Department of Civil Engineering
University College London

Royal Academy of Engineering Visiting Professor in Innovation
End of Year 5 Report

Visiting Professor (VP) in Innovation:
Ed McCann
Director of Expedition Engineering

During the session 2014 – 2015, Ed's input continued much as in previous years with a combination of activities within the department and more broadly across the undergraduate sector in the UK but also internationally.

As this is the final report before the funded phase of this initiative finishes, we thought that it would be useful for the Academy if we were to summarise and reflect on the overall experience and impact of Ed's appointment. As such I have asked Ed to write a personal account of what he has been up to, the insights that he has gained and what he believes his appointment has achieved.

Overview
The aim of my appointment was to explore, develop and disseminate innovations in teaching for engineers. It was understood from the beginning that the role would be somewhat different to the normal RAEng VP role as I was planning to engage widely across HE, PE and other institutions developing teaching approaches for general benefit rather than working with intensively within a single university group department teaching students. This approach was intended to maximize the impacts of the work and was something of an experiment.

I was initially appointed to Strathclyde University where I worked with Andrew Briggs and Professor Iain McLeod to develop the undergraduate design program. For practical reasons the funding was transferred to UCL at the end of the first year although I continue as a RAEng VP at Strathclyde.

For the remaining four years of the appointment I have been based at UCL where I have worked primarily with Professor Chris Wise, Dr Paul Greening, Brian Cahill and Oliver Broadbent (a RAEng Teaching Fellow).

I have also developed productive and ongoing relationships with the University of Sheffield where I have been appointed as a VP and the University of Limerick where I am in the process of being appointed as an adjunct Professor. I continue to have significant interaction with Imperial College, Bath University and the University of Cambridge. I have visited and lectured at several other universities.

Most of my work has been related to civil and structural engineering although I have also worked with architecture departments.

In all cases the focus of the interaction has been in the teaching of design and the use of technology enhanced learning resources. Each of these areas is discussed in more detail below.

Design Teaching

Before this appointment, I worked for several years with Prof Chris Wise at Imperial College developing and delivering what was at the time regarded as an innovative design teaching program. Based on this experience and that gained subsequently through membership of the JBM and other educational involvement, I believe that much remains to be done to improve the early and effective development of design skills for engineers.

Design process models

In particular, I believe that the existing models of the design process are usually either inadequate or ineffectively used in UK engineering schools.

Similarly, whilst it is true that design teaching is usually enthusiastically and diligently done by teams of practitioners and academics, I believe that the lack of an appropriate pedagogy limits the effectiveness of the learning process.

As such, over the period of this appointment we have researched a number of different potential models and developed one that we find useful in our teaching. Additionally, we have researched and experimented with different techniques for helping students develop the skills relevant to the overall exercise of the design process.

I have found it helpful to be able characterize the design challenge as the resolution of a paradox, namely that "we can't fully define what we want until we fully understand the consequences; and we can't fully understand the consequences until we can define what we want".

Engineers resolve this paradox by iteration around and convergence within (some version of) a nested cycle within the design process involving the following stages:

1) establish the challenge (analyse the brief, establish the context etc)
2) propose solution (research possibilities and generate ideas)
3) model proposal (develop appropriate models to explore, communicate and test the proposal)
4) evaluate results of the model
5) judge whether the proposal is adequate and decide whether to go back around the cycle or some part of it again or indeed proceed.

Framing the process in this way allows us to isolate and focus on developing specific skills like having ideas (proposing solutions) or modelling proposals or making good judgements and so on.

Additionally, in my experience engineering students are unfamiliar and often uncomfortable with iterative processes. Once the design process is framed in this way it is easy for students to understand the benefits of fast iteration and rapid convergence and to start to develop strategies to help them be more effective. Such strategies include: good initial proposal; rapid idea evaluation; refining the modelling between iterations and so on.

Dealing with assumptions

All real engineering problems are based on incomplete data and this requires

assumptions to be made. It is therefore important to develop the skill of making good assumptions which are progressively and deliberately confirmed or revised. In my experience most engineering students are uncomfortable making assumptions but it is perfectly possible to help them develop their confidence and ability to do this.

Judgement

All real engineering challenges require a blend of subjective and objective judgements where: objective judgements are those where well intentioned, competent and diligent people will all come to the same view and subjective judgements are those where well intentioned, competent and diligent people may come to very different views.

In effect subjective judgements involve personal values whereas objective ones do not. Most engineering education is targeted at equipping students to make good objective judgements. One of the big challenges is to help students develop competence and confidence in making subjective judgements.

Whilst making "good" subjective judgements is always a challenge, it is helpful for students to learn about different techniques that we can be used including for example: consulting an expert; polling opinion (consulting a crowd!); deliberately adopting different perspectives; and so on. Even getting students to realise that subjective judgements are based on personal values is very helpful in enabling them to understand what is going on when they as a team struggle to come to a shared view.

Generic vs Domain Specific Design Skills

Most of the skills that are described above are generic and would be recognizable to any experienced engineer, or indeed any designer. Over the years we have had considerable success in helping students develop these sorts of skills in relation to abstract design challenges. At the same time we struggled for a long time to see much improvement in our student's ability to do realistic engineering design projects. It appeared (to our dismay) that the teaching of these generic design skills did not result in significantly better performance on real engineering problems like designing a flood alleviation scheme or a bridge. It took us a while to realise why this was the case but in the end we think we have unlocked the problem, and as is often the case the reasons are obvious with hindsight.

Interestingly, our insight came from watching the performance of experienced practitioners. We observed that notably expert designers from one field found it much harder to make effective progress in another. It became clear that we had not properly appreciated the relative importance of domain specific skills and knowledge compared to generic design skills.

When we pulled these two groupings apart and began to focus on the domain specific skills we were able to make significantly more progress. Incidentally, this observation largely explains why there is a plethora of similar but different design process models each emerging from different areas where the domain specific processes are subtly different.

Whilst it is obvious that different domains will require different sorts of knowledge it was less obvious to us that there would notable differences in the optimal design strategies in those different domains.

To explore what was going on we interviewed some experienced designers and undertook some informal classroom experiments.

We asked three award winning designers of "iconic" pedestrian footbridges to list out the 10 key factors that needed to be addressed in the design of these bridges. For all practical purposes they produced identical lists. We also asked them to order the factors in the way that they would attempt to deal with them in the design process. Again to all intents and purposes they gave me very similar answers. None of this was very surprising.

We also asked two cohorts of 90 students working in groups of 5 to produce their list of 10. Interestingly they produced very similar lists to the experts, typically getting 80% or so commonality. When asked to order the factors, there was some coherence between student groups, but very little between them and the experts.

Specifically, whereas the experts all began with consideration of the site and the vertical alignment of the deck the students generally began with the choice of and analysis of the structural system. This "cart before the horse" problem was the primary reason why they found it so difficult to make progress in bridge design challenges. In effect they ended up with very slow design iteration cycles because they were doing too many detailed calculations too early. They also had typically poor quality outcomes, probably because no-one has ever calculated their way to a good idea and they generally ran out of time trying to be the first.

Further exploration with the students suggested that the reason that they did this was because they had been taught a lot about the analysis of structure and assumed that it was the most important thing in the design of structures!

Perhaps even more interesting was that when one of the expert bridge designers was asked to identify and then arrange in order the factors influencing the design of a flood alleviation scheme, he was pretty much in the same boat as the students. It was not obvious that in this area the key to success is getting a really good understanding of the existing system. This is quite different to the situation found in many structural engineering challenges where there is no equivalent hard to understand existing system.

This informal exploration suggests that in different design domains there are different optimal design strategies which become tacitly known to experienced practitioners over time. This with hindsight is not at all surprising.

Based on this general observation we have started to compile simple models for typical domain specific design strategies by interviewing experienced practitioners. These comprise a simple list in each domain of the key factors to consider and a rough ordering of how they should be approached. It is too early to measure the success of this approach but early results are very encouraging.

Designer Personality Traits

Another area that we have focused on is the performance of design teams. Through running the Royal Designers for Industry Summer School over several years, Chris and I observed that within design teams there appear to be different motivations and

attitudes that manifest themselves in different individual behaviors. In psychological language we are observing personality traits. We observed that the balance of these traits across the team appeared to significantly influence team success. Moreover, we observed that certain stages of the design process and different design challenges required different blends of these traits.

In the realm of occupational psychology, a lot has been done on team performance and most of us have experience of the work done by Belbin. What we observed and have been exploring in relation to design teams is analogous to the Belbin model but is specific to design team activities which depend critically on the ability to analyze complex problems and generate good ideas etc.

We first identified three traits which we labeled: Artist, Artisan and Philosopher. So far we have described these (slightly tongue in cheek) as follows:

The Philosopher
….pursues meaning
….focuses on problem definition
….is obsessive about matching answers to questions, and solutions to problems……
….is relatively slow to propose an answer and will propose very few
….can (and will) explain precisely and at length why one thing is better or worse than the other
….may well disappear up their own profundiment

The Artist
….pursues interest
….uses the bionic man algorithm (invented by Ed, the philosopher)
….finds it easy to generate ideas
….is happy to ditch a bad idea in the hope of a better one
….struggles to explain why one idea is better than another
….is likely to move onto something more interesting when it surfaces
….may well be found dead in a ditch…..murdered by an Artisan

The Artisan
….pursues perfection
….struggles to begin without a pre-existing concept
….draws on precedent and the ideas of others
….struggles with difference
….focuses on improvement
….can be worth a fortune……at least for a while
….tends to the pragmatic
….determined and difficult to shift….
….may well be found guilty of murdering Artisans and Philosophers

Having experimented with this model for a few years now, we have found that the model helps people to understand both their own design process and that of others. Moreover, we have used it to form and structure design teams to good effect.

We can see how particular design challenges require people with particular traits. For example, it appears that people with strong philosopher traits are valuable for particularly complex system challenges. Similarly, if what is required is an optimal

version of a standard solution it helps to have strong Artisan traits. When novel answers are required then Artist traits are helpful and so on.

On balance and, although it is far from the finished article, I believe that this is worthy further development. For example, we think that there is another trait that we haven't captured properly yet. This is the pragmatist and is analogous to Belbins completer finisher who is motivated by getting finished or "satisficing". Moreover, we need a proper and rigorous means of identifying traits through structured questioning.

To this end we have recently considered 54 of the 150+ psychometric tests on the BPS website site, all of which have been the subject of rigorous review, to see whether they would be adequate for us to characterise and identify traits of particular relevance to the activity of design. We found four that we believe offer something, although each would need further development.

I believe that a proper understanding of motivational factors and personality traits in relation to design is beneficial both the initial and through life development of engineering design skills.

Finally over the last 18 months or so we have begun to explore the features of high performing design teams with a particular focus on idea generation and the importance of "relating" effectively. In doing this we have explored the role of humor in both idea generation and relating. The response from engineering audiences to the observations has been very interesting and encouraging.

Overall I believe that the work that I have been doing in this area is a useful complement to the work that the academy has been doing on Engineering Habits of Mind.

Technology Enhanced learning

A key part of my work under this appointment has been in the development Technology Enhanced Learning resources targeted at engineers.

Along with colleagues at Think Up and with the support of several funders including the Academy, the Ove Arup Foundation, the ICE R&D fund, the IStructE, the CITB Growth and Innovation Fund and Expedition Engineering, we have produced a wide variety of Technology Enhanced Learning Resources. These are all free at the point of use but to get them made and to maintain them in the future we have had to secure funding streams from several sources.

The grant from the Academy has been critical in enabling me to devote time to this work, much of which my colleague Oliver and I presented at the VP conference last year.

The following sections provide a brief overview of the key initiatives:

Engineering Mastermind
http://engineeringmastermind.org/.

The idea of this online game is to enable learners to develop basic knowledge of about engineering and construction, although we believe that the technique is highly effective across all disciplines. The game is relatively new but we are very confident about its value and future success. We will build more question content progressively as sponsors come on board.

Key features of the game are that:

1) It is available free to anyone with an internet connection.

2) The questions have been developed by very experienced practitioners and reflect the sorts of things that through their experience they have found to be important in their work.

3) The involvement of sponsor organisations in the game provides a really interesting opportunity for linking employers up with potential recruits and making sure that their brand is widely recognised in a positive context among a wide group of undergraduates both in the UK and overseas. Expedition Engineering have offered highly sought internship opportunities for students who have achieved mastermind status and it other sponsors propose to offer similar prizes. ThinkUp has run free design workshops for universities that manage to top the leaderboard for a sufficient period of time.

4) The questions and the game structure have been carefully designed and beta tested to ensure that appropriate behaviours are encouraged. The rankings are based on achieving mastermind status with minimum errors and the player is encouraged to reflect on whether they know the answer and if not, is directed to research on the internet to find an answer rather than repeatedly guess.

Bare Essentials:
http://thinkup.org/innovation/bare-essentials/
These are videos of top academics providing key insights to their subject areas. The idea is that rather than waste resources by encouraging every junior lecturer in the world to video themselves, we invite top academics to do the job, investing as an industry to enable high quality production. We give each of the academics involved what we call the "death bed challenge" which is to say in not more than 5 four minute video chunks the things that they believe to be the bare essentials of their subject such that a learner can make rapid progress. The feedback on these videos is really positive.

Industry Insights
http://thinkup.org/innovation/industry-insights/
The idea of this series of videos is to allow the general engineering community to learn from the insights of leading practitioners. The first in the series is Ian Firth of Flint & Neill talking about how to design bridges.

Materials Lab on line
http://thinkup.org/innovation/materials-lab-online/
These are a series of videos of materials being tested to destruction. These are used by students around the world to supplement their learning. We have good coverage of steel, concrete and timber and in due course we plan to extend the set to include water, soils

and so on. Whilst primarily targeted at undergraduate students your junior engineers may find these useful in understanding exactly what it is that they are often designing to avoid.

Makeascape
http://thinkup.org/innovation/makeascape/
This is an app based game using a real time physics engine to allow players to develop their structural engineering abilities through play. It is currently coming to the end of the beta stage of development and will be launched later this year.

We have learned much about the production of these sorts of resources and we have shared our experiences and insights through the (soon to be released) Best Practice Guidance document that we produced for the Academy's Education Committee.

Feedback from academics and students has been very positive both in the UK and overseas and there is steady growth in the use of these resources in teaching. I am optimistic that over the next months and years as we implement our marketing and dissemination strategies we will see substantial impact.

Expedition Workshed
http://expeditionworkshed.org/
This is a web based portal which provides access to high quality on-line learning resources. This is used by students and academics in the UK.

Overall reflections on the appointment

I am extremely grateful to the Academy for the award. Frankly, given the difficult trading conditions in our industry over the last few years it would have been impossible for me to give the level of commitment that I have given to this subject without the Academy's support.

Like many others I believe that the VP program offers real potential for experienced engineers to positively interact with the HE community.

The badge of RAEng VP is very helpful and in my experience is highly regarded by academics and engineering professionals alike.

I don't feel that we as VP's have really managed to realise the potential of the group as a whole. We appear to operate almost entirely in isolation of each other. The VP group are a busy bunch and with so many competing demands for their time the pull of forming a general community of VP's doesn't appear sufficient.

Based on my experience at the ICE and elsewhere the Academy might want to consider using initiatives to encourage the growth of communities. For example, if the VP's were tasked with producing a best practice guide on the teaching of design, I am fairly sure that you would see the development of an energised and active community around that challenge.

For my part, I intend to continue my involvement with the HE community although necessarily this will scale back somewhat when the funding is finished. I firmly believe that the well-being of society in the 21st Century depends fundamentally on the quality

and number of the engineers that we have. As such few tasks are more important than making a real and positive contribution to their education.

I would like to thank all of those who have participated in this program, students academics and practitioners. We have had many fruitful conversations (and lunches) and I hope pushed things along a bit too.

Finally, I would like to thank my host institutions University College London and the University of Strathclyde, and my academic "minders" Dr Paul Greening and Andrew Briggs, for looking after me so well. I hope that they feel it has been worthwhile.

Ed McCann
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