FROM LAB TO FACTORY: A KNOWLEDGE BASED APPROACH TO UNDERSTANDING AND LOWERING THE BARRIERS TO NEW TECHNOLOGY UPTAKE IN INDUSTRY, AS APPLIED TO IN-PROCESS MONITORING OF COMPOSITE MATERIALS.

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Abstract

In the composites sector, where fast growth is forecast to increase even further, use of in-process monitoring to understand and improve manufacturing processes and the resulting parts has huge potential. Despite having been used in academia for some time, such technologies are not popular in industry.

The reasons for this are many and varied, however it is notable that academia and industry communicate their knowledge, both within and without their organisations, very differently. This paper explores these differences in the composites community and reports on the development of an industry-targeted resource for the case of dielectric cure monitoring, designed to enable industrial uptake of this technology and to provide a template for others.

1. Introduction

Knowledge is a crucial aspect of composites manufacture, from cutting edge research to a skilled technician's ability to get the very best from their tools. In order to move a technology from academia to regular, widespread use in industry, it can be useful to consider not only the technical requirements of an industrial setting, but also the challenges inherent in knowledge transfer between these different arenas.

Davenport and Prusak [1] describe knowledge as "*a fluid mix of framed experience, values, contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information*". This description makes clear a crucial fact- knowledge is that which exists inside a person's brain. This is not restricted to explicit items which can be written down, in manuals and other such documents, but is founded upon tacit knowledge- indeed, Awad and Ghaziri [2] estimate that 95% of all knowledge is tacit.

To better understand the transfer of knowledge in industry and in academia, a questionnaire based study has been carried out. This includes investigation of knowledge transfer within the sample group from each organisation and correlation with self rating of skill level, opinions on current knowledge transfer practices and questions to elicit how people in different jobs prefer to learn. This is valuable from a business perspective, in terms of making the most of staff talents, providing the right training where needed, and dealing with any problems which may not previously have been clear.

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For in-process monitoring, better understanding of knowledge transfer within industry can enable resources to be targeted at providing materials and training in a manner which fits industrial practices and the preferred learning methods of those who will use the equipment.

During the study presented below, representatives of the participating commercial companies, plus a number of others at a more general workshop, were asked their opinion on dielectric cure monitoring, in informal conversation. The majority had not heard the term before- the only exception being those who had previously heard the author speak on the topic. While anecdotal, this is a clear indication that more can be done to engage industry in order to improve uptake of technologies of this nature. As described by Maistros and Partridge in 1995 [3], dielectric cure monitoring has been in use in academia for a number of decades, yet it has made little progress in an industrial setting. This technology enables direct monitoring of the progress of the cure, through the placement of electrodes in contact with the resin, or in an area the resin will flow into. A current is passed through this sensor and the response of the resin measured. This response changes as the cure proceeds, allowing features of the cure to be picked out and the effective end of cure identified, which can facilitate more efficient cure cycles or identify incompletely cured parts.

A number of companies are selling such monitoring technologies, and industrially focused research on the topic most certainly exists, with the work of Devillard et al [4] on control of RTM using resin arrival monitoring, and Kim et al [5]'s use of dielectric sensors to study the effect of out-time on out of autoclave prepreg being good examples.

2. Survey methodology

The survey was carried out by questionnaire. Participating groups included two academic organisations, one research institution which positions itself between academia and industry, and - to date- four SMEs, of varying technology levels. This should not be considered a complete dataset, as other companies are due to participate in short order. All organisations are located in the UK or Canada. The questionnaire has been approved by the University of Bristol Ethical Committee and only anonymised results will be presented.

SMEs were targeted as there are a large number of SMEs in the composites industry, who are less likely than multinationals to engage in cutting edge research and thus require factory-ready solutions.

The survey was initially piloted at the research institution, using an online questionnaire. Despite initial expressions of interest, the response rate was too low to draw meaningful conclusions. A second pilot, using a modified questionnaire on paper- undertaken with a different group, who had not seen the first pilot- was far more successful, and became the basis for this study, with the results of that group included within it. A paper based questionnaire has the advantage of immediacy, and is more practical for those who do not have computer based jobs- true of many working in manufacturing on a 'shop floor' level - but incurs a significant burden in terms of data entry.

The questionnaire is split into two parts, which are physically separated- as the first part requires the participant's name, wheras the second should be anonymous in order to encourage honest answers to opinion based questions.

3. Using Knowledge Networks as a quantifiable comparison to self- rating of skills

3.1 Knowledge Network Analysis

The first part of the questionnaire consists of three questions, two concerning knowledge networks and one forming a skills matrix.

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A knowledge network shows the connections between people in a group, elucidating who the key people who teach, answer questions or provide connections between others ('Knowledge Brokers') are, and who may be isolated. This is of considerable business value, as identifying key staff is crucial to retaining them- and when such a person does decide to move on, filling both their place in the knowledge network and their technical role can be important considerations in dealing with the change, both in hiring/restructuring and succession planning.

As described by Helms et al [6], knowledge networks can be considered to be of two types. A 'pull' network is that formed by people asking questions - who asks whom and how often. The frequency of questioning is shown in the network diagram by the strength of the line connecting the nodes, each of whom represents a person. An example, from the research institution, is shown in Figure 1.

The 'push' knowledge network represents one person teaching another (or many others), by methods such as taught courses, seminars or mentoring. The teaching may be formally arranged or informally provided. The connection is rated - by the receiver - on a scale of 1 to 8, according to how active the learning is, where 1 is very passive, such as listening to a lecture, and 8 the most active, such as guided experimentation. The scale of Helms et al [6] is used. In this case, the strength of the connecting line in the resulting network disgram indicates the most active rating of that connection. An example is shown in Figure 2. Both Figure 1 and Figure 2 were generated using the UCINet software [7].

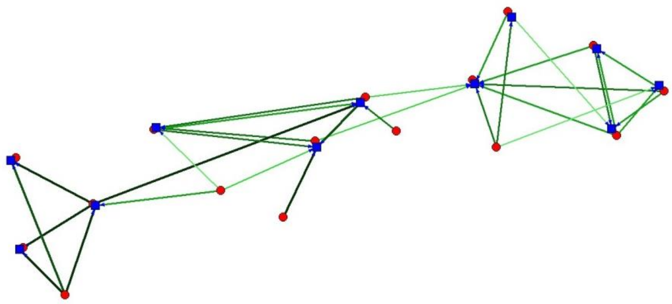

Figure 1. 'Pull' Knowledge network from research institution study

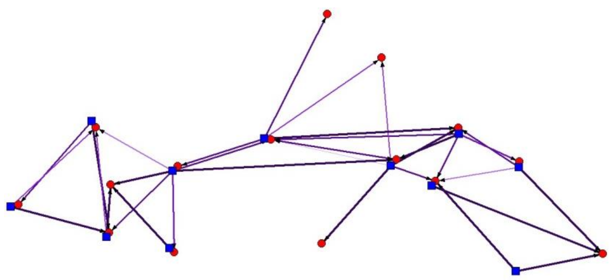

Figure 2. 'Push' Knowledge network from research institution study

In each diagram, each node- represented by either a single red dot (receiver of knowledge), blue square (transmitter of knowledge) or both is a person. One can see clearly in Figure 1 the three subgroups of the research team, and the people who provide the key links between them. Not shown (for clarity) is the 'cloud' of people outside the study participants who were also named as receivers of knowledge.

This analysis was carried out for all participating organisations, but is not shown for reasons of space.

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3.2 Combining with a self-rated skills matrix

A skills matrix is a well known tool for measuring employees' abilities, where each person is asked to rate their skills, from 0 to 5, in practices or areas of interest which are important to the business. While guidance is usually given as to the meaning of each level (e.g. 'beginner'), this is intrinsically subject to a person's own biases, and many people will tend to either modesty or exaggeration.

The numerical results of the knowledge network analysis - how many connections each person has and the sum of their connection ratings - can be used to provide a simple, quantitative sense check on these otherwise biased results. An example is shown in Figure 3, where one can see that the person with the highest rating from the knowledge networks- the person most effectively transferring their knowledge to others- rates themselves lower on these particular topics than others in their group.

		Person 1	Person 2	Person 3	Person 4	Person 5
Fibre-Bragg sensors	Theory	0	2	1	3	1
	Practical	0	1	2	2	1
Infrared cameras	Theory	3	2	2	1	3
	Practical	5	2	2	1	3
Direct tool heating	Theory	3	2	3	2	1
	Practical	4	1	3	1	1
IR lamp heating	Theory	5	2	2	2	2
	Practical	5	2	2	1	2
Flash lamp heating	Theory	2	2	2	3	1
	Practical	1	3	2	2	1
Autoclave cure	Theory	3	2	3	3	3
	Practical	3	1	3	1	2
Microwave cure	Theory	0	2	1	2	1
	Practical	0	2	1	1	1
NDE	Theory	4	2	1	2	3
	Practical	2	2	1	1	1
Adhesive application	Theory	3	3	4	4	1
	Practical	4	3	4	3	1
Fixturing	Theory	3	1	4	2	1
	Practical	5	1	4	1	1
Debulking	Theory	5	2	5	4	2
	Practical	5	2	5	2	2
KNA totals	Push	13	13	34	40	8
	Pull	10	8	25	35	6
KNA connections	Push	2	2	5	6	1
	Pull	2	2	4	7	1

Figure 3. Exerpt from self rated skills matrix from research institution study showing comparison with results of knowledge network analysis. Darker cells are higher rated.

This is not a perfect method of identifying experts, as it does not take into account personality- someone unapproachable but highly knowledgeable may not be the first choice for advice- but it is a clear way to see who is most effectively transferring their knowledge.

For the person who rates themselves as highly skilled but is not transferring knowledge to others, the manager or those who know that person well are best placed to judge whether they are overstating their ability, or correct in their self assessment but in need of some training in how best to teach others. Expertise does not automatically confer teaching ability or in some cases ability to carry out tasks associated with the knowledge.

4. Comparison of knowledge transfer current practices between academic and industrial groups.

Answers to the opinion based questions - in the anonymous part of the study - were sorted by job type and by age, so that correlations in these areas can be identified. A selection of the results are presented below.

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Academic group 1 is a collaboration across a number of universities and had 39 participants. Academic group 2 is based at a single university with two campuses and had 13 participants, including most of the group. The research institution is at one location, there were 16 participants all from the same team, most of whom were included. Company 1 is a relatively high-tech manufacturing company at the larger end of the SME scale and had 11 participants drawn from a larger workforce. Company 2 is also a higher tech SME, working on software and hardware for composites manufacture, and had 19 participants, which is most of the staff. Company 3 and Company 4 are small, lower-tech manufacturers, working largely in consumer goods, with 9 and 5 participants respectively. However, they have different internal processes so are presented separately.

4.1 Search

Participants were asked to rank where they would go first when searching for either specific information, such as how to fix a particular fault, or generic information, such as finding out more about thermoplastics.

Taking the top three choices for each participant at each institution, the top ranking methods for each are shown in Figure 4. These are the options participants prefer when searching for information.

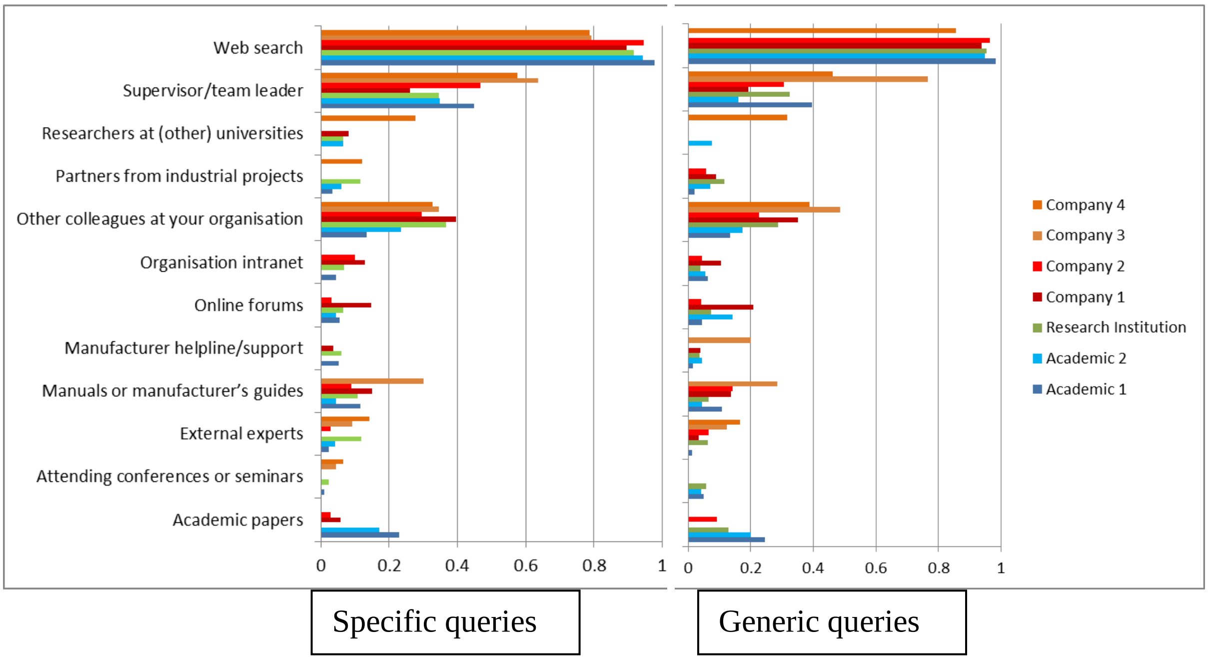

Figure 4. Search study results, for specific (left) and generic (right) queries. Results are normalised by number of responses from each organisation and represent the top 3 choices for each participant.

While web search is popular for almost all cases, it is notable that the next most popular options involve asking other people, be it the participant's supervisor or other colleagues. Perhaps unsurprisingly, academic papers are more popular in academic groups. Company staff are more likely to refer to their intranet or to online forums than academics.

Overall, it is clear that web search and talking to others are the most popular methods of searching for information in all the organisations studied, and that academic papers should be considered a poor method for informing industry - and indeed a relatively low ranked option for academia.

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4.2 Current and desirable knowledge transfer practices

Figure 5 shows the positive results- those saying ‘yes’ or ‘sometimes’ of asking participants whether they or their working group engaged in the activities listed. Literature reviews are a largely academic affair, but all groups fall down somewhat on the common business practice of identifying, recording and – crucially – refering back to lessons learned during a project, as shown by items 7-9. It is interesting to note that in a number of cases, participants said they did not write down lessons learned- but did refer back to them in subsequent projects.

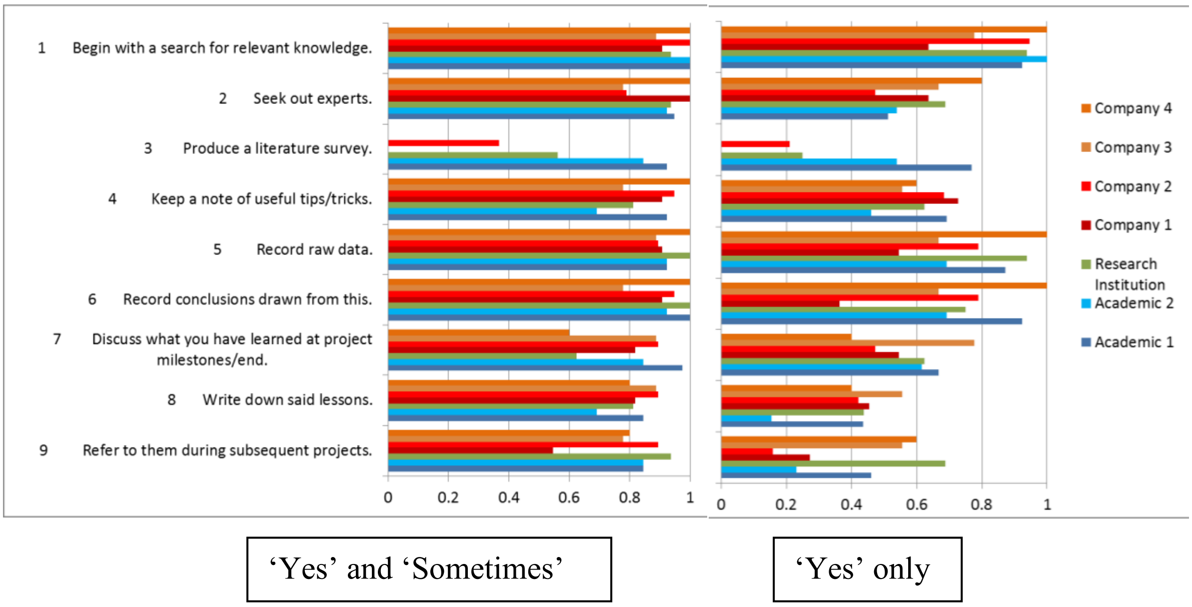

Figure 5. Proportion of participants answering positively to *‘During a project, do you/your team do any of the following?’* for the statements given. Normalised by number of participants.

Detailed questioning regarding current knowledge transfer practices was tailored to each organisation, however it is worth noting that **all organisations rated casual or targeted conversation (e.g. over a cup of tea) a among their top three most effective methods of knowledge transfer, and all but one rated on the job learning among the top three.** Taught courses were considered more effective in the academic organisations and research institution, but rated very low in most of the companies.

Figure 6 shows the highest rated potential knowledge transfer methods among those listed. That is, those that participants consider they would be most likely to use if they were available.

Despite the poor opinion of taught courses in the companies studied, demand for formal training courses is high, as it is among all the institutions studied. Difference between the various institutions is slight here, with a central store of manuals, external internet based knowledge repository and mentoring programme all popular.

Discussion forums, internal or external, are far less popular than the other options. This may be related to the time pressures involved in interacting with such a resource. The final question asked how often participants would be willing *and have time* to contribute to such a resource, or to a wiki or similar platform to exchange information. Very few people across any of the organisations answered that they would be able to do this daily. The most popular response was monthly, with a significant proportion answering yearly or never - making useful dialogue over such forums unlikely.

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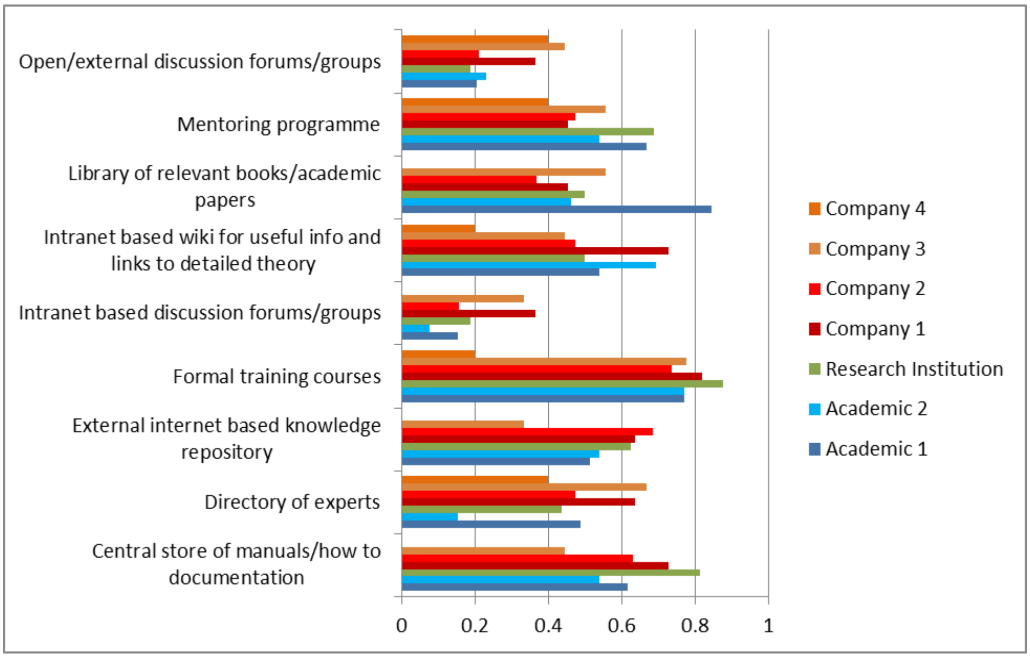

Figure 6. Number of participants rating the listed options 4/5 or higher in answer to the question *'How likely would you be to use each of the following options, if they were available?'* Normalised by number of participants.

It should be noted that what a person considers they would do in the future may not reflect the reality. A central store of manuals/how to documentation is a very popular option, but, as can be seen in figure 4, manuals are not within the top three choices when searching for information for most people. It is possible that simply locating them in a more convenient manner might indeed make the large difference seen between figures 4 and 6, but also possible that the clear preference for web based or interpersonal asking of questions would continue to dominate. It is also notable that directory of experts scores relatively low, despite asking others being a very popular choice when searching for information, again in figure 4.

5. Conclusions and future work

The questionnaire and results presented so far have been well received by the participating organisations. The knowledge networks and quantitative 'sense check' this provides for a standard skills matrix are seen as particularly useful, and the results of the opnion based questions give the organisation in question a realistic assessment of how their current practices are working, and indications of where improvements could be focused.

In order to facilitate the progress of technologies from academia to regular use in industry, knowledge transfer underpins technical readiness. The results of this investigation are intended to be useful in the creation of industry targeted resources. These results suggest that, while an information resource is useful - particularly as seen in the demand for an external, internet based knowledge repository and a store of manuals- knowledge transfer occurs best at a person to person level, through either informal discussion or on the job learning. The clear demand for a mentoring scheme bears this out, though it should be borne in mind that these results must be considered in the context the organisations studied and cannot be considered representative of the composites industry as a whole, particularly at only SME companies are included.

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An industry focused composites information resource, which may fit the 'external, internet based knowledge repository' mentioned, is under development at UBC Vancouver, as described by Fabris and Poursartip [8], with whom the author is working on the topic of dielectric and DC cure and resin flow monitoring. The challenge of further developing true routes for knowledge transfer, through teaching and training, is of increasing importance in the fast growing composites industry, particularly in countries like the UK which are set to suffer a shortage of engineers in the future, as detailed in the Perkins Report [9] amongst other documents. This is an important area for future development.

Acknowledgments

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The resource under development to assist knowledge transfer from academia to industry is led by the Composites Research Network at the University of British Columbia, of which the work on dielectric cure monitoring is a one part, currently being undertaken by the author in collaboration with Professor Anoush Poursartip and Janna Fabris of UBC.

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