Use of a Research Role Playing Exercise to Fast Track the Development of Early Stage PhD Researchers

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Abstract: This paper reports on the student experience of a week-long group research role playing exercise, based on the manufacture of metal foams, developed for early stage PhD researchers. The main focus of the task is to highlight to students the critical transferable skills such as time management, project planning, literature analysis, personal relationship building, etc, needed for successful completion of a large research project. This is done in parallel with a number of classroom based seminars on developing good practice in research. The task involved developing a process route for the manufacture of a metal foam within 3 days of experimentation. No guidelines were given on how the task should be undertaken and the groups were given complete freedom to plan, allocate resource, execute, analyse, and re-evaluate their strategy without any outside influences. In all cases a metal foam was produced, but a subsequent survey of the participating students suggested that in order to improve their effectiveness in future projects they would prioritise background research, experimental planning, setting of goals, re-evaluation of goals, meeting the academic support, and seeking 3rd party assistance. Thus it is concluded that the traditional methods of highlighting good practice in research, such as seminars, should be supplemented by role playing activities like that presented here to reinforce the ideas presented in the classroom, which can often appear dry and detached from reality.

Keywords: graduate studies, engineering education, UK, role playing exercise, early stage researchers.

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1. INTRODUCTION

1.1 General Introduction
The last 10 years has seen the majority of the UK Research Councils initiate enhanced graduate research training programmes through the development of Centres for Doctoral Training (CDTs). Unlike a traditional PhD route, students enter a CDT as a cohort and undertake a substantive PhD level research project together with additional individual and group training activities. These typically include taught coursework, training in a wide range of transferable skills to
enhance their research efficiency and industrial readiness levels, and group activities such as outreach projects to engage the public in science and engineering. In most cases CDTs are based around a multidisciplinary theme and have an intake of around 10-20 students per year and expect completion of the PhD within 4 years. The multidisciplinary nature means students have a wide range of first degrees; thus, the first 6 to 12 months of the programme are generally front-loaded with technical training as well as soft skills courses to fast track the transition to independent research. In this paper we report on a week-long group role playing exercise, developed within the Advanced Metallic Systems Centre for Doctoral Training (AMSCDT), based on the manufacture of metal foams. This particular exercise, in addition to enhancing general engineering knowledge, aims to highlight to students the critical transferable skills such as time management, project planning, literature analysis, personal relationships building, etc, needed for successful completion of a large research project.

1. Advanced Metallic Systems Centre for Doctoral Training

The AMSCDT was established in 2009 with a £6.3M investment from the Engineering and Physical Sciences Research Council (EPSRC). The Centre is hosted jointly by the Universities of Sheffield and Manchester and builds on their international reputation in metallic materials science and engineering research.

Students come from a range of backgrounds in engineering and physical sciences and spend the first year studying core materials topics through taught courses and case studies. Students also visit a range of companies in relevant industries during their first year to provide 'real world' context for their studies and help with PhD project selection. PhD projects are chosen about half way through the first year. Projects are put forward by the CDT staff and students also have the opportunity to develop a project with the help of a supervisor. Research starts with a mini project and initial training in experimental skills leading into the PhD project carried out during years 2 to 4. The majority of projects are in collaboration with industry, providing students with opportunities for placements and a commercial perspective on their research.

Running parallel to the technical training and PhD project, students also undertake a Postgraduate Diploma in Personal and Professional Skills, which runs part-time through the 4 years of the programme. The first year consists of courses on personal effectiveness, research skills, and the exploration of emerging transformative technologies. Years 2 to 4 then concentrate on refining research skills, communicating science and engineering to a public audience and preparing students for industrial leadership. The emerging transformative technologies module is a hands-on laboratory based exercise and is the first opportunity the students have to apply their newly acquired technical knowledge in conjunction with teamwork, networking and communication skills in the context of a research problem. To date, the most successful of these tasks has been based on the emerging technology of metal foams. A description of metal foams and the task given to the students is given in the following two sections. This is then followed by an analysis of how the participating students felt the exercise influenced their thinking on research project preparation and implementation.

2. METAL FOAMS

2.1 Metal Foams

Metal foams are an example of an emerging technology with potentially transformative effects. Although some students may have heard of them, few are likely to be familiar with the detail of
their processing and properties, and so practical activities involving these materials are apt to capture the attention but it is unlikely that any of the students in the cohort will already have the technical skills or background to manufacture them in the laboratory.

2.2 Nature of Metal Foams
A metal foam (or sponge) is essentially any combination of metal and free space (e.g. a gas phase), although they normally would have an appearance similar to a sponge (an open cell foam, where the pores are interconnected, and connect to the outside environment) or a froth of bubbles (a closed cell foam, where the pores are isolated and separate). Many natural materials (such as bone and wood) have a structure that can be categorized in these ways, and so we may intuitively expect that there may be some advantages to making a foam out of a metallic material (Gibson and Ashby, 1999). The low density and large surface area of metal foams makes them suitable for applications such as lightweight and impact energy absorbing structures, heat exchangers and electrodes.

2.3 Manufacture of Metal Foams
Many methods have been suggested for the production of metal foams. Summaries of the major methods can be found in review articles such as Banhart (2001), but an overview of the main methods can be provided quite simply.

Classification of production route methods can be broken down to four methods: 1. pores created by gas, 2. pores generated by a porous template, 3. pores generated by a removable second phase, and 4. pores generated by assembling individual elements. Our method was based on pores created by gas. In these techniques gas is introduced into the metal, either by bubbling it through the melt, or by introducing chemicals that break down at high temperatures to produce gas. Examples of these compounds include TiH\textsubscript{2} (producing hydrogen) and CaCO\textsubscript{3} (producing carbon dioxide).

3. THE ACTIVITY

3.1 General Methods Used
The design of the practical activity was based around work reported in several recent research papers. These papers report low cost manufacturing routes for closed cell aluminium foams based around pores created by gas methods. We chose two approaches: the foaming agent method and combustion synthesis.

In the foaming agent method a gas release agent is combined with metal powder, compacted and later heated. These methods frequently use aluminium with TiH\textsubscript{2} or CaCO\textsubscript{3} (Gergely et al. (2003); Kanetake (2010)), but any material that breaks down to give a gas, like ZrH\textsubscript{2}, should also work.

Kanetake and co-workers (Kanetake (2010); Kobashi and Kanetake (2010)) have also suggested a related process to produce intermetallic foams of Al-Ni and Al-Ti. This involves a combination of elemental powders, but also boron carbide. When heat is applied to this combination of materials, there are a number of exothermic reactions, which not only form intermetallics, but release sufficient heat to propagate the reaction throughout the sample; this type of reaction is called a combustion synthesis reaction.
3.2 Procedure
Within 3 days of experimental time, the students were challenged to develop a process route to manufacture a metal foam using combinations of different metal powders and foaming agents. Students were given access to and basic training on a laboratory balance, beakers and spatulas, a machine-driven hydraulic press with 5 tonne capacity, a die set for compressing cylinders of 20 mm diameter, and an oxy-acetylene or propane torch. There were, however, no guidelines given on how the task should be undertaken. Only a rudimentary description of the foaming agent and combustion synthesis methods were given and there was no reference to published literature. This gave the groups complete freedom to plan, allocate resource, execute, analyse, and re-evaluate their strategy as well as prepare the final presentation without any outside influences. In addition, the students were not introduced to any of the technical staff, who could give access to training on other pieces of testing or analysis equipment, though there was no restriction placed about approaching them.

The groups were then able to mix the different constituents in any proportions that they wished, press them to form a compact (with the limitation placed that the final compact could be no more than 3 mm thick; this limit was imposed for safety), and then perform a heat treatment according to their own design using the torch. This last step was chosen for the heat treatment as it allowed the students to directly see what was happening to the sample (all samples reacted to the heat and foamed in under 1 minute), and respond with increased or decreased heating as required, in a way that would not have been possible with a furnace. After the samples were cooled, they were cut in half and examined so that the pore structure and porosity could be assessed.

The students continued with several iterations of this process and/or re-evaluation of their manufacturing route until they had created a foam product they were satisfied with. The project was then assessed, with each group asked to pitch their foam as a product for a particular application that they would select themselves.

4. ANALYSIS

4.1 General Observations
In all cases run so far (9 groups over 2 cohorts), every group has produced a metal foam within the 3 day limit. Two successful examples are shown in Figure 1. This success, in most part, can be attributed to a combination of enthusiasm for the task, competition between the groups, and a willingness to work very hard. In contrast, it cannot be attributed to advanced planning or a systematic approach to the task. Some general observations on how the project was initially undertaken include:

1. No group made a plan covering all 3 days.
2. Most groups tried to make foams within 1 hour of the start of the task.
3. No group undertook an initial literature survey to see what had already been done.
4. There was little evidence of resource allocation within the groups to undertake specific sub-tasks.
5. No evidence of design of experiments, all initial experiments were done using a random initial approach followed by small increments.
6. There was little discussion of what data needed to be recorded or what other analysis techniques could be used to identify the critical variables.
Figure 1 – (a) Comparison of volume of powder compact (left) and foamed product (right) and (b) cross-section of foam displaying significant porosity.

This would suggest that while the students had been exposed to many of these concepts in the classroom environment, little connection had been made to an actual task. However, as the task progressed a number of positives emerged. These included:

1. All groups spent significant time in the lab and performed more experiments than the suggested minimum.
2. All groups managed to find a saleable aspect to their product, whatever its quality.
3. Some groups displayed initiative in developing alternate manufacturing methodologies, using alternative analysis techniques, and contacting technical staff for assistance.
4. Some groups carried out literature searches in the later stages of the task.
5. Some groups carried out parallel experiments using ‘safe’ and ‘risky’ material combinations.
6. Most groups realised that better planning at the beginning would have allowed for greater levels of experimentation, possibly leading to a better outcome.

4.2 Student Experience

On completion of the project the students were asked to consider a number of factors relevant to research (outlined in Table 1) and indicate what level of priority (none, low, medium, high, very high) they attached to them during and after the task. They were also asked to choose their top 5 priorities during the task, and in the light of their experience, for their PhD project. In addition, students were asked to describe what they learnt from the task and what ideas they had taken from the task to use in their own research.

| Table 1 – Factors students were asked to consider in terms of relevance to research |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Setting of goals                              | Background research                           | Experimental planning                         |
| Recording of experimental details             | Resource allocation                           | Understanding experimental equipment           |
| Safety                                        | Seeking 3rd party assistance                  | Evaluation of results                         |
| Re-evaluation of goals                        | Internal communication                        | Competition                                   |
| Secrecy                                       | Reproducibility                               | Understanding customer needs                  |
| Research costs                                | Meeting the academic support                  | Academic approval of methodology              |
| Product identity                              | Preparation of final deliverable              | Successfully completing the task              |
Figure 2 shows the student priorities for factors relevant to research during the task and after the task. Note that in this figure only the factors that showed a big variation between during and after the task are displayed. Significant increases in priority level after the task are shown for background research, experimental planning, re-evaluation of goals, meeting the academic support, setting of goals, and seeking 3rd party assistance.

Figure 2 – Chart showing student perception of priority of the factors relevant to research during the task (darker shade) and after the task (lighter shade). Note, only factors that showed the largest variation between during and after the task are displayed.

Figure 3 shows the student response in defining their top 5 priorities in a research project before and after the task. A similar trend about prioritising setting of goals and doing background research is again observed.

In answer to the question “What did you think you learnt from the task?” the following student responses were given:

- It is important to understand the already existing literature base before diving into experimental resources. Logical methodology is a better approach than trying to do everything all at once. Do not be afraid to ask as many questions as possible.
- How to work well within a group, being positive with disappointing results and thus coming up with alternative scenarios to successfully attain results.
- To set out goals from the start and to organise the group/yourself to try to be most effective at meeting those goals quickly, and to share thoughts/ideas with the group at keys points to focus efforts towards the final product.
- The task taught me that I am able to use my knowledge and collaborate with others from other disciplines to successfully take on and complete a task of which none of us had
extensive prior knowledge about. It taught me that I enjoy being proactive about a task and that this is the best method to be successful.

- Experimental work takes much longer than anticipated and equipment will break.
- I found that doing things the simple way is probably the best. I spent a lot of time programming code in time which I didn't really have. I need to take a step back, understand the goals set and make sure these are achieved first before pushing things to the next level.

**Figure 3 – Chart showing student top 5 research priorities before and after the task.**

In response to the question “What ideas you would take from the task that you would use in your own research project?” the following student responses were given:

- Read first, act later. Do lots of reading! Make use of the knowledge that's hiding in the heads of academic staff. Careful planning and effective time management are important; you never know when you'll be waiting for equipment or are unable to do as planned - have back-up plans... also, back up your back-up plans! It's never too early to start writing a presentation.
- Background research is critical to the success of any research.
- Be methodical. Don't be afraid to ask for help. Be positive.
- To set out clear goals; to prioritise and to organise oneself in order to make progress; to evaluate progress at keys points.
- Technicians run the department! In order to be successful in a PhD project, befriending the technicians is a must. It also reinforced how important utilising time efficiently is when trying to complete a task. I will definitely carry this over.
- Keep very clear experimental records.

Interestingly all these topics were previously covered in classroom seminars on good practice in research, but it appears there is little cross-over into practice without actually doing a task. This could also suggest that the dry nature of seminars is not the most appropriate method for
maximising learning. It is important to note that although this activity was developed with a specific group of doctoral students in mind, the same skills are required in all PhD students, and they could all therefore benefit from this type of process at an early stage of the research program, or part of a Graduate School.

In order to get the most out this type of exercise it is important that students appreciate the behaviours that would have been helpful in completing the task. It is therefore suggested that a wrap-up session is undertaken as early as possible in order to help students reflect on their learning outcomes and how they would apply them to future research.

5. CONCLUSIONS

• We have successfully developed a research role playing exercise for early PhD researchers. Its success lies in being experimentally simple but with scope for higher levels of complexity, a variety of strategies can lead to a successful result, students can carry it out independently with little training or supervision, and it covers a relevant topic.

• Students made mistakes common to first year PhD students such as lack of planning, prioritisation, time management, and background research. As a result of this the students quickly identified these weaknesses and recognised the need to address these issues in their approach to their future PhD research project.

• Experiential learning opportunities such as that presented here are a valuable addition to the traditional seminar based teaching of good practice in research.

6. ACKNOWLEDGEMENTS

The authors wish to thank the 2010 and 2011 AMSCDT cohorts for their participation and contributions and thus making the transformative technologies module a success. The financial support of the EPSRC is also gratefully acknowledged.

7. REFERENCES

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