Study groups with industry: what is the value?

By Martine Barons, Chris Budd OBE, Joanna Jordan and Matt Butchers

Mathematical science study groups with industry have been running for over 50 years and, having started with pioneering work in the UK in the 1960s, these groups now take place all over the world in a huge variety of shapes and sizes.

"The flexibility of study groups is probably one of the hallmarks of the British sprit and has ensured the spread of the study group model across the world."

Prof Odile Marcotte, Université du Québec à Montréal, Canada

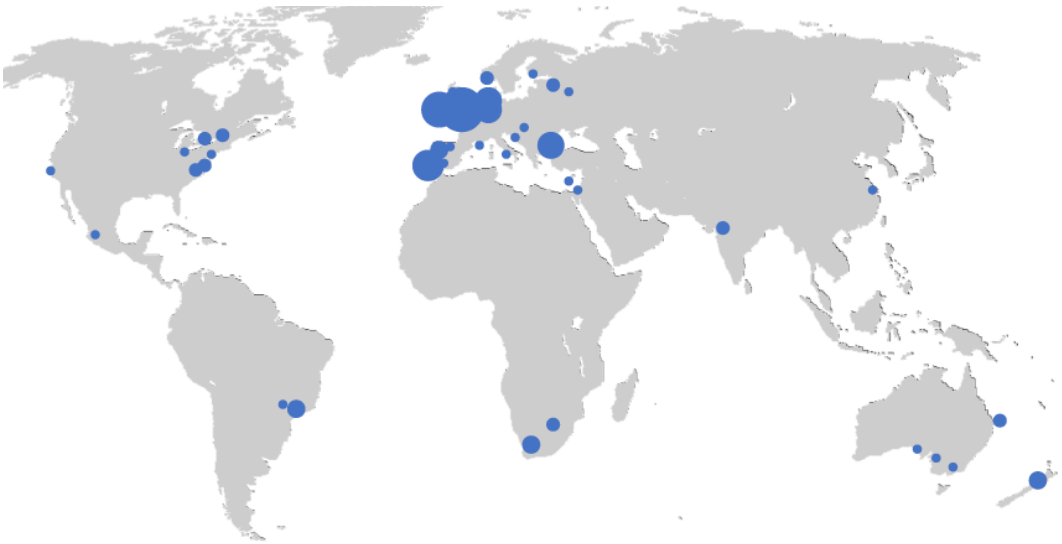

Figure 1. Locations and intensity of mathematical science Study Groups in the past five years.

A study group is an open workshop in which academics, PhD students and companies work together as equals, usually for a week, and in particular without any form of NDA or IPR restriction, to share ideas freely, and to engage in very focused discussions. They are based on the premise that industry is a valuable source of interesting problems to stimulate new research and that in addition, the mathematical sciences can solve key industrial and societal challenges of economic and societal value. One of the goals of the study group is to provide companies and institutions with mathematical tools for solving problems.

A study group also allows academics and students in the mathematical sciences (including data science, statistics, optimisation, numerical analysis, mathematical finance, machine learning, etc.) to be exposed to, analyse and solve real-world problems. Through this they become familiar with, and up to date in, some of the latest problems and methods arising in industry. The research started at study groups often leads to long lasting and deep mathematical investigations.

The UK's position in mathematical study groups

The UK is part of a broader network of European Study Groups with Industry (ESGI) which has a degree of central coordination and is closely linked to the European Consortium for Mathematics in Industry (ECMI) [1]. ESGI workshops are organised regularly across the whole of Europe. There are now long-established annual study groups in the Netherlands, Denmark and Ireland, with new countries running study groups every year. In 2019 alone there are study groups in Holland, UK, Spain, Estonia, Austria, Lithuania, Portugal, Denmark and the Basque Country. From 2015-2019, the UK-coordinated EU-funded Mathematics for Industry Network supported the establishment of study groups in new countries and has written a handbook on how to organise a study group [2].

More recently, Knowledge Transfer Network (KTN) has provided leadership in more focused, three-day study groups, concentrating on particular, strategic areas. Examples of these include study groups in agri-food, energy, manufacturing and health. These three-day study groups are seen as strategic whereby gaps in engagement and / or pots of available R&D money are driving the need to engage the mathematical sciences. These strategic study groups have seen a large number of SMEs and start-ups come through the doors and receive support.

In general, study groups are a very important feature of the knowledge exchange activity of the UK mathematics community. They represent an area in which the UK is world leading. The recent Bond review – *the Era of Mathematics, an independent Review into KE in the Mathematical Sciences* [3] made the following recommendation:

Resources for workshops with industry should be broadened and increased. In particular the Mathematical Study Groups with Industry should be expanded in scope.

Professor Philip Bond, The Era of Mathematics. An Independent Review into Knowledge Exchange in the Mathematical Sciences (2018)

Case Study 1 – The Mathematics of Food

In 2017 a three-day agricultural study group was hosted by the IMI at Bath in close partnership with the Knowledge Transfer Network. One of the problems worked on during this study group was brought by Mondelez and looked at modeling the effects of climate change on cocoa production in Ghana. A report on this was written up. This project was then developed through an LWEC grant and an MSc project and through journal publications. It is now being worked on by a PhD student at Bath. This work was reported in the Gresham Lecture 'How Much Maths Can You Eat' by Chris Budd [4].

At a follow up agricultural study group at the ICMS a similar problem was brought by PepsiCo looking at the effects of climate variation on orange production in Florida. Using the earlier report as a basis, substantial progress was made on this problem.

[1] https://ecmiindmath.org
2 https://mi-network.org/resources/handbook-for-running-a-sustainable-european-study-groups-with-industry
[3] https://epsrc.ukri.org/newsevents/pubs/era-of-maths/
4 https://www.youtube.com/watch?v=GplDsuHnVXI

Motivated in part by the success on the problem above, PepsiCo brought two problems to the Bath Study Group in 2018. The follow up to these problems has led to two contracts between PepsiCo and Bath IMI, an MSc project at Bath, an ITT at Bath, a further problem posed by PepsiCo at the Cambridge Study Group and a one-day workshop at the University of Huddersfield, and ongoing collaborations between PepsiCo and many of the academics who attended the Bath Study Group, with a paper in preparation.

A press release led to further publicity of the PepsiCo problem [5]

"Study groups like this one in Bath are a wonderful opportunity to get the best brains working on your problem in a focused collaborative way, getting initial results in just five days.

"Working in this way brings together expertise from a variety of fields with different perspectives on the problem, so the resulting mix is more than just a sum of its parts.

"Over the five days, the delegates take the challenge, redefine the problem and focus on solving it. Study groups like the ESGI can really help build a better product and equipment that will help improve the productivity of processes in the long term.

"I would definitely recommend that other businesses get involved in these workshops."

Stacie Tibos, Associate Principal Engineer. PepsiCo

What kind of problems are brought?

When the study groups started the problems were typically focused around mechanics, mathematical modelling and differential equations, this is typified in the first ever summary report of a mathematical Study Group in 1968 [6]:

Mr Herne from the National Coal Board, came to discuss the problem of the analysis of moving granular material and, in particular, the motion of large quantities of coal in a bunker.

However, in the last 20 years there has been an explosive growth in the range of problems considered. The majority of the problems in recent study groups have been in areas such as data science, optimisation, financial maths and signal / image processing, although mechanics is still a vital component of the study group sessions. The increasing mix of mathematical science disciplines involved in the sessions dramatically increases the range of problems accessible and allows for multi-disciplinary knowledge exchange which has led to countless fruitful collaborations at the intersection of the mathematical sciences.

[5] https://www.bath.ac.uk/announcements/how-number-crunching-can-optimise-crisp-frying/
[6] http://www.maths-in-industry.org/miis/566/1/Oxford_Study_Groups_1968-1988.pdf

The range of sectors now taking part in these sessions has also been growing, in the past decades challenges have come from sectors as broad as manufacturing, energy, agriculture, financial services, food, health, automotive and many more. As an example, the ten problems at the 2019 Cambridge Study Group were a mixture of data and modelling as follows:

1. Identification of changes in noisy spectra – to detect incipient problems in rotating equipment (Faraday Predictive)
2. Statistical Modelling and Pattern Recognition for Predicting Evolution of Temperature Forecasts (BP)
3. Uncertainty in Seismic Inverse Problems (BP)
4. Identifying Potential Hardening Techniques for Image Classifiers (Defence Science and Technology Laboratory)
5. Limits on Simultaneous Transmit and Receive (Defence Science and Technology Laboratory)
6. The Value of Information in Managing the Electricity System (National Grid)
7. Conditional Quantile Estimation using High-dimensional Time Series Data (Prudential)
8. Improving Weather Models for the Insurance Industry (Aviva)
9. Towards Managing Landscapes: How can we Interpret and Design Better Environmental Monitoring Surveys? (Syngenta)
10. Analysis of Shear Forces during Mash Disk Formation (PepsiCo)

Who attends, and why?

But even tried, tested and successful schemes such as the study groups - with such a rich heritage should reflect on current trends and to make steps to keep them agile to changes in industry needs. A recent survey explored these ideas; what are the motivations and expectations for business and academia alike to take part? The below figure shows the motivation behind industry participation:

Figure 1. Why does industry attend?

It is important to bear these differences in mind when running a study group, smaller companies being more agile and responsive often come with specific challenges which if solved in a few days would be transformative to their business. Larger companies often come with broader questions and what is needed are new ideas which could be applied to multiple industry questions.

On the other side, there are plenty of other pulls on a busy academic's time, what makes researchers give up their valuable time to attend these sessions? Understanding these help us to structure the meetings optimally, and also have implications on where funding and support comes from.

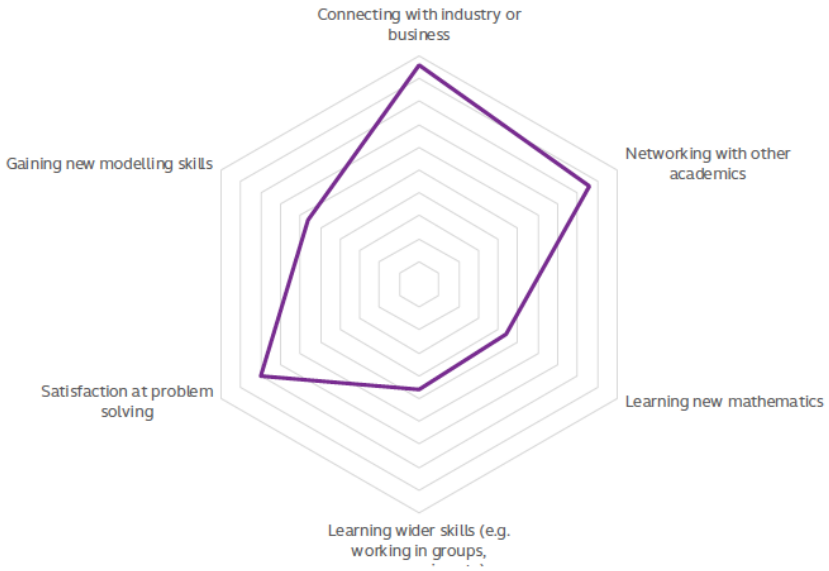

Figure 2. Why do researchers attend?

Researchers attend for a variety of reasons. From the survey results it is interesting that as well as the benefits of connecting with industry and academics, many attend for the sheer satisfaction of solving problems. This is not unreasonable given that they are mathematicians. Certainly, study groups have a major benefit of stimulating an interest in knowledge exchange through problem solving in both students and experienced academics. All of the academics consulted felt that study groups were good value for money.

Case Study 2 – Mathematics of Drug Discovery

In 2017, AstraZeneca bought the challenges Improved Drug Discovery Through Better Machine Learning Models to the Thirds Uncertainty Quantification & Management Study Group with Industry at the University of Warwick.

The researchers explored novel descriptors to describe the candidate chemical structures, and a comparison between a number of machine learning algorithms.

The activity directly resulted in two PhD Students being sponsored through the new HetSys Centre for Doctoral Training, who are building Study Groups as a key part of the industrial engagement strategy.

"It was a great experience and we were exposed to a lot of new and interesting ideas"

Ola Engkvist, Associate Director, Computational Chemistry R&D, AstraZeneca

Do they work? What is the impact?

In the survey of 64 academics, 46 journal papers were easily identified as coming directly from study group problems. These enriched journals as varied as: New. J. Phys.,J. Appl. Math., J. Eng. Math., J. of Colloid & Interface Science, Appl. Phys. Lett., J. Optics, Phys. Fluids, Simulation Modelling Practice & Theory, SIAM Review, SIAM Applied Maths, Phys. Rev. E., J. Nonlin. Mech., Discrete Cont. Dyn-B., Sports Engineering, and topics as varied as: rotor dynamics, crystals, machine learning, vortex dynamics, material science, PDEs, ODEs, network theory, signal processing, inverse problems, environmental science, chemical engineering, rheology, non-smooth dynamics, uncertainty quantification, and financial maths.

Whilst it is difficult to assess the long term impact of study groups on the development of mathematics, it is certainly true that work on problems arising in them they have led directly to the development of such areas as free boundary problems, non-smooth dynamical systems, exponential asymptotic, and financial mathematics for example.

The reports of the problems examined at study groups, which are maintained on the MIIS archive [7] provide a valuable source of teaching examples for both undergraduate and post graduate courses and contain nearly 700 reports.

7 http://www.maths-in-industry.org/miis/view/studygroups/

For the companies who take part, there is good evidence that the study groups both save time and money for the companies and also generate new projects for both small and large companies. In many cases the estimated value in terms of real value of new projects and the value of time saved on existing projects exceeds £100,000! For the companies contacted, there was also evidence that the study groups had led to many new partnerships and jobs. Study groups also enjoy repeat business from many companies; 80% of the companies surveyed have taken part in one study group, 15% in two-four and 5% in five or more.

The study group enabled a company staff member and his company supervisor to make contact with the leading academic (and after the study group several other leading academics) in the field of uncertainty quantification and emulation. This in turn influenced several company people (of the order of 10), including senior managers, to modify projects. To quantify the actual value of new products is dependent on rather many assumptions. However, it is very clear that the study group enabled interactions with several academics that would otherwise have been too difficult and expensive to organise without the help of the study group. The study group mechanism is a unique method of facilitating consultancy and academic interaction that provides benefits lasting many years after the study group. This happened to me as a result of study groups that I attended from 1973-2008 during my industrial career, and I am still collaborating with students and academics that I met while attending many of these study groups. Long may study groups continue and flourish.

Anonymous Study Group Feedback (2019)

Case Study 3 – Mathematics and Aircraft Shimmy

In 2007 Airbus came to the Study Group at Bath and brought the problem of shimmy in the undercarriage of aircraft. One of the PhD students who worked on this problem during the week, so impressed the Airbus team that he was offered (and took) a job with them shortly afterwards. The problem itself was then developed as a research project at the Department of Engineering Mathematics at Bristol. This led to a series of papers, and PhD projects with Airbus, on the application of non-smooth dynamical systems to aircraft undercarriage design. One of the PhD projects at Bristol was undertaken part time by the original poser of the problem from Airbus. This work has also been adopted as an evaluation tool for new designs within Airbus.

"The Study Group provided us with two main outcomes. The immediate outcome was the discovery of the network of people, who were interested in the topic area and were looking to take the study forward. As a result, we setup a 3-year research associateship at the University of Bristol, to extend the study. The by-product is that our relationships, between the University of Bristol and Airbus, are further strengthened."

Sanjiv Sharma, Modelling & Simulation Expert, Airbus

Summary

Study Groups have been a key part of mathematical science knowledge exchange for the past 50 years. Due to the flexibility of the format, they have evolved to address the pressing challenges of the day and flourished as a result. They have enriched industrial challenges with tools and solutions, and a growing body of evidence shows that they are transforming academic topics through this inter-reaction.

Authors

Professor Chris Budd OBE is Professor of Applied Mathematics at the University of Bath, Deputy Director of the Institute for Mathematical Innovation, and Gresham Professor of Geometry. He works on a variety of problems in which mathematics can be applied to the real world, including industry and environmental science. Most recently he has been working closely with the UK Met Office and Hadley Centre on the development of improved methods for weather and climate forecasting. He also works with energy, food and insurance companies, to develop mathematical models to assess the impact of climate change on them in the future. He is also a passionate communicator of mathematics, giving talks and workshops on many subjects, including climate change, to audiences all over the world.

Dr. Martine Barons is the director of the Applied Statistics & Risk Unit (AS&RU) at the University of Warwick, UK, and leads for the statistics department on interaction between researchers and business and government and industry. AS&RU has a strong record of achievement in major societal risk and decision analyses. Dr. Barons has an extensive personal track record of research in mathematical sciences, decision support and risk with a strong component of interdisciplinary work and applications in food security, pollination, electricity system stability, digital archive preservation and uncertainty visualizations. She is also a passionate communicator of mathematics, through outreach, education talks and workshops on many subjects; "Saving the bees with maths" is a particularly popular topic. She is a Chartered Mathematician (CMath) and a member of the Royal Statistical Society and the Institute of Mathematics and its Applications.

Dr Joanna Jordan is a freelance mathematics knowledge exchange specialist. Previously, as the Manager of the Mathematics Applications Consortium for Science and Industry, she led engagement with industry partners, and as Manager of the Bath Institute for Mathematical Innovation she set up a new mathematics knowledge exchange team. She founded and chaired the Horizon 2020 funded Mathematics for Industry Network (MI-NET) and served on the Expert Review Committee for the 2018 Bond Review. She is a Fellow of the Institute of Mathematics and its Applications (FIMA) and a Registered Technology Transfer Professional (RTTP).

Dr Matt Butchers is KTN's Knowledge Transfer Manager, Industrial Mathematics. With a background in experimental physics, Matt is responsible for ensuring that the vital underpinning methods associated with mathematical sciences and the value they can add are appreciated and exploited using the KTN network. He also promotes collaboration potential and funding in the sensors and instrumentation sector. Matt holds a PhD in Physics from the University of Warwick and prior to joining KTN was a design technologist for BosTech.