellectual property issues could be a source of difficulties with academic–industrial projects, but I think it's best to take a pragmatic approach and be generous in these negotiations. The reality is that patents cost money and for an institution to bear the cost that they may need researchers to be interested in taking on the development of the product. There are different models for agreements on intellectual property, and you should take advice from the relevant group in your university, but be aware that for some companies, particularly smaller ones, intellectual property is one of their main assets and they will want full control. As with all discussions and agreements, if you feel uncomfortable with the way that things are going, then it may be an indication that this isn't the right partnership for you. There should be high levels of mutual trust and understanding of each other's motivations to be involved.

Publishing can cause tensions, as companies will often want to keep advances to themselves rather than put them in the public domain. Again, with experience you will learn what it is reasonable to ask for and what you must be reasonable about accepting. During negotiations I often agree to a six-month embargo on publications, which I think is a good compromise and seems to work well.

Professor Penny Gowland

Professor of physics (magnetic resonance) in the Sir Peter Mansfield Imaging Centre at the University of Nottingham

"I trained as a physicist and specialised first in medical physics and then imaging. My research is in developing MRI techniques to improve understanding of how medical conditions develop and can be treated. I now consider myself to be a general biomedical scientist as so much of my work is collaborative and touches on so many different fields, but it is important that I retain my core expertise in physics.

Collaboration suits me because I'm most motivated when I can see my work is having a tangible benefit, particularly in the clinical environment. I also enjoy the balance of breadth and depth that collaboration brings – you need to know about your area in real detail but be able to relate this broadly.

My research is often led by clinical need – a problem is identified and we work together to find solutions. This process can also lead to interesting offshoots that I will pursue from a more purely physics perspective – but even these independent projects usually grow from partnerships. As a physicist I bring more than knowledge and technical skills to these projects. I feel that my training and disciplinary culture has given me a clear logical mindset that helps to structure some projects. As an academic who works with practising clinicians, I also have the space to grow ideas in a way that sometimes they don't.

I'm rarely the lead investigator for the collaborations that I'm involved in – this wouldn't make sense to funders as it would imply that the technology was more important than the problem being solved. I'm comfortable with this, but it's important that early in a research career, you don't end up as a handmaiden on projects. You should get recognition for your contribution and be sure that you are benefiting intellectually from the partnership right from the start. Early in a collaboration, your contributions may inevitably be quite functional, but you should aim to work with people who are either interested in the deeper potential of your work or willing to let you explore it in the project.

As collaboration becomes an increasingly common model for research, the academic system is beginning to catch up. Joint first authorship is now increasingly used in my field, which is an important step in ensuring fair recognition. I wouldn't recommend that a heated discussion about authorship is the first topic for discussion with a potential collaborator, but it is something that you must address before the project becomes too advanced. Having said that, sometimes the best way to overcome tensions between partners is to do science – generate results and data to focus your discussions, and you may find that problems resolve themselves.

There are more rewards with collaborative research, particularly if, like me, you are motivated by applications and are interested in broad topics. However, there are also risks. I'd strongly encourage any young researcher to find a more senior colleague with whom they can discuss these – a mentor is important and valuable. The main problem that I've had has been with collaborators who come and go – academic careers can be very international and mobile, so it's important not to build your career on one project or person. If they move away and become ineligible for funding or find new interests, your career could be set back.

Having mentioned the potential risks, I should say that I'm generally very optimistic and assume that most things will work out. I'd encourage all emerging scientists, but particularly women, not to let the fear of complication or set back slow down their ambitions. Life does get complicated and I know that I've sometimes been worried about how I'll balance my career with the demands of family, but I've always found a way. Get stuck in, find a mentor, and ask for what you need – whether collaborating or not, this advice should help you achieve more in your career.

Dr Loretta Dunne

Co-leader of the H-ATLAS survey and a research associate at Cardiff University

I am interested in the evolution of galaxies, both in the nearby and distant universe. What most fascinates me is how galaxies turn their gas into stars, and by measuring the far-infrared emission we can trace the cold dust inside galaxies, which is closely related to the amount of gas in their interstellar medium. In order to do this we need specialised instruments, and my research has been dependent on the Herschel Space Telescope launched in 2009.

During my PhD, my supervisor and I had always talked about how great it would be to make a blind survey of the nearby universe in this part of the spectrum, looking at a large area of sky and counting all the galaxies found. While it sounds simple, from my PhD in 1997 up until 2009, this was not possible as the instruments we had were not capable of imaging a large area very quickly. We realised that Herschel could change this, but the big guaranteed-time teams, who got first dibs on the science that they wanted to do, were not interested in such an idea. A few years later there was a call for Key Legacy projects with Herschel, and I came back to the idea when the Herschel instrument team announced that their detectors were more sensitive than they had predicted. This happy situation never happens in astronomy, but it meant that we could apply to do this wide area survey ourselves and it was now feasible in terms of telescope time.

It took about a year to get the H-ATLAS collaboration together – there were more than 100 members included in the proposal – and to plan the observing schedule for 600 hours of Herschel time. This involved many meetings and a core team of about 15 people contributing to the proposal. My supervisor, Professor Steve Eales and I shared the work and responsibility for managing things. The survey was approved and began in late 2009. Since then I've co-led the project and we are still working hard on analysing the data and making products for release to the community. The team has so far produced 83 refereed papers.

Before H-ATLAS, my work was largely individual or working with one or two other people in a small group. Since H-ATLAS all my work has been collaborative – and even collaborations of collaborations. Astronomy really has gone down this road in a big way. However, within the big overarching consortium, there are smaller sub-teams who work on individual papers and projects. These are the usual supervisor-plus-postdoc-plus-student kind of groups, often collaborating with a similar colleague plus a student in another institute. In my day-to-day hands-on science work, the collaborations I'm successful in are driven by a good relationship with the person that I'm working with.

H-ATLAS received funding from the national research councils through the combination of ambitious science, strong governance and a clear vision of how the collaborative effort would benefit a really wide community of scientists. This isn't to say that it has always run smoothly. Keeping up with communications and management tasks always threatens to dominate my workload, so anyone involved in running projects on this scale has to be very disciplined to keep their own scientific interests moving forward. I have really only managed this through having great PhD students for a few years, but now I'm itching to do my own research.

Although the amount of work required to set up and manage a collaboration on the scale of H-ATLAS sounds terrifying, it was worth it. We are successful in scientific terms because we deliver results that could never have been achieved by individuals or many smaller teams. Scientific progress is facilitated through data and resource sharing. Put simply, the impact of the whole is greater than the sum of the parts.

We were as light on procedures as much as we could be, and always welcomed new people and talent into the consortium. We worked on a reward-for-work-done basis, which provided you with the opportunity to contribute, collaborate and take initiative. That, I believe, has helped, as has trying to protect the interests of the people who put in the real hard work.

Dr Dick James

Senior lecturer in the Department of Physics at the University of Bath

I trained as a computational physicist and the main focus of my research is to develop and use computational methods for the analysis of patterns and processes in populations of social animals. Almost all of my work is now done in collaboration with biologists. I am interested in the interplay between local movement rules and global patterns of aggregation, but my particular interest is in the use of network theory to unravel the social structure of group-living animals such as fish, ungulates and mammals, and the dynamics of the passage of goods through colonies of social insects.

As a computational physicist, I can develop programmes to simulate, analyse and solve a huge range of problems, but I've been drawn to collaborate with biologists because of a long-term interest in natural history. My first foray into this field came when I was trying to devise a new undergraduate project. While off duty one weekend I observed the behaviour of a swarm of insects and thought that if they were molecules, I'd be able to analyse and understand their movements. This piqued my curiosity and I did some desk research to find someone working on these kinds of ideas. I then spoke to mathematical biologists in Bath and attended a talk given by Jens Krause, then at the University of Leeds, which ultimately led to a long-term and very fruitful collaboration.

Another reason for the success of my work with Krause is that he was very open about what he needed and we were able to discuss this from our different perspectives. The level of complexity and noise in biological data means that clarity about experimental or field design is critical. As a physicist and the person who aims to draw out meaning in the data, I will only collaborate with people who have really thought about this and designed their observation process to minimise any clouding. This understanding of the complexity of the data creates common ground between us and is the foundation of our collaborative work.

There is also a good argument for running small pilots in the early stages so you have something to discuss and you can get a good feel for how a larger project may develop. Apart from the science, this also helps to build trust as you get to know the other people and can see how they work.

Finding funding for interdisciplinary collaboration can be a challenge because of the way grants are reviewed. Although this is improving, it's likely that the reviewer will sit in one discipline and judge the value of your idea from that perspective. Similarly, the Research Excellence Framework (REF), which reviews research in UK universities, takes a disciplinary view, although this has benefits as a great interdisciplinary paper can be entered into more than one unit of assessment even in the same institution (unlike collaboration between physicists where only one is allowed ownership for REF purposes). It's therefore very important to find a funder who understands the challenges of working at the interface between fields and encourages this. You may need to look beyond the research councils to places such as the Leverhulme Trust, although there is a gradual move towards consortium models of funding from all sources.

Co-authorship and co-ownership of the project are more likely if you are engaged in the project from the outset. This won't always happen – sometimes you will be invited into an established project to provide analysis skills – but view these opportunities as starting points. If you make significant contributions to these projects and are able to add wider value, you should be invited to develop future ideas. This means playing a longer game – it can take years to go from initial contact to a tangible outcome. Even though there may be a lot of interesting problems to solve along the way, you need to ensure that your research portfolio is balanced with other projects that will deliver more quickly.

Dr Sheila McBreen

Lecturer in the School of Physics at University College Dublin

I'm an astrophysicist and I research gamma rays, specifically gamma-ray bursts (GRBs). I've worked on high-energy observations of extragalactic sources at the European Space Agency in the Netherlands and at the Max Planck Institute for extra terrestrial physics (MPE) in Munich as a Marie Curie Fellow. While at MPE, I joined the Gamma-ray Burst Monitor (GBM) team and continue to work with them in collaboration with NASA.

Collaboration is important because of my field but also my location. Astrophysics research doesn't tend to happen without access to a large telescope or a space mission, so it is naturally a team effort. Resources and networks for research in a small country like Ireland are limited, so I've always looked overseas for potential partners and funding.

This began when I was a PhD student and I secured an Irish Research Council fellowship that gave me a generous travel stipend. I took advantage of this by going to as many meetings and conferences as I could – not all of them in my specific field. Funding is available to go to conferences either through the IOP or from individual meetings and I encourage my students and researchers to use this to build their reputations and profile.

Another advantage of my funding at PhD level was that I had the opportunity to go to at least one meeting per year – it meant that I usually travelled alone and this made me network, introduce myself and generally join other groups and people so that I didn't have to eat alone. If you tend to travel to conferences with others from your research group make a point of spending time meeting people from other groups. I've held onto my open and curious approach throughout my career. As a postdoc in Munich I joined a number of collaborations and maximised my exposure to topics outside of my direct area. My interest in their work has continued and we have developed a successful collaboration.

Once you've identified a person or group that you want to work with you need to explain what you want to get out of the connection, being realistic about what this is. Don't start the first conversation with a list of demands about authorship and credit – explain in scientific terms what the advantages are for you and your research. It's a difficult balance for early-career researchers – you want to build a track record but are likely to be less experienced than many of your collaborators, so need to be realistic about what you will gain, but you don't want to be taken advantage of either. Don't forget that apart from papers and a share of the funding, that you are going to grow and develop as a result of being involved in the partnership – this may be particularly valuable to the funder as many schemes that support postdocs are looking for evidence of training and development through projects and visits.

I've worked in a number of collaborations and coordinated sub-groups of some of those teams. A lot of the issues about credit and fair recognition are the responsibility of principal investigators and the coordinators in these positions. I usually develop and apply rules about authorship and credit that I hope are fair and ensure that the less experienced researchers are rewarded. Larger projects will often have rules and processes to ensure this, but for smaller projects it is important to feel that you will get credit. I'd suggest you talk to the students and other researchers in the group as they will be honest with you about how publications are managed.

The people side of collaboration is important. There are lots of different personalities in science and you won't find it easy to work with everyone. My best advice is to maintain a broad network within any collaboration. Don't confuse personal disagreements with differences over the science, which should be discussed and debated openly – particularly by early-career researchers as this a great way to build your profile in larger groups. Also, learn not to take criticism personally.

Darran Milne

Lead physicist at Penteract28

Penteract28 is a small company, very newly formed, and we work in the area of big data. Big data is a broad term and the field is currently very active, but our specific interests are in information density holography. We are developing this approach to improve the storage, transmission and security of big data.

My background is in theoretical physics, having previously worked at the University of St Andrews on continuous variable systems, then a large financial software company. I joined Penteract28 a few months ago because they needed a theoretician to develop their ideas and concepts. I think there are really stimulating opportunities for theoretical physicists in high technology small- and medium-sized companies, especially those in the early stages of business development where ideas are first being explored.

I work alongside a mathematician who was recruited from academia for her expertise – she developed a new technique that our CEO sees as being critical to developing our theories into product. Our backgrounds mean that we feel very comfortable and familiar with the academic environment, which has contributed to successful partnerships with universities. Another key factor is the collaborative mindset of the academics we work with.

One key collaborative relationship is with the Integrated Photonic and Electronic Systems Centre of Doctoral Training (CDT), which grew from an initial contact initiated by our CEO. He is an alumnus of University College London that hosts the centre and was aware of the CDT partnership with the University of Cambridge, and saw the potential overlap in interests. During the initial meeting there were discussions about what we were aiming to do in the company and what the CDT model involved. This meant that we were able to agree about what the projects would achieve for us and for them.

There are ways for us to protect the idea (through non-disclosure agreements with the researchers) and a way for them to publish (by focusing on the underlying ideas rather than specific applications), which we've been able to work out through regular meetings and communication.

The exchange of ideas is only one aspect of the collaboration. There is also an exchange of approach and resources. When the first project students joined us we had an idea but no code and no theory to work with. The students worked as researchers and independently explored the area but used a project management approach that I adapted for use with a research problem. This involves regular meetings, reports, identification of blocks and challenges, and focused discussions to find solutions. The pace at which we work is rather quicker than purely academic projects, so the researchers have gained from experiencing this, we have benefited from the free thinking of the students and this combination has been really fruitful – we expect papers to come from the short projects and the students have written reports at the standard of leading international conferences in this field.

With recently secured investment from government we are now recruiting. I'm looking for people who can demonstrate that they have taken on leadership in research projects and can work independently. The latter is critical in the start-up environment as you need to be familiar with your own part of the research landscape and be able to make decisions about where to focus, what to do and when to accept that a line of enquiry doesn't look promising. I'm keen to recruit more theoretical scientists because we are still working with concepts, although with time, roles for experimental scientists will emerge as we develop products. Clearly, anyone who has had experience of working on a short project with a company will have an advantage, so look for these opportunities if a move to commercial research appeals.

One frustration with being in a small company full of bright people is that there are always more ideas generated than there is ever time to explore fully. This again is where the project students are so valuable. Over time, I can see that they will be a great resource for exploring some of the ideas that we are currently having to put on hold simply because we don't have a large enough team. I'm sure that we aren't alone in this, so it's worth having conversations with companies not just about what they are doing, but what they would be doing if they had the skills and people.

Collaboration in physics: main messages

The main messages emerging from these interviews are that:

- the natural curiosity of physicists doesn't and shouldn't stop at the boundaries of your department
- collaborations are more challenging than working independently, but will deliver success through planning, good management and communication
- early-career researchers should be proactive in building their own networks and finding support

Your next steps

Talk to people who are involved in collaborations to understand the processes in managing them

Lessons can be learned from areas of physics with long histories of collaboration, so identify these in your department; do some research into the companies that might be potential partners and start to understand their culture and needs; find examples of fair processes for recognition and reward in collaborations so that you can introduce these to future projects.

Step back from your own research to see where there's potential for collaboration

Join a diverse range of IOP groups, go to seminars in other departments, ask for permission to attend the meetings of other research groups, talk to the business development people in your institution, go to conferences without your supervisor or group, and attend summer schools.

Start developing the skills that you'll need when working with groups of other physicists, scientists, researchers and non-academic partners

Get involved in public engagement to build your communication skills, but also get experience of managing different kinds of events and projects; use your research skills to look at people as well as science – start to understand what the profile of a good collaborative researcher looks like.

Do some research into the companies that might be potential partners and start to understand their culture and needs.

Section 3
Collaboration in context

As the case studies illustrate, collaboration is encouraged in the current research environment. There is a recognition that many problems require more skills and knowledge than any one person can draw on. A range of connected experts can address these problems if they are able to identify each other, understand each other's work and develop effective working practices.

There are many sources of support to help you establish collaborations. In this section we'll hear from people who work in some of the organisations that are trying to encourage and fund partnerships. They will describe the support available to early-career researchers who want to develop collaborative ideas and what they look for when choosing which projects to support.

This section looks at support from

- The IOP, described by Anne Crean, head of science and innovation
- Research funders, illustrated by the Engineering and Physical Sciences Research Council and Science Foundation Ireland
- Universities, illustrated by Strathclyde and University College London

The main messages from their interviews are summarised at the end of this section along with a short action planning activity to help you explore the support you can access.

There are many sources of support to help you establish collaborations.

Anne Crean

Head of science and innovation at the Institute of Physics (IOP)

Early-career researchers are really important to the IOP and we can support you in a number of ways. The career challenges that you are facing probably aren't unique and the IOP will have developed resources, events or people to help you. We want to support your professional development and help you to explore the wider context of physics in the world and apply your skills. There are many people that you can contact if you need help identifying these resources – the IOP officers working in your region, staff based centrally, and other members.

The IOP facilitates connections and collaborations through 48 special-interest groups open to IOP members and hosts more than 40 national and international conferences each year.

We help to create a stimulating environment that encourages physicists to work across traditional boundaries and in which innovation can thrive.

Each group has a budget to run events where members can explore their discipline. They also run events, produce papers, run poster competitions and award other prizes, and encourage peer mentoring. Each group can also award bursaries for students to develop their careers through attending international conferences or visiting other researchers. By building a wider network you will develop your career and also have a great foundation for developing collaborative ideas. These groups also publicise other activities such as our developing support of open innovation.

There's more support available from the IOP than many realise. If you want to develop your research interests and to work with other people in physics, in other sectors and more widely, it's likely that we'll be able to help you.

Suzanne Foley

Programme manager in the Post-Awards Team at Science Foundation Ireland

Collaboration has become an increasingly attractive model to us as a funder because the problems that we face in society are so complex. Single disciplines and lone researchers are unable to address many of these and the potential impacts of scientific research lie far beyond the boundaries of individual disciplines. Our grant review process gives equal weighting to the quality of the science and the potential to have impact. Success in both of these criteria is often only possible through collaboration.

We recognise that Ireland's success in international research depends on our researchers being connected and able to work together so there are schemes for all stages of a research career. At postdoc level I'd encourage people to look for money to travel, visit important conferences and run workshops. As careers progress there are fellowships for industrial and academic research, leading right up to our large-scale funds for research centres and the Horizon 2020 funding for European partnerships. It's likely that collaboration will be an essential element of research careers, so start building your network and reputation now.

Collaboration leads to more than just papers and money. If you secure an academic post you will need to recruit students and postdocs to work with you on your ideas.

Finding good people is a real challenge, but a benefit of collaboration is access to a wider pool of people. You will also have access to the infrastructure and equipment of your partners meaning that you can carry out research without the added barrier of trying to secure funding for large pieces of scientific apparatus.

We welcome email, phone and face-to-face contact so we can help you understand what we are looking for, help connect you with the right funding schemes and make you aware of events and networks at which you could meet potential partners. We can only achieve our vision of making Ireland a global leader in scientific and engineering research, discovery and innovation if our researchers are connected and collaborative.

EPSRC
Investing in research for discovery and innovation

James Dracott

Portfolio manager for Atomic, Molecular and Optical Physics at the Engineering and Physical Sciences Research Council (EPSRC)

Collaboration can provide avenues to expand the impact of your research and bring in techniques, ideas and experience that may not be readily available within your research group, department or discipline. At the moment, 42% of our research portfolio is multidisciplinary and 45% is collaborative, reflecting the opportunities to widen access to your research and bring in external ideas.

There are two main aspects of collaboration that we support – that between research groups and that between academics and outside partners, industrial or otherwise.

We recognise that partnerships need to be supported from the outset, not just when there is a well-formulated project ready. Where there is benefit to your research from reaching out to collaborators, be they within your discipline or from another aspect of science entirely, we encourage you to ask for funds to facilitate this. EPSRC believe that pairing the best scientists with their best counterparts in other organisations, fields or countries will lead to the best groundbreaking science.

If your ideas would benefit from an industrial partner, funds can be requested to increase industrial engagement. We provide Impact Acceleration Accounts to universities to administer to their academic staff. These can be used to help speed up the contribution that your research makes towards new innovation, collaborate with industry and ultimately deliver the impact of research to users and the wider community. We encourage all researchers to engage with this stream of funding – it has been designed to create maximum flexibility for researchers to deliver the impact of their research. EPSRC Industrial Co-operative Awards in Science and Engineering can provide PhD studentships to industry who work in partnership with academics, which can benefit your research, foster greater links and deliver a high-quality student training experience.

It can be difficult to know what you can ask for at the start of your career, so don't hesitate to contact us either through our website or by phone. Once we understand what your research ambitions are we can help direct you to the right schemes. There's a lot of flexibility built into our approach that helps to reduce the barriers to funding good science. We want you to ask for what you need to perform the highest quality science, deliver the greatest impact and make the UK the best place to do research.

Professor Rob Martin

Vice-dean of research in the Faculty of Science at the University of Strathclyde

"I have a range of responsibilities, including ensuring the research environment at Strathclyde stimulates collaboration, innovation and ambition. Collaboration is one of our five core values. This is embodied in our new Technology and Innovation Centre, which co-locates research groups from physics, chemistry, engineering, pharmacy, future cities, etc, as well as industrial partners such as the Fraunhofer Centre for Applied Photonics. We are also part of the Scottish Universities Physics Alliance, which pools the expertise, resources and facilities in physics in eight universities to offer networks, industry engagement, exchanges and placements, jointly supervised projects and outreach. For many areas of physics, there is the additional driver that the scope and scale of the ideas being investigated are vast and far less meaningful progress would be made without combining skills and efforts. My own research in semiconductor physics demonstrates this.

Institutions are working hard to improve this landscape and I'm very pleased with what we've achieved here at Strathclyde. The tools that measure research activity must be fair and reflect more accurately the contributions that people make. A big step forward here has been to improve our approach to facilitating and managing collaborative research. Each investigator's share of the grant is recorded separately on our systems allowing for fairer recognition.

In addition to this recognition of success, we are also offering financial support to start new collaborations.

We are investing internal funds to develop internal cross-faculty collaborations and welcome ideas from early-career researchers. For collaborations with non-academic partners, I'd strongly recommend people to look at Impact Acceleration Account funding, or similar, which can be used for short projects, placements and other initial steps in collaboration that will ultimately lead to greater impact from your research.

There is always a tension in the early stages of a career, particularly in academia, between developing an identity based on individual expertise and growing partnerships with others. I think it is possible to find a balance and also to demonstrate independence within a collaborative research profile. I advise looking to have a clearly defined role in a joint project, for example having responsibility for a particular element, and then seek to allow this to build up in future collaborative projects, such as leading up to managing a work package. Mentoring is key, but happily, collaborations tend to bring you into contact with many people, making the process of identifying and approaching a potential mentor easier.

Rob's interview demonstrates how institutions are re-thinking their systems and structures to support collaboration. Look for similar developments in your institution – most institutions are willing to invest financially in potential collaborations, so ask your Research Support Office for advice.

Tim Bodley-Scott

Administrator/manager and marketing officer for the Centre for Doctoral Training (CDT) in Integrated Photonic and Electronic Systems (IPES)

My role really reflects the collaborative nature of my work place. The CDT model differs from other PhD programmes in that it focuses around a community of doctoral researchers. Our CDT is jointly run between the University of Cambridge and University College London but also involves many other partners, principally the companies that we run collaborative projects with. Academics from both institutions suggest project ideas and the students choose the one that appeals most – in many cases they collaborate with the supervisor to fine-tune the details of the proposal and tailor it to their interests and strengths.

PhD projects go ahead when a funded student chooses them, rather than the traditional model where the academic has the money and students apply.

Our students are drawn to projects and supervisors that have strong collaborative links with businesses, so a number of new projects have emerged that may not have been pursued without the CDT. In this way the CDT model has influenced the research cultures in both institutions and provided a home for academics who were already collaborating or keen to do so.

PhDs include a placement, which is attractive for companies as it lends itself well to short projects with tight timescales. These enable the scientists in the company and universities to get to know each other and often lead to longer-term relationships. They also get access to high-quality students who have already demonstrated an interest in industry and who have developed a commercial focus in the first months at the CDT when they receive tailored training.

Collaborations bring challenges for instance, with business–university interactions these include novelty, intellectual property, and publishing. We overcome a lot of potential problems by being clear about the values of our institutions and the demands of academic research – this means that the projects must be novel so that they can count towards the students' PhDs and the companies must understand how important publications are for academic career progression. Sometimes this tension can't be overcome but at least it is clear from the outset and everyone involved can accept it. With intellectual property issues we try to be as relaxed as possible and to recognise that this is usually more important for the company than the universities. I don't think we are alone in this – there seems to be a recognition that over-policing of intellectual property in the past affected academic–business research relationships and that a more open approach is better.

Collaboration in context: main messages

The main messages emerging from these interviews are that:

- collaboration is now embedded in the research culture in the UK and Ireland
- early-career researchers are expected and encouraged to engage in this
- there is a wide range of support available, through networks, mentoring, placements and funding
- recognition and reward systems are being developed to better acknowledge collaborative achievements

Your next steps

Build your awareness of the strategic reports and reviews that are influencing funder and institutional support.

The web page supporting this guide includes links to a number of key publications including the IOP Strategy, The Dowling Review of Business-University Research Collaborations and Irish Science Strategy.

Identify the main people and departments who support collaborative activity in your institution or organisation. Also identify them in any institution or organisation that you would like to work with.

Academics and senior researchers who are active in collaborations may be able to help you identify opportunities. Remember that business development staff in research support offices may be able to connect you with external organisations.

Look for initiatives, infrastructure and networks in your institution designed to bring researchers together.

Find out who manages the Impact Acceleration fund and ask them what types of activity it is used to support.

Get to know funders' schemes and approach
The funders' websites will have details of schemes, but you should also contact them by phone if you have any queries, particularly about funding to support visits, workshops and conference attendance.

Make better use of networks and societies
Look again at the list of special-interest groups on the IOP website and join those that relate to your research interests. Then take a step back from your current work and look for other groups that may have overlapping interests and give you access to potential collaborators.

Section 4
Intellectual property

Kate Adamson, a trainee patent attorney at Marks & Clerk, the largest intellectual property firm in the UK, has written this section of the guide. You can read more about Kate's career on p44 but here she gives an introduction to intellectual property for physics researchers to help them understand what it is and why it is so important to consider when working with others.

What is intellectual property?

In technical projects, the most common sort of intellectual property (IP) to consider is patents. These protect the technical details of new products and how they work. If you have a patent for an invention in a given country you can stop other people making or using the invention in that country without your permission.

It's important to remember that you may be able to get several patents for a single product, and that even if you have one patent for a product, you may be able to get another patent for an improvement to that product. Therefore, even if one party comes into the collaboration with something they've already invented, it's possible that the other party may come up with a patentable improvement to the invention.

One of the most important things about obtaining a patent is that, in most cases, you can't get a patent for something that's already been disclosed. In other words, if you have published something, you generally won't be able to get a patent for it, although there are limited exceptions in some countries. This is particularly important when one of the parties in a collaboration is a university, which will normally be under pressure to publish results.

If you're developing a commercial product, it's possible that you might also come up with something that could be registered as a design. Designs protect the appearance of a product rather than the technical features.

Each party to the collaboration may have valuable confidential information (for example, know-how, trade secrets or customer information) that in the course of a collaboration might be shared with a collaborator. It's important to consider how that information can be kept confidential, for example by having all parties to the collaboration sign a non-disclosure agreement.

A successful collaboration from an IP point of view is one where everyone gets what they want from the IP. What that looks like may be different for different parties.

Background IP

Usually, one or more of the parties in a collaboration will have some IP before they start, which is called background IP. We often have clients who want to file a patent application because it's a good way of pinning down their background IP before they enter a collaboration.
You don't want there to be any doubt about what IP each party owned when it started. In this way, a collaboration agreement can be a bit like a pre-nuptial agreement, saying what each party brought to the marriage.

Something to consider for a party bringing background IP into a collaboration is the extent to which their partners in the collaboration will have the right to use the background IP. A normal condition may be to license their partners to use their background IP for the purposes of the project, and for exploiting the results of the collaboration.

Foreground IP

It's also likely that the collaboration itself will generate IP. This is called foreground IP. It's important to reach agreement about who owns any IP generated during the collaboration, and also about who will arrange and pay for the IP to be protected.

A patent can take several years to grant, and can last for a total of 20 years, which may well be longer than the life of the collaboration, so you need to decide what will happen to the IP after the collaboration ends.

Something that you may want to figure out at the start is how you'll decide whether or not to file a patent application on a possible invention, and on which countries to file it in. Filing a patent application is expensive, so it's usually not possible to file one for every single new idea that comes up. If one partner in the collaboration isn't interested in filing an application in a particular country, will the other partner be allowed to do that on their own?

One common way to divide the IP is by technical area, with each collaborating partner owning any IP generated in their technical area. Another way is by who the inventors are, with each partner owning IP generated by their own employees. In some circumstances, a patent or patent application may be jointly owned by two or more parties to the collaboration. In that case, you need to decide what each party may or may not do with the patent – for example, can they sell or license their rights to the patent without the consent of the other party?

Before you start

If you really think about the IP situation early on, it can save you a lot of pain further into your collaboration. I'd recommend getting everything in writing at the start. Focus on what you want to achieve and what you want to take away from the collaboration.

Even if you think that what you've agreed is entirely clear, things can change over the course of a project. The people involved can change and the project itself can change direction. You may want to consider what happens if one party leaves the collaboration, or if a new one joins.

For academics, the university's IP department should be involved from the beginning. Think about how aware your researchers are of IP issues, and how you'll capture any inventions that they generate. At Marks & Clerk, we often give presentations on the basics of IP to employees of client companies or universities. It's good if employees are really clear on who to go to when they think they've invented something, so that you don't miss anything they've invented. It's also good to have an approval process in place for publications, so that nobody mistakenly destroys their chances of getting a patent by publishing the invention before a patent application has been filed.

A few weeks ago I walked into a meeting with an academic collaboration between multiple universities and it was clear straight away that the participants were really focused, had clear goals and, most importantly, respected each other's expertise. They had obviously spent time on considering what they expected the collaboration to produce, how they intended to get there, and how IP would help them meet their goals.

What does success look like?

A successful collaboration from an IP point of view is one where everyone gets what they want from the IP. What that looks like may be different for different parties.

Take the example of a collaboration between a university and a small- or medium-sized enterprise (SME). The university partner may want access to the IP for research purposes, royalties from any exploitation of the IP, and publications. If the SME is only interested in one use of the IP (for example, in one technical field), the university may want to be able to exploit the IP in other technical fields, perhaps even through other collaborations.

The SME may be most interested in having access to the IP to commercialise it, for example to take a product to market. The SME may also want to own as much of the IP as possible, to make itself attractive to investors. In order to exploit new foreground IP generated by the collaboration, the SME may need access to background IP owned by the university.

Balancing each party's definition of success can be difficult but a successful collaboration will deliver results for all participants.

If you really think about the intellectual property situation early on, it can save you a lot of pain further into your collaboration.

Section 5
The wider benefits

Finally, we have interviews with two physicists to look at the wider career benefits of collaboration.

Kate Adamson found that her collaborative approach as a university and company researcher influenced both her subsequent choice of career and boosted her employability.

Tom McLeish has a distinguished track record in physics but talks about how his natural curiosity has led to a startling range of collaborative interests, including the study of interdisciplinary research itself.

Final messages

The aim of this guide is to equip you with an understanding of the value of collaboration to your career and to learn from the experiences of more established researchers and experts. A range of different collaborations has been presented but is only a tiny sample of the possibilities for physicists. Working with others brings challenges, but also fantastic opportunities.

We hope that you are now inspired to look at your research interests more broadly and to seek out partners to develop your ideas with. Take advantage of the support offered by the IOP, universities, companies and funders to achieve your collaborative goals.

Working with others brings challenges, but also fantastic opportunities.

Dr Kate Adamson

Trainee patent attorney at Marks & Clerk

I work for Marks & Clerk LLP, which is the largest intellectual property firm in the UK. I'm training to become a patent attorney. At Marks & Clerk, we see the whole ecosystem of collaboration – universities collaborating with other universities, universities with companies, and companies with other companies. We advise clients when they're preparing to collaborate, when they're deciding which parts of a collaboration's IP to protect and how to protect it, and when they're using IP that was developed as part of a collaboration.

I work for a wide range of clients including universities, multinationals and SMEs, in technical fields across the whole of physics and engineering. My work includes meeting with inventors, drafting patent applications for their inventions, and dealing with those applications at patent offices around the world. It takes several years for a patent to be granted, and usually involves a few rounds of objections from the patent office that we respond to on behalf of the client. I also advise clients on IP issues. While I'm a trainee, a qualified attorney signs off on all my work first.

A patent trainee is hired for their science or engineering background (I didn't have a law qualification when I started) and then starts working on patents from day one, while studying for exams outside work. I'm currently part-qualified and studying for my final exams.

I started my career as a physicist. After a theoretical physics degree from the University of St Andrews, I moved to Durham University for a PhD in high-energy particle physics. Having figured out that an academic career wasn't for me, I moved on to QinetiQ in Malvern where I designed and modelled radar antennas. At QinetiQ I worked on research projects, mostly for the Ministry of Defence (MOD), and learnt how to understand MOD requirements and how to report my work to non-specialist reviewers.

In 2008 I moved back to Scotland to design mobile-phone base-station antennas for Andrew Limited in Fife (now part of Commscope). My job title changed from scientist to electrical engineer, and I became much more involved in actual product design. During my first year at Andrew I was part of a collaboration between it (an established US-based multinational) and Ubidyne (a much newer company based in Germany), in which we pooled our expertise to develop new active basestation antennas. They had high-tech offices with table football. I worked in a traditional Scottish factory in the middle of a field.

As has been the case in every collaboration that I've seen, the most important thing was good communication. We'd have weekly phone meetings involving participants in the UK, the US, Germany and the Czech Republic, but it was also incredibly valuable to meet up in person when we were able to – it's much easier to pick up the phone and call someone once you've had a chance to develop some sort of rapport.

Technically, it was important to understand which company was taking the lead on each part of the product, and how those different parts would interface. For example, sometimes we needed to negotiate when the requirements of the electronics (which they were leading on) would conflict with those of the antenna (which we were leading on).

I did find that sometimes having a second pair of eyes on a situation is incredibly valuable. Showing something to your collaborator can be almost a test run for showing it to the client. They're coming from a different commercial or technical background, so they can ask questions from a different perspective.

I was keen to build on the collaborative experiences I'd had throughout my career (in particular having worked with a variety of companies) and see my work as a trainee patent attorney as being the ideal collaborative career. An important part of this job is understanding the needs of different sorts of businesses, and working with/for people who have different expertise and backgrounds. It's an attractive career and there is great competition for training posts. My insights not only helped me to identify this as a great career, but also strengthened my application.

Professor Tom McLeish

Professor of Physics at Durham University

I'm naturally collaborative and can't keep my nose out of anything. My research interests are diverse and include the molecular rheology of polymeric fluids, macromolecular biological physics and issues of theology, ethics and history of science. Through my work I've been involved in large and complex projects, notably the EPSRC- and industry-funded microscale polymer processing project, which brought together 40 scientists from 10 major UK and international universities and global industrial partners. I've also worked with medievalists to re-examine scientific thinking in the 12th–14th centuries.

My former role as pro-vice-chancellor for research at Durham University gave me the opportunity to experiment in developing better structures and a stronger collaborative culture. I'm pleased that connectivity between disciplines and sectors now carries a premium here and we've worked hard to ensure that our administrative systems facilitate collaboration. We can assemble interdisciplinary teams quickly and have recruited professional services teams who have backgrounds in other sectors and can help our researchers engage with industry, policy and culture. These resources are open to all our staff and we don't see early-career-researcher status as a barrier to developing high-level collaborations.

There have been different scales to the work I've done, but I'm drawn to collaboration and large funding opportunities because they enable the pursuit of broader potential of research ideas. One version of research sees 20 years' work ahead for a lone scholar, but a complementary team of scholars working together can do more and better, both for the emergent whole of an interdisciplinary research project and for the health of the single disciplines working within it. We also need to be constantly aware of the need to develop the next generation. The lone-scholar model leaves us in real danger of subjects and expertise withering away. Recruiting PhD students within diverse but coherent research teams is very important. There is enormous collaborative potential and by working across schools we can change the landscape of subjects. We want to have a legacy. All this can be achieved through the big team and big funding model.

There are obviously challenges with collaboration. You need to allow lots of time to explore ideas and possibilities. With my recent work in theology and the history of science, we spent days talking about options. We've had to engage with each other's disciplines and challenge each other. The historians have had to learn the science and I've had to have the courage to challenge expert translators when they don't make scientific sense. This experience encapsulates my two golden rules of collaboration – that there are no stupid questions and that trespassers are welcome. These concepts have emerged in the spaces between disciplines so everyone must feel engaged with the work that develops and feel comfortable about challenging or suggesting ideas.

The same approach worked with my industrial partners. Effective collaborations happen when the academic and business systems are carefully mapped. Traditional university structures put subjects into silos, which reduces opportunities or motivation to talk to each other. In industry, people from different disciplines constantly communicate. To make sure that the projects are successful we had to create similar interdisciplinary teams within the universities involved. The relationship with the industrial partners was developed over many years – the ideas grew naturally as we learnt more about each other and the challenges each had.

Interdisciplinary collaboration has been an essential aspect of my career and is one that I'm fascinated by. I think that it is vital for researchers to understand the methodologies and mindsets needed to bring complex collaborations to successful outcomes. Another strand of my research is to better understand these. I've published and run workshops with academics to stimulate thinking about interdisciplinary research and I'd strongly encourage anyone who is serious about this model to learn about its features. A huge amount of good practice can be learnt and time saved by understanding the model and appreciating the challenges and opportunities it presents.

Notes

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