

# PhD Education Through Apprenticeship

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## Abstract

*We describe and analyze the PhD education in the visualization group at the Vienna University of Technology and set the education in a larger perspective. Four central mechanisms drive the PhD education in Vienna. They are: to require an article-based PhD; to give the student freedom to choose research direction; to let students work in shared offices towards joint deadlines; and to involve students in reviewing articles. This paper describes these mechanisms in detail and illustrates their effect.*

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## 1. Introduction

This article describes the philosophy behind the PhD education in the visualization group at the Vienna University of Technology. The article can also be interesting for PhD students in motivating their work and setting the education in a larger perspective. While our specific field is visualization, we believe we describe a generic procedure. In general, the goal of a PhD education from a university's point of view is to teach students how to perform independent research and expand on current knowledge. In contrast, the education for Masters and lower degrees typically is to teach students current knowledge. For a prospective student, the path to, and requirements for a PhD can be vague and blurred. This might frustrate and discourage the student at the beginning. For a supervisor, it might be difficult to know how to guide students towards becoming an independent researcher, and also to evaluate if one has succeeded.

To improve the success rate and clarity of the PhD education, the visualization group in Vienna gives new PhD students introductory PhD material [Grö08, Grö10a, Vio07, Jon04, Mik11, Ead11, Grö10b, Lar10]. In addition, the group has a clear evaluation criterion for students to qualify for the PhD degree and, partly as a consequence, a strategy for reaching this. This criterion is to publish three or four articles as lead author, in about six predefined publication forums. These forums have to be journals or conferences of international renown. It is sufficient to publish fewer articles, provided these appear in the most highly acclaimed forums.

The justification for this criterion is that, during a three-year period, one publication might entail a certain de-

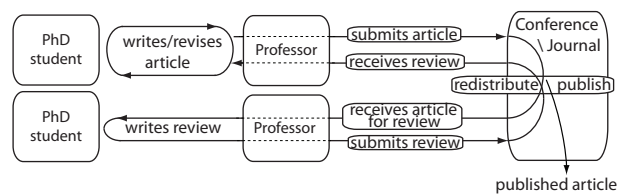
gree of good fortune; two publications might indicate talent; whereas three or more publications would more likely demonstrate the ability of the candidate to continue to produce research of international quality after completion of his/her PhD study. This publication requirement provides the PhD candidate with a concrete goal. In addition, a set of mechanisms are introduced in the education to facilitate meeting the PhD requirement. Four of the most central mechanisms are described in the following chapters. In short, the mechanisms are: to require an article-based PhD; to give the student freedom to choose the research direction; to let students work in shared offices to meet joint deadlines; and to involve students in reviewing articles.

## 2. Article-based PhD

Mechanism 1 is for the student to read relevant articles and then write one with a similar structure, tailored for a specific publication forum. This mechanism is induced by the publication criterion. The PhD requirement automatically turns the student's attention to publications in the selected forums. Out of necessity and curiosity, the student selects and reads articles from these forums to better understand the topics, the layout and difficulty level of the papers that have been accepted for publication. Having a limited selection of publication forums with strict annual submission deadlines makes the goal more concrete. This is somewhat in contrast to PhD courses where the focus is on writing an article with no specific forum or deadline in mind, and subsequently finding a suitable venue on completion of the article. Another common, but even less concrete goal, is the

manuscript-based PhD where the student delivers one large unpublished and unrefereed manuscript to a PhD committee. A large unrefereed document makes the committee evaluation more difficult to perform. Furthermore, the outcome of the evaluation will be less certain since the thesis has not been subjected to international quality assurances. Such an education is less feedback-oriented and the student will not get the training that comes from periodic reviews. However, for research directions which are new or otherwise have no well-established evaluation forums, this can be an appropriate strategy. This also applies to PhDs of a qualitative nature, such as in social or art sciences, in which the thesis must be evaluated as a whole. In any case we find it helpful that article publishing provides a fine-grained progress bar towards completion of the PhD thesis.

Publishing work as early as possible is advantageous in competitive fields. This reduces the risk of having the originality of the student's article and work nullified when others publish the same or similar ideas first. Should this happen, the student might believe that the months of work invested in creating and developing the ideas are lost in an instant. It is an expensive but also valuable lesson to realize how tough the competition is, and that unrelated research groups can independently come up with very similar ideas. Continual publications also provide timely and effectual indicators to the supervisor about the student's research capabilities and how well the student integrates into the research group. During the writing of an article, the supervisor gives detailed feedback on the text, which the student then addresses. After a few internal review cycles, the article is submitted. Due to the low acceptance rates of competitive forums, papers are rejected more often than not. When a paper is rejected, the student goes through the review feedback together with his/her supervisor to discuss how to address the comments and which forum the article should be sent to in a subsequent attempt. See Figure 1 for an illustration of this publishing cycle. The path from initial idea to publication has distinct phases of how the student works, of supervision and of the student's state of mind. First the student is in a phase where he/she is developing an idea within the scope of the PhD topic. The student gets inspiration and knowledge from articles, the work of co-PhD students and discussions with the supervisor. The student might in this exploratory stage feel uncertain and unfocused due to the lack of a clear goal. Another phase is entered when an idea has solidified. Then the student becomes more independent and focused and starts with programming and result creation. In this phase, the supervisor is mostly involved for evaluating results. Compared to programming and result creation, the writing process is often considered painful and slow and is therefore easily postponed. Procrastination is effectively avoided due to strict external deadlines. The student must write and create a full description of her/his solution within a predefined, often short period of time. To avoid getting trapped in low-level writing details, a top-down approach is followed. The

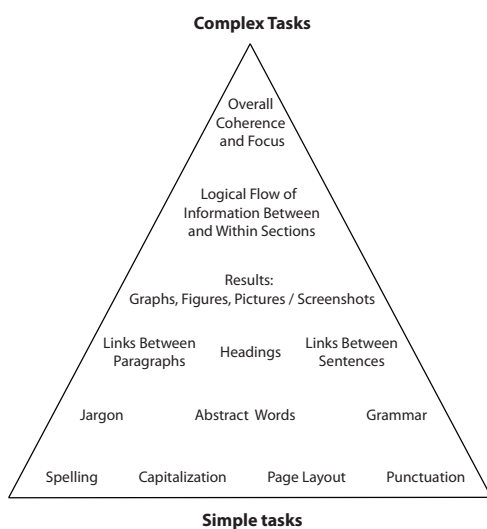


**Figure 1:** The actors and processes in article writing. Most of the actions described to the right of the professor is performed by the student. The dashed lines through the professor is illustrating that he/she is the outward representative. The figure also shows how paper submission and review assignment in one research unit is connected with reviewing in another institute through journal/conference redistribution. The feedback cycle between student and professor and between student/professor and the research community work as a two-level quality control.

first version of the paper gives a coarse overview by only containing chapters, headings and possibly results in form of figures (see Figure 2). The high-level structure of the document is expanded to become an article and is given to the supervisor for a major review. Here the supervisor comments on the text, suggests rewritings, marks out parts that are not clear and poses questions without criticizing. The student then addresses the feedback and clarifies with the supervisor remaining open issues. After the supervisor's feedback has been addressed, the article is given back to him/her for another, typically minor review. When these comments have been addressed and the student has consent from the supervisor, the article is submitted for external review. This two-step internal-reviewing procedure shall ensure that a coherent and polished article is sent out to the reviewers.

After the article has been submitted, the student is typically exhausted from working towards the deadline. A period of rest and low-intensity work follows. As the notification time approaches, tension rises. At notification, the student enters a state of mind of strong happiness at acceptance or one of demotivation at rejection. At this stage it is important that the supervisor is supportive in case of rejections. After rejections, the student might enter an emotionally depressed period and even consider giving up the PhD. Students that have experienced acceptances earlier are often more confident in their abilities and take a rejection easier.

For supervisors, mechanism 1 reduces the need to do summative evaluations, i.e., evaluations of the quality of the student's submitted work. The summative evaluations, which can be criticizing and demotivating, are in the case of papers provided by anonymous reviewers and, for the final PhD thesis, by the external PhD committee. The supervisor will instead give neutral formative feedback, i.e., providing advice about what the student should do to efficiently reach his/her goal. On formative and summative assessments see



**Figure 2:** Writing an article in a top-down approach by starting with tasks at the top and then working downwards. Doing this from bottom to top is not uncommon but can be considered non-optimal. Figure adapted from Brown [Bro94]

for example the work by Scriven [Scr96, Scr91]. Formative guidance to help the student reach his/her goals is provided by the supervisor by supporting the student in addressing the external summative feedback. When the stipulated deadline for completion and funding of a PhD approaches, the student may attempt to convince the supervisor to approve the submission of the PhD for final evaluation. However, the publication requirements are clear. Therefore the supervisor does not need to enter uncomfortable summative discussions regarding whether the PhD work is adequately mature to defend. Relieving the supervisor from the role of providing summative critique can facilitate the creation of a productive working relationship with the student. Critique is provided by external sources whereas the supervisor and the student can be considered as a collaborative team addressing external comments with the goal of publishing papers together.

Due to this collaboration, the supervisor is typically coauthor of the paper. The student is first author, the supervisor is last author, and other contributing authors are listed in the order of their contributions. Having several collaborators to work on a paper can teach the student the importance of defining clear subtasks and delegating them. The student can realize the potential that lies in cooperation for getting large pieces of work done but might also learn the difficulties and administrative overhead that follows from it. In general this develops a student's skills in leadership and management. It is a difficult topic to define the degree of contribution required for being coauthor. In some institutions or areas it may be common to include group leaders or depart-

ment heads irrespective of their actual contribution to the paper. Using honorary co-authorship by adding well-known names for increasing the probability of paper acceptance also happens. Several guidelines for co-authorship have been made. The established ICMJE guidelines [ICM10], made for the biomedicine field, do not allow these types of co-authorships. Co-authors should be able to understand and defend the contents of papers they are on. This received focus in the Sudbø deceit, where papers were published based on material fabricated by the main author. Subsequently all co-authors were investigated for counterfeit [Ger06].

### 3. Freedom To Define Own Research Topics

Mechanism 2 is to let the student find a topic of interest within the scope of the PhD project description. The degree of freedom should go as far as possible yet be within the constraints defined by the funding party. However, sometimes the exact limits are not precisely defined and therefore, to a certain degree, up to interpretation. The supervisor does not strictly determine what needs to be done, but gives advice and allows the student the freedom to make his/her own choices. When the student is in doubt about which path to take, he/she presents possible options to the supervisor, who in turn offers opinions on each option and possibly introduces new ones. It is then the responsibility of the student, not the supervisor, to make a choice based on this new information. This causes the student to take high-level decisions and become an independent planner, whereby the student takes ownership of the idea and responsibility for decisions. With no prior experience, getting published internationally typically requires more working hours than available in a normal work week. To work more than the norm is less of a burden when one has ownership of and responsibility for the project idea. Knowing that the research idea is one's own, creates an inner drive which can be less pronounced when being closely guided about what to do. This is supported in the work of Holburn and Bligh [HB97], who showed that students become more motivated when they are allowed to identify their own projects. Also Alon [Alo09] discusses the importance of considering the students' research interests and how to create a nurturing environment to maximize the potential of students.

A very different supervision strategy can be seen in projects with clear low-level goals where the supervisor might also have specific plans about how to reach these goals. Here the student is instructed in the research. The student will learn how to perform research, but might learn to a lesser degree to take high-level decisions, such as choosing what methodology to apply during the research work. It is also possible that project ownership is more skewed towards the supervisor than the student. However, such a supervision strategy can have positive effects as well. It can lead to fewer mistakes and research dead-ends due to experienced and detailed leadership and thus to a higher produc-

tion of publications. This can be particularly advantageous for students who do not work well independently but prefer a more closely guided working style. Such supervision is also beneficial for students who plan to enter similar work environments found in certain industries. However, in a research group, low-level supervision of PhDs and post-docs can suppress creative ideas that could result in opening new fruitful research fields. A research group under a strict leader can stagnate over time as it mostly executes research formulated by the leader. The group can become overly dependent on the leader and not be prepared to perform its own independent research in case the leader stops producing ideas or leaves the group.

Supervision with the goal to produce publications in a short time frame using closely guided management requires a different strategy than supervision where the goal is to produce independent researchers. At the extreme ends of a scale one may have the following types of supervisors:

- supervisors who advance their own career by creating research, using researchers primarily as resources,
- supervisors who educate researchers that become enabled to independently create their own research.

Appel and Bergenheim [AB05]:p25 show that there is a great variation between supervisors as to whether they consider the main result of a PhD education the produced research work or the involved learning process. Mechanism 2 promotes the latter.

#### 4. Positive Group Dynamics Through Joint Deadlines And Shared Offices

Mechanism 3 ensures that the PhD candidate is part of a research group where students work in shared offices to meet joint deadlines for publications. Positioning students close to each other, where there are few barriers to initiate contact, fosters cooperation and information exchange. It enables peer discussions with people working on related problems. New students also learn how to use the lab tools, article-writing tools and other subtle tricks of the trade from more senior PhD students. Programming advice and knowledge is exchanged between students. Such knowledge is quickly changing, therefore the supervisor will typically be less competent on it than the students. Out of curiosity, students might also read through and give feedback on other students' paper drafts. This mechanism relieves the supervisor somewhat from such basic tasks. Working in shared offices creates a social setting and stimulates the exchange of ideas. When several students work to meet the same deadlines, a group spirit arises making them work harder and longer. Furthermore, social mingling and relaxing is incorporated in an shared office work-environment. Research shows that working in teams has positive effects [HL06]:p34, that students in work groups are more satisfied with their supervisors [LM85], and that research cooperation has a positive

effect on welfare and on results [Sme02]. However, there is a fine balance between comfortable shared offices and large, overcrowded and noisy office landscapes.

When the group submits articles to the same forum at the same time, they also receive the review results more or less simultaneously. To communicate the results, the reviews are emailed to the rest of the group. This has an educational value for students that have read few or no reviews before. The students themselves then arrange so called acceptance or rejection parties or a mix thereof, depending on the results. This effort gives collective credit to success and also collective comfort for failure. Reviews might be discussed; fellow rejects share disappointments and are motivated by the accepts. All students go through rejections and acceptances in their PhD career. Social get-togethers make them realize this and feel less isolated, both in their failures and in their successes.

This fusion of personal goals, on the one hand, and identification with the group as a whole creates a positive environment which seeks to maintain a healthy balance between collaboration and competition. Weaker students feel encouraged to excel while stronger members of the group are motivated to help their peers. Positive identification with an entity, may it be the department, university, or even country is in general considered to be a contributing factor to achieving successful group dynamics. However, it can lead to adverse effects when individual members feel unable to influence the success or failure of the group through their personal actions [For06]. Hence, the research group may be a particularly effective target unit for efforts which bring a sense of identity, such as common social events or the establishment of certain rituals.

#### 5. Performing Article Reviewing

Mechanism 4 is that the student participates in the reviewing process of conferences and journals by reviewing articles submitted by others (see Figure 1). In many fields, senior researchers are asked by journal editors to review articles. To ease the burden of the senior researchers and to educate the PhD students, the students are encouraged to perform such reviews themselves. The PhD students are taught to perform a review by writing their first one and then analyzing it together with the supervisor. Common reviewing mistakes could be a lack of good argumentation for the critique or too negative critique. Being too critical is one common mistake whereas being too uncritical when suggesting references to own articles is another one. References should be suggested if they are key, not if they are only somewhat related. Weakly relevant references can reduce the paper quality and invalidate the double blind procedure by revealing the reviewer.

In order for students to evaluate the quality of an article, they must first understand the specific treated topic. They read papers that are referenced in the article and independently find other related work. This teaches students to look



up relevant articles. The students also expand their knowledge horizons on topics possibly not directly related to their thesis problem, or topics which they might not have taken time to investigate otherwise. Conducting reviews also gives access to research before it is published and thus gives information on the latest research developments. This, however, must not be exploited [Sig10]. A paper undergoing peer review is typically sent to several reviewers. After the reviews have been submitted, a decision is made. At the end, the reviewers are often given a review summary containing the overall decision and all the regular reviews. Reading the summary review can be informative as it shows whether your opinion accords with those of the other reviewers. Studying the sections where all the other reviewers have similar opinions that differ from yours and sections with diverging opinions can improve your own paper-writing skills in terms of novelty, exposition and clarity required for a publication. In review procedures involving several review cycles, the authors can improve their article based on the received reviews and re-submit it. Such a review procedure can be a source of inspiration to PhD students. The student is then part of a dialog with the paper writers and experiences how other researchers strive to address identified weaknesses. Getting papers published increases the visibility in the scientific community and a student might be asked directly by the paper chairs or journal editors to perform reviews. This typically happens if a submitted article builds on, or refers to a publication of the student. It is motivating for the student to realize that his/her work is being recognized and built upon in international research. Taking part in reviewing has thus many positive effects:

- Getting early access to the latest research.
- Getting inspiration and ideas from fields one otherwise would not investigate.
- Learning to read articles from a different point of view. When reading published articles, one takes novelty and accuracy for granted; when reading articles under review one cannot do this.
- Learning to write reviews.
- Becoming part of the international research environment.
- Paper writing skills are improved by becoming aware of common pitfalls and mistakes.

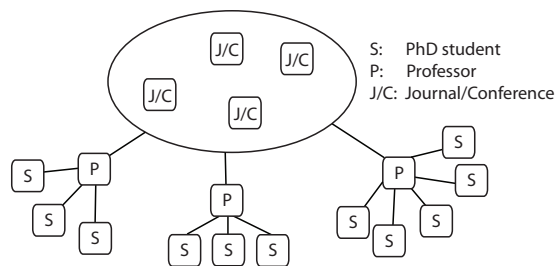
## 6. A Unified Organizational Identity

The four mechanisms from the previous sections for helping a student to gain a PhD and to learn how to become a researcher play a dual role. They also reduce the burden of the supervisor in his/her daily work. The student is not only explicitly being taught how to conduct research but also implicitly, e.g., by writing papers and performing reviews. The process also socializes the student into the worldwide research community as illustrated in Figure 3. In addition to these main mechanisms, the students help out with different types of organizational tasks, from designing the yearly

Christmas cards to being part of the evaluation committee when hiring new PhD students. This makes the PhD student feel as part of a group where the supervisor, post-docs and PhD students are peers. The mechanism of different types of group meetings strengthens group identity in addition to their main purpose as a forum for discussion. Once a week, a joint meeting with all PhD students is held for about one-hour and a half. Every second week the meeting is about scientific topics, every other week organizational topics are treated. The organizational meeting discusses topics like hardware needs, traveling and teaching duties. For this meeting administrative personell is present. Students are kept up-to-date on on faculty-related issues, and a democratic process for strategic decisions is adopted whenever possible. Such a behind-the-scenes view helps PhD students to better understand university politics and can establish active participation in non-research related matters. By encouraging this type of involvement, students can acquire the necessary knowledge and skills required for a future academic career. The exchange of information is open and transparent based on the premise that students are more motivated when they fully understand the inner workings of the research group. In the scientific meeting, students discuss research ideas and problems and perform literature reviews by presenting recent publications. The meeting starts by reciting the mission statement ‘Visible Facimus Quod Ceteri Non Possunt’ (We make visible what others cannot) which also helps to create a common identity. Also, once a year, a three-day so called ‘closed meeting’ is held at different locations away from, but in the vicinity of Vienna. This meeting combines organizational and scientific meetings with socializing and excursions. Strategic planning for the upcoming year is performed and the personal development of each group member is discussed in a casual manner. Here, alumni are also welcome for staying in touch and for joining scientific discussions. On a more daily basis, the group has joint lunches. Frequently, visits to bars or restaurants take place giving an informal atmosphere for students to interact with prominent visitors.

The status of a PhD student within a research group varies widely between educational systems. In many universities, for instance, the status of a PhD student is not fundamentally different from an undergraduate. They are primarily students, i.e., customers of the university even though their costs may be offset by receiving funding from their advisors’ research grants. In particular, this is true for many North American universities. In some European countries, including Austria, on the other hand, PhD students are full-time employees. They report to their advisor as their direct supervisor. The research group, in fact, exhibits many characteristics of a small startup company including a flat hierarchy and organizational flexibility. The vis-group in Vienna has their own technicians in close proximity who can quickly assist. This important facility is not hidden for example in a ticket-based help desk system where problems must be issued on the web. A secretariat is available in a similar fashion.

The ongoing trend of centralizing previously distributed resources such as administrative and technical facilities may have a negative influence on the fine-tuning of such a functional entity. Procedures well-adapted to the specific professional and personal preferences of the involved actors can be hampered and the intended gains in efficiency may not be achieved. The managerial experience of group leaders is neglected in favor of a top-down organization scheme which only superficially eliminates redundancies. As PhD students typically form one of the lower levels of such a hierarchy, they commonly suffer most from complex communication pathways and bureaucracy which the advisor, as their direct supervisor, is now unable to influence.



**Figure 3:** The worldwide research community with actors. Lines denote the flow of articles and reviews and show how each professor makes use of several PhD students as support in doing research.

## 7. Conclusions

The student-supervisor relationship at the PhD level in the vis-group at the Vienna University of Technology matches the so-called 'Master-Apprentice' relationship ([NK99, LW96], [HL06]:p56) in which the student is trained as an apprentice in a handiwork. The student is introduced to a workplace of a craft (the craft of doing research and writing articles). The student learns this craft by working side-by-side (in shared offices) with more experienced craftsmen (senior PhD students) where the student observes and mimics while getting advice from the supervisor (the Master) and feedback (reviews) from the customers.

Scientific productivity determined primarily by published articles and granted research proposals is commonly used to measure the success of a research group. Other factors such as the personal growth and satisfaction of its members are equally important, yet much more difficult to quantify. Apprenticeship, as described in this paper, offers a model in which these factors do not necessarily contradict each other.

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