Broadening technical understanding and enhancing non-technical skills in doctoral students

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INTRODUCTION: PH.D. STUDIES IN GERMANY

The traditional way to obtain a doctoral degree in Germany is mostly a training-on-the-job kind of education, following a typical master-apprentice model. In 1985, a more structured form of doctoral studies was promoted by the Fritz-Thyssen-Stiftung at the University of Cologne [1]. Several different types of structured Ph.D. programmes have since been designed after the Anglo-American example, typically aiming for a correction of assumed weaknesses in the traditional approach [2]. Specific goals were: higher-quality dissertations, shorter graduation times, improved mentoring, better integration in interdisciplinary research environments and in the respective scientific communities, explicit training in non-technical skills, promoting independence and individual responsibility, stronger international orientation, and attention to competences that are helpful for obtaining employment within and outside of academia [3, 4]. Despite the presumed benefits of structured programmes,

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up to now the majority of the successfully completed dissertations are carried out in the traditional German model [5, 6].

Ph.D. programmes financed by the DFG

Since 1990, the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) supports structured Ph.D. programmes [4] called *Graduiertenkollegs* (GRKs). These programmes serve as examples for other structured Ph.D. programmes. According to the DFG, the overall aims of the GRKs are excellence, innovation and internationality in academia, plus the promotion of young researchers [4]. In addition to the stand-alone GRKs, addressing Ph.D. students in a specific research area [7], GRKs are also integrated in Collaborative Research Centres (Sonderforschungs-bereiche, SFBs). The DFG sponsors Collaborative Research Centres to foster scientifically challenging and complex interdisciplinary research endeavours in academia, designed for long-term research. The above-mentioned aims of stand-alone GRKs also apply to any GRK integrated in an SFB [8], generally referred to as a *Modul Graduiertenkolleg* (MGK).

Absent from these aims is a focus on the development of expertise in teaching. This is particularly notable since (a) teaching will be a major aspect of the daily work for at least those Ph.D. graduates who later obtain faculty positions, and (b) it is an opportunity of the structured programmes to provide experiences that complement those of the traditional research trajectory. Since doctoral students within structured programmes are usually exempt from teaching responsibilities – which on the other hand are almost standard for those candidates who obtain their degrees while being employed as academic staff members – the need for some basic training of teaching skills is even more apparent.

1 THE *GRADUIERTENKOLLEG* IN THE *SFB 986*

The “SFB 986: Tailor-Made Multi-Scale Materials Systems” aims to develop experimental methods for the production and characterization of multi-scale structured materials which have tailor-made mechanical, electrical and photonic characteristics. In close collaboration, 20 principal investigators at Hamburg University of Technology, the University of Hamburg and the Helmholtz-Zentrum Geesthacht work on the development of new types of material in an interdisciplinary consortium. The doctoral students in the integrated doctoral programme (MGK) come from a broad range of scientific fields like mineralogy, physics, chemistry, mechanical and electrical engineering, and material science. Besides these Ph.D. students, the programme is open to master students and postdoctoral researchers working in the SFB. Due to the internationality of the group, English is used for most communication in the SFB and, consequently, in the MGK.

1.1 Goals of the MGK

Besides the general aims of all GRKs (as mentioned above), our specific goals stem from the widely differing backgrounds of the members. For the long-term success of the SFB, the cooperation between the individual projects is essential. Therefore, all members of the SFB should be familiar with the basics of the other participating projects. While this may be taken for granted for the project leaders, more junior scientists will probably need help in developing this knowledge. This concern is corroborated by our observation that after specialist lectures, mostly senior scientists

are actively involved in the discussions while Ph.D. students are mostly listening. Thus, a better integration of the young scientists in the scientific community of the SFB requires that the MGK helps them develop a broader understanding of the various projects. Besides benefitting the SFB as a whole, such measures should also help the individual doctoral students in their Ph.D. research and foster their later careers within and outside the academic field. In addition to these goals, as argued above, we believe that the MGK should provide an opportunity for the members to gain experience in teaching and obtain feedback about it.

In summary, the goals for our MGK have been stated as follows: (1) to strengthen broad knowledge of technical basics, (2) to support networking and cooperation among members of different projects, (3) to promote autonomy in their research, (4) to convey basic knowledge and skills about academic teaching, and (5) to provide other non-technical competences. In the following subsections (1.2 through 1.4), we will explain how we plan to achieve these goals. We will refer to the individual goals by the above numbering.

1.2 Tutorials

Beside the usual aims of structured doctoral programmes, we identified two special requirements to be addressed in our MGK. On the one hand, a profound exchange between members from different projects (goal 2) requires an understanding of scientific basics relevant for the respective topics (goal 1). The broad range of disciplines involved in the SFB then requires that the MGK members be explicitly trained about the basics of the different fields in the MGK. For this purpose, we aimed for an environment involving an active-learning approach. On the other hand, we wanted to emphasise teaching abilities (goal 4) as part of the supplementary qualifications of the doctoral candidates. We were encouraged in our approach by recent results indicating that teaching opportunities using active methods increase the quality of research performed by doctoral candidates [9].

Based on the above considerations, we decided to complement monthly research presentations by the doctoral candidates with *Tutorial* worksheets focusing on a basic understanding of the respective research field. The design of the worksheets is motivated by materials that are commonly used in physics teaching in the USA and found effective [10]. The aim of the inclusion of such Tutorials in our programme is two-fold: For the participants from other fields, the materials are intended to provide the necessary background knowledge to appreciate the subsequent research presentation and to connect it to their own work. This broad knowledge is relevant for later employment in science as well as in industry. For the participant presenting her or his research, the experience of designing the worksheet is intended to deepen their own understanding of the field and to gain some experience in facilitating a constructivist teaching environment, which is helpful for (intended) academic careers.

The preparation of the Tutorial worksheets requires technical expertise but also pedagogical content knowledge. The MGK staff therefore closely supports the candidates in designing the worksheets, choosing content and style for the research presentation, and balancing the link between both Tutorial and seminar talk.

1.3 Seminar

Cooperation between scientists across different projects within the SFB (goal 2) requires that the doctoral students gain an overview of the entire field of the SFB in order to see their work in context. This overview is provided (for the members of the audience) by project presentations in the seminar.

For those presenting, the seminar is intended to strengthen not only their presentation skills but also their ability to identify those details of their topic that are essential for the audience to understand the main goals of the project. The individuals presenting are thereby expected to learn to identify connections between their own project and those of their peers, which we consider an important aspect of autonomy in their research (goal 3).

Working with the Tutorial worksheets prepares the group for the technical understanding required to follow the seminar talk in which one candidate presents his or her research project. The transfer from the Tutorials to the presentation is supported by interactive elements in the talks. Several small questions posed during the talks call for active thinking, as suggested by the method of *Peer Instruction* [11].

Our first experiences revealed that the understanding of the talk does not only depend on the background knowledge, but also on the perceived connection between Tutorial and talk.

1.4 Kick-off and Summer Schools

The MGK was started with a kick-off retreat in an off-campus conference centre. The main goal was to support networking among the participants and provide an overview of the MGK structure (goal 2). The programme covered workshops on scientific integrity and self-organisation (goal 5) and an introduction to the Tutorial worksheets. For a technical introduction to the SFB 986, the project leaders presented their sub-projects in three rounds of parallel sessions. In each session, the presentation was kept short, leaving ample time for discussions.

Additional workshops and scientific input are offered in yearly summer schools, alternately on non-technical (goal 5) and technical subjects. Non-technical subjects include job application training, scientific writing, and project management (goal 3). For the technical programme, international experts will be invited for presentations and discussions, and MGK members will present their work.

2 EVALUATION

The state of knowledge about the effectiveness of structured doctoral programmes is poor. With implementing the Tutorial worksheets, we added an element to our MGK that is worth being evaluated. This involves both the comparison between our MGK and other programmes not offering Tutorials, as well as examining the effectiveness of the primary goal for the Tutorials to provide the group with an understanding of the basic concepts needed to follow the subsequent seminar talk.

2.1 Evaluating GRKs

Up to now, there is no convincing empirical evidence for the advantages of structured Ph.D. programmes over the traditional German model [5, 12] and integrated Ph.D. programmes in SFBs [8]. For evaluating such programmes, the most challenging problem is that in Germany, only successfully terminated doctoral degrees are registered and thus can be considered in existing studies, whereas initiated but unfinished Ph.D. projects are not included [2, 13]. Furthermore, a comparison of the GRKs with other structured programmes funded by the DFG or other funding agencies, or with other structural developments is hardly possible because there are just isolated comparative studies [4]. In a comparison of Ph.D. students in GRKs and Ph.D. students doing a traditional Ph.D., it became evident that Ph.D. students in GRKs complete their Ph.D. degrees faster than Ph.D. students without structured Ph.D. programmes. This is especially the case in the life sciences and in engineering [12]. Additionally, Ph.D. students in structured programmes attended more conferences and received a better support in publishing their work. Nevertheless, the results of such evaluations should be considered with caution because it has been shown that generally more successful individuals are more likely to take part in such surveys [14]. Another report on the quantitative development in GRKs struggled with the problem that only active members of the GRK in the reporting period were included in the survey. Persons, who completed their Ph.D. mainly in the GRK but terminated shortly after the ending of the membership in the GRK, were not recruited for the survey, so the number of completed degrees was around 10% per year, whereas in a structured 3-year programme it may be estimated to be around 30% [4]. Additionally, a fundamental problem in such evaluations is that significant indicators for the development and effects of GRKs only make sense in relation to their scientific environment [4].

2.2 Evaluation of the MGK in SFB 986

The effectiveness of our concept should be tested against other GRKs or MGKs not offering Tutorials. Moreover, we hope to be able to extend this survey to doctoral students who are not members of structured Ph.D. programmes. Due to the discipline-specific conditions and habits, comparisons may only be done within a scientific field [4]. We will therefore restrict this survey to candidates in engineering at our institution.

We are currently in the process of developing an evaluation concept for our MGK. Elements to be used in this process include monthly feedback after the Tutorials and the seminar, as well as a more substantial survey administered to all participants.

2.3 Evaluation of Tutorial worksheets in the MGK meetings

The concept of integrating Tutorial worksheets in the MGK activities is a novel approach in German structured doctoral programmes. The prospected gain in understanding basic concepts has not been investigated and may be hindered by various factors, e. g. communication habits in the different research fields. It is therefore required to continuously monitor the success of using the worksheets in the group of MGK participants. We consider the feedback that the participants give in qualitative feedback queries asking to state (1) what has become clear, (2) what is not yet clear, and (3) what other comments arise.

Systematic results have not yet been derived from the first few sessions, but our first experiences concerning the interdependence of worksheets and seminar talk have already led to modifications in the schedule for the meetings, strengthening the mutual connections between worksheets and project talks.

3 DISCUSSION

Presenting their projects to the other MGK members requires the candidates to first explain the relevant fundamental technical concepts. For the untrained speaker, it is difficult to identify potential misconceptions that may arise from inappropriate explanations or—even more problematic—references to concepts that are believed to be well known from prior education but have never been properly understood. The purpose of the tutorial worksheets in their usual applications is to reveal and resolve such misconceptions.

In the context of the MGK, the academic level of the discourse is far beyond the usual scope of Tutorial worksheets. Still, we consider the worksheets to be an appropriate tool for gaining insight in the conceptual basics. In previous sessions, we observed that even with well-prepared worksheets and well-structured talks, participants from different research areas were not able to apply the newly learnt basics to understanding the main goals of the presented project. Based on the qualitative feedback, we traced this issue to missing connecting links between both the worksheets and the talk. We therefore modified the agenda for the subsequent meetings: The speaker first introduced the topic and key problems of the project before the worksheet was administered. The main aspects from the worksheet were summarised and then referred to in the subsequent talk. The feedback from this meeting suggests that the rearrangement of the schedule was successful.

The benefit from the Tutorials may actually not only apply to the group, but also to the candidate preparing Tutorial and talk. Indeed, we observed that the candidates improved their ability to clearly explain fundamental principles of their field over the weeks of preparing their talk and worksheet (comparing their first presentation of concepts in front of the MGK committee with their seminar talk). Nevertheless, this observation may be difficult to quantify.

The design and use of special teaching material has not been done in structured doctoral programmes in Germany. Also in the USA, most doctoral programmes do not provide significant training in teaching, even though the need to do so has been argued previously. The reasons may be that “faculty members fail to recognize the need for improvement in their own teaching and hence think that doctoral students should only focus on learning research methods or discipline knowledge” [15].

According to the DFG [8], positive effects of MGKs in general have not yet been validated. We hope that our evaluation can make a substantial contribution in this respect

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