Teaching Nanotechnology through Research Proposals

Jurica Bauer\*

\*Inholland University of Applied Sciences, De Boelelaan 1109, Amsterdam 1081 HV, Amsterdam, The Netherlands

# Supporting Information

Instructor’s Notes

**Table of Contents**

Lectures 3

Student Presentations Sessions 6

Written Research Proposal 10

Anecdotal Observations of Student Development and Growth 13

Miscellaneous 14

Lectures

* The lectures are best kept interactive. This can be best done by asking open questions about the topics discussed and stimulating critical thinking. Ask questions that you would like to see addressed in their own research proposals. This is a great opportunity to convey your expectations about the proposal and for the students to practice. Examples of questions you can ask are:
* What do you think is novel and innovative in this approach?
* Which limitations to this approach do you see?
* How would you overcome this limitation? Can you suggest another design of… ?
* To which extent would it be easy to scale this up to industrial proportions?
* Which potential applications can you imagine for this phenomenon?
* Where do you see this field in the next 5 to 10 years? Which problems do you expect to be solved and which new challenges do you foresee?
* …
* In the first lecture you should take some time to introduce the concept of a research proposal. You can initiate a discussion with the students by asking them what they think a research proposal is or should be and why it is relevant. From there you can ask them which aspects they think it should convey. You should try to guide the students to the conclusion that a research proposal is supposed to convince the audience/readership, in their case peers and the lecturer, that their proposed research is a good idea. Their proposal should convey what they would like to research and how, and why it is worth researching in the first place. To this you can link the importance of a clear justification and the originality of the proposed research. A few ideas on what to include in this discussion may be found here: <https://gradcoach.com/what-is-a-research-proposal-dissertation-thesis/>

The details and specifics of their own proposal can be introduced using the example from the lectures (see next point).

* To further practice coming up with an original research proposal, take 10-15 minutes of your lecture (especially in the first two weeks) to have students discuss and come up with a new design of the presented system from the literature (for example: a new nanocar or a new way of producing graphene, etc). This will give students an idea of what is expected of them in their research proposal so it’s very important to do this in the first few weeks of the course. This exercise is not about solving a real-life problem but about addressing it, coming up with ideas and critically discussing them. This is a great opportunity to steer the students’ thinking in the right direction and to make sure they start asking the right questions. At the beginning of the course students need this exercise as they are not sure how they should analyze and tackle a problem. If someone suggests something unrealistic, we discuss with the group why it would not work. If they suggest something promising, we go on to discuss why it is a good option and then attempt to go into more depth to see how one could work out the proposal further. No real-life problems are solved in these short discussion but they do give the students an idea of what is expected of them in the research proposal. Students are also enthusiastic to be thinking about these real-life challenges that top researchers are trying to solve as well. The first time you practice this with the students, you may want to hand out the assessment forms for the written research proposal and the presentation. This way the students immediately see how their proposals will be assessed, which elements they should definitely include in their proposal (and with how much depth) and what they should focus on in their written document and presentation. Go through the assessment forms point by point and make clear what you expect. There are no special materials (like a handbook or slides) or lectures to introduce the concept of a research proposal as this works well during regular interactive lectures and with the help of the assessment forms as described above. This approach allows for plenty of interaction and the students are already busy with such a mini-proposal during this very lecture making it easier to identify the key elements of the proposal.
* The document “Additional Information” in the Supporting Information offers an extensive bibliography which may be used in the lectures. Not all the reported articles should be presented and discussed in detail but only those which illustrate the most important concepts best (this changes every academic year as new articles come out). Other articles may simply be offered as further reading material and provide additional examples of the concepts discussed in the lectures. Many students will use this further reading materials for the assignment in which they need to read and summarize two articles non-related to their own project.
* The bibliography used for the lectures presented in “Additional Information” in the Supporting Information is updated every year with newly published articles. Sometimes, however, some examples from older articles are still kept in the lectures in order to illustrate the beginning, the development and the current state of the art of a certain area of research within the field of nanotechnology. This allows the lecturer to tell a good story and students will generally appreciate how quickly or slowly a certain (sub)area has progressed.
* It may sometimes seem challenging to make a selection of the literature to present in the lectures as new interesting articles keep coming out. If you make a choice to present a newly published article instead of an older one but still find it very useful, you may opt to offer it as further reading material.
* When using examples from the literature in the lectures emphasize which ones are most recent even though that is visible from the references on the slides. That way the students become aware of the relevance of recent literature. This is also what you would like to see in student presentations and written research proposals.
* When discussing examples of new concepts, make links to other courses the students followed such as concepts learned in organic or physical chemistry. This will give students the sense of appreciation for everything they “had” to learn until this point.
* As illustrated in Table S6 in the Additional Information of the Supporting Information, the topics nanoelectronics and photovoltaics, quantum mechanics and effects, size-dependent properties, simulations and computations, and science fiction and ethics are not explicitly covered in the lectures. These topics are either briefly mentioned within one of the main focus areas (see Table 1 in the manuscript) or during student presentations (the focus of which depends on students’ choice of topic; the list of project topics is available in Figure S1 in the document “Additional Information” in the Supporting Information). This choice of focus in this course (Table 1 in the manuscript) in no way reflects the relative importance of relevant topics but is a mere consequence of the focus of our curriculum which is chemistry and in the third year, more specifically, either drug discovery or polymer materials. The reader who wishes to adopt our approach, may want to change the thematic focus of the course to better meet their needs. Likewise, it is also possible to change the schedule of the weekly topics (Table 1 in the manuscript).
* It’s good to have a break halfway the lecture to give the students and the lecturer a chance to freshen up.

Student Presentations Sessions

* You want to keep this session highly interactive. Encourage the students to ask as many questions as possible as they need to practice asking questions and not everyone dares. Let a discussion develop. In the first weeks of student presentations, students may still feel somewhat inhibited or shy to ask questions and when they do, it is not always the most constructive questions. Lead by example and in a few weeks’ time, they will learn how to ask the right questions themselves and become more critical. As the course goes on, the students will be asking more and more critical questions and the lecturer fewer and fewer.
* Telling students that the more questions they ask, the fewer questions the lecturer will ask, usually works well to get them started.
* Every once in a while the lecturer should also ask a more difficult question so that they can get an idea of what kind of questions get asked at conferences.
* Examples of questions you can ask about the presented topics to stimulate critical thinking:

- What is the state of the art in this field?

- What makes this system/approach innovative and novel?

- What are the remaining challenges in the field?

- Which limitations do you see?

- When do you expect this solution to be brought to the market?

- What are the researchers working on at the moment?

* Sometimes the students will present a topic in more depth than discussed in the lectures and sometimes they will present a new topic altogether. It is important to remember that the audience is supposed to learn from their fellow students’ presentations too and not only from lectures. Stimulate the students to look for elements/ideas in these presentations that they can use in their own proposal.
* After the session ask the group to give feedback on the presentations. What did they really like (and why) and what could have gone better? Hand out the assessment forms for the presentation and discuss the expectations. Follow up on that with your own feedback. Make sure you also give feedback on the research proposal and not just on the presentation skills. This is crucial during the first two sessions in order to shape their presentations (and research proposals) to the expectations. Typically, the research proposal will not have been worked out sufficiently. Give examples of what you would like to see mentioned in the presentation and the written research proposal. Also try to stimulate critical thinking. Examples of questions that serve as feedback:
* How would you prepare the proposed molecule?
* How does your system compare to the existing ones?
* Which problems in science and technology will your idea solve?
* What are the limitations of the system you propose?
* Which are the most recent advances in the field?
* …
* After the group has left the room, stay with the presenters and discuss how the presentation went and how you assessed them. Start by asking how they think it went and then give your assessment (with the exception of the criterion regarding the activity in lessons that will not be ticked until the end of the course). This usually means that the final grade for the presentation can still go a bit up or down depending on how active they are in the lessons. Emphasize this to the students as this will motivate the students further to participate in the group discussions. Give additional feedback specific to each presentation. They should work this out in the written research proposal.
* Student presentations are graded according to the Assessment Form (see Supporting Information) and this grade contributes with 30 % to the final grade for the course. A vast majority of students (99 %) gets a passing grade for their presentation. Even though the presentation is an official assessment, its more important aim is to introduce certain topics to the audience, to initiate discussion and critical thinking, and to provide the presenters with feedback on their proposal. If student presentations are to be used as such a teaching tool, they cannot all take place at the same time but should rather be spread over the duration of the course. Since the presenters receive feedback from the audience and the lecturer after their presentation, the students presenting in weeks 6 and 7 would indeed have an advantage over students presenting in week 3 or 4. This is compensated by slightly milder grading in weeks 3 and 4 and with more focus on feedback after the presentation and explaining what is expected from the presentation and the proposal. As the course progresses, more and more feedback (in total) is provided to the group, the assessor’s expectations rise and the grading becomes stricter. This works well to stimulate the students to improve their presentations and proposals and an increase in the quality of the presentations is observed throughout the course. This also shows that the students learn from good and not so good presentations from fellow students and from the feedback provided.
* As discussed in the manuscript, in our approach the students deliver their oral presentations throughout the course and have to submit their final proposal in written form at a later stage. The one approach reported in the literature (reference 69 in the manuscript), that also mentions orally presenting a proposal, describes a different order of student assignments; the oral presentation is the final product of the course and is delivered after the submission of the written proposal. We do not feel or claim that our approach is better or more efficient than the one published in the literature but merely offer it as an alternative. If you wish to put a stronger emphasis on oral presentation skills (and consequently give that part of the grade more weight), you should indeed have students orally present the final version of their research proposal as opposed to having them write a proposal using an article template (and therefore put more focus on the writing skills and also more weight on the corresponding partial grade). We feel, however, that it is the critical discussion with the audience of peers that follows such a presentation that is most valuable to the presenters as it offers them a fresh perspective and stimulates them to think further about their proposal. In our approach, they receive this feedback (more or less) halfway their project and can still work it out for their final version which they present in the written form. In the approach from the literature, they receive this feedback from the audience at the very end of their project, obtain their grade and do not do anything further with the received feedback which we feel is a pity. In that approach, however, the students do receive some feedback from their coach and peers throughout the project which they then need to incorporate in the final version of their proposal. As mentioned earlier, it is not about which approach is better or not but what suits your curriculum better. In our study program students often need to incorporate the teachers’ feedback but rarely ever their peers’ feedback. Also, we deem their oral presentation skills on average better than their writing skills which more often than not still require some practice/training. For those reasons it makes more sense to use our approach in this course. Needless to say, this may be different at other schools and the reader who chooses to adopt this course, should also critically look at their curriculum as a whole and adapt this course if necessary in order to integrate it better in their curriculum.
* According to the Assessment Form for the student presentation, students also get assessed on their participation in the discussion in the class (interactive lectures, student presentations and the guest lecture). This is one contribution to the final grade for this part (see assessment form). Since in our case the group is of a medium size (typically 30-50 students) and the lecturer knows all the students personally from previous courses, the lecturer observes and remembers how active or inactive individual students have been throughout the course. This is of course not completely accurate but noting down who asked or answered how many (relevant) questions throughout the whole course (including the lectures) would be highly impractical. In practice, the students can be categorized in three groups: those who stand out by being very active in class, those who moderately participate in the discussion and those who never (or hardly ever) participate. The grades that are then given to this criterion are 8 or >9, 6 or 7 and 5 or <4, respectively. Only those students who strongly stand out receive the highest grade (excellent participation) or lowest grade (never asked or answered a single question) for this this criterion. As this criterion only presents one contribution to the grade, in practice this comes down to the following: for moderately active students this will not have (a large) influence on their final grade but it may increase or decrease the final grade by one point if the students stand out (either in positive or negative sense). This serves as a motivation to the students to obtain a higher grade for this course. This partial grade, and then consequently also the final grade for the presentation, is given at the end of the course when all the lectures and student presentations have been given.
* If the attendance criterion has been met (see Assessment Form), the final numerical assessment of the presentation is determined by calculating the average grade for all the numerical criteria and rounding it off to the nearest half point.
* In the student presentation the research proposal need not be fully worked out yet (and the literature need not be very critically assessed yet) as this is an important feedback and learning moment for the students. For that reason this assessment criterion in the assessment form may at this point be graded with a failing partial grade and still allow the students to pass this partial exam (it is not a knock-out criterion). For the written research proposal, on the other hand, a sufficiently worked out research proposal is an assessment criterion which must be met in order to obtain a passing grade (knock-out criterion). This reflects the structure of the course in which the presentation is more of a feedback/learning moment than a hard assessment and the written research proposal is a final product that is assessed more strictly.
* The slides of student presentations are made available to the students on intranet after each session.
* As described in the manuscript, there are typically 30-50 chemistry students enrolled in the course. In case of more than 35 participants, the group is split in two and there are two parallel student presentation sessions organized to ensure an interactive session in a smaller group. The students taking the Drug Development package in our third-year curriculum form one group and those taking the Polymer Chemistry package form another. Since this course is a joint course for both packages, diving up the group like this still allows students to have more focus on the topics of their choosing.

Written Research Proposal

* Even though research proposals in academia are not typically written using an article template, literature reviews are and during our program, students are encouraged to use an article template to make sure they become skilled at it; we feel that at the undergraduate level it is more important to familiarize students with article rather than research proposal templates. Moreover, introducing a new template before they’ve become sufficiently skilled at writing articles may cause unnecessary confusion. For these reasons, we have decided to have our students write their research proposal (a big part of which is a review) using an article template. Another course coordinator and school may not share our opinion in which case we would recommend to use the NSF proposal outline. The outline may be found here: <https://www.lsu.edu/osp/files/NSF_StandardProposalOutline.pdf>
* As guided by the Student Manual, students have weekly tasks that they need to complete in the process of coming up with an original idea and working on their written research proposal. As part of that, they are encouraged to ask the lecturer for feedback on the literature they have found and on the outline of their written research proposal (which sections and topics they plan to incorporate and in which order). It can be a lot of work to give feedback if you have a large group but this will significantly increase the quality of the written proposals. This is an opportunity to steer the students in the right direction and to make sure they have all the key elements in their proposal. For example, you should make sure that they have enough recent scientific articles, that they give the final product sufficient structure and focus, that the proposal is original enough and that they work out the proposal part enough, and that they present an outlook in a “Conclusion, Outlook and Perspectives” paragraph.
* The Conclusion part of the “Conclusion, Outlook and Perspectives” paragraph refers more to the review part of the written document than the proposal part and allows students to sum up the topic in a few sentences and identify existing challenges. This usually serves as a bridge to the Outlook and Perspectives part as well as to their research proposal.
* Make sure the students stick to the given format/template. They find it difficult to follow a format/template.
* Make sure the language is professional and scientific. The language that is acceptable for a presentation, is not necessarily acceptable for a written document.
* The students are asked to write a research proposal that is approximately 3-5 pages long but this will often be longer as they are very excited about their topic and want to work it out thoroughly. This should not be a problem unless it is much, much too long. This guideline was first introduced to provide the students with a rough idea of how long their proposal should be and it was more considered as a lower than an upper limit to the proposal’s length. As important as it is to be able to write an article or proposal of the “correct” length, for us it felt more important to focus on our students’ developing own original ideas and being critical than to teach them to adhere to the given document length. This has to do with the fact that our Bachelor graduates are not likely to write a real research proposal soon after their study but will in near future probably need to develop own research ideas and be critical in science (as part of their Master study, PhD or a job in industry). For this reason our focus is on the content of the proposal and not on its length in this case. Therefore, if some students are very enthusiastic about their project and need more space to discuss their proposal and topic, we are not very strict with that. It is also for that reason that we have provided two student research proposals of significantly different length in the Supporting Information to show the reader what to expect. The reader who adopts this course may also want to reconsider this (in the context of their curriculum) and be more strict with respect to the length of the proposal.
* One of the most important elements of the proposal is a good justification where the students are required to identify a gap in knowledge or a practical need that their research proposal is supposed to address. Even though this is not set as a separate criterion on the assessment form, it does fall under “*An original, relevant and plausible research is proposed and (fully) worked out based on the consulted literature*”. In the interactive lectures, where the students are introduced to the concept of the proposal, they are instructed to include a clear justification in their proposal. A reader who is looking to adopt this approach, may want to mention “Justification” on the assessment forms more explicitly.
* Make sure the students worked out their proposal sufficiently based on the received feedback during their presentation. It does not need to be perfect or 100 % correct but it is important that they have critically thought about the proposal and based their ideas and claims on the literature. This is also a knock-out criterion here which means that the they cannot get a passing grade if the research proposal is deemed insufficient.
* In our course the focus of the research proposal is on proposing a new line of research (research direction) and the students’ original ideas. Since the students will not carry out their proposed research, there is less focus on the details relevant to actually out the research (like a detailed Experimental). An example of this is that we ask our students to reference the work where suitable experimental methods can be adapted from for their research proposal as opposed to reporting a detailed experimental section. This has to do with the fact that the students write research *plans*, that focus on these details, in other courses where this aspect gets assessed. Course coordinators who choose to adopt this method, may want to put more emphasis on experimental details if that fits their curriculum better.
* According to student evaluations and personal communication with the students, they find it most difficult to work out the “Conclusion, Outlook and Perspectives” section and to critically analyze their own research proposal. You want to see that they know the literature on their topic enough to formulate expectations for the future and recognize limitations. You can practice this in the interactive lectures to give them an idea of what you expect.
* Stimulate a bibliography with as many recent scientific articles as possible.
* The work discussion should take place in the last third of the course to allow sufficient time for the students to have a draft of the written proposal ready. At the same time, it shouldn’t take place too late into the course because then the students will have insufficient time to improve the paper based on the received feedback before handing it in in week 8. For that reason the work discussion could take place in weeks 5 or 6. During the work discussion in study week 6 (in our case) students may present the first draft of their written research proposal for feedback. The lecturer gives some pointers on their scientific writing as well as on the proposal and any other aspects that require improvement.
* Since the students have received a basic training in scientific writing prior to this course, they are encouraged to check the scientific articles from the field as inspiration for their scientific writing.
* The Supporting Information also presents two examples of student written research proposals. In these examples, however, original figures used by the students (taken over from published articles) have been omitted for copyright reasons.
* According to the Assessment Form, the text in the written research proposal should contain no more than 5 % of copied text from other sources (as determined by the Ephorus software). This, however, is relative and you should always check the details of such a plagiarism report. Sometimes it is just the titles of the references that exceed the 5 % criterion. Check whether they have really committed plagiarism before you communicate the score.
* Once the written research proposal has met all the criteria related to the form and once the criterion “*An original, relevant and plausible research is proposed and (fully) worked out based on the consulted literature.*” has also been met (see Assessment Form), the final numerical assessment for the written proposal is determined by calculating the average grade for all the numerical criteria and rounding it off to the nearest half point.

Anecdotal Observations of Student Development and Growth throughout the Course

* In the first weeks of the course most students still appear rather shy and dare not ask questions in English while by week 5 they readily participate in scientific discussions and ask more constructive and critical questions. Students begin to inquire more and more about the scientific and societal relevance of certain developments in the field as well as of other students’ research proposals. They often also ask about potential drawbacks of the presented ideas like high costs or health impact of the system at play. Students also show their understanding of nanotechnology by suggesting improvements for research proposals of others by quoting examples from the literature they may have heard about in the lectures or in another student presentation. The discussions in the interactive lectures also become more scientific and constructive. This is also reflected in the assessment of the students as their participation in discussion is also graded (see Assessment Forms in Supporting information).
* The presentation skills also improve throughout the course. Most students present with enthusiasm and capture the attention of the audience which is an improvement compared to the oral presentations given in their second study year (assessed by the same lecturer for a number of students). The presentations are usually also better structured than in previous study years. Even though most presentations turn out rather good, students admit being quite nervous about giving a presentation and usually report feeling relieved when it is over.
* The scientific writing skills also improve throughout the course. In our study program this can be observed by comparing the overall quality of the written third-year research internship plan and report to that of the fourth-year research internship (graduation) plan and report which the same lecturer also assesses for a number of students (this Nanotechnology course typically runs between the two internships). Whereas the first draft of the former typically requires major revision for a passing grade, the first draft of the latter most often requires only minor revision or sometimes even none. More specifically, the graduation products typically feature much more elaborate bibliographies and significantly more in-depth and critical scientific discussions than the corresponding third-year internship products. For the third- and fourth-year internship supervisors and assessors (one of which is the Nanotechnology lecturer in our case) it is therefore possible to observe the academic growth of the students. This course, typically running between the two internships, is therefore thought to contribute to the students’ training in achieving the academic level of scientific writing necessary to start their graduation project.

Miscellaneous

* Sometimes there will be two pairs of students who want to work on the same topic. That should not be a problem if they focus on slightly different aspects of the topic. Most topics are broad enough to accommodate this. An example is Gold Nanoparticles; one team can focus on the use of gold nanoparticles for cancer imaging while the other team focuses on their use in drug delivery.
* Every year there are a few pairs that do not work well together. Try to get to the bottom of the problem and make it work. They also need to learn how to work together with colleagues they do not particularly like. If at the end of the course it turns out that one person did much more than the other, you may want to revise the individual grades for the joint products. In order to do this, you can either reward the student who did more with a higher grade or punish the student who did less with a lower grade. The former is often a more constructive solution but this may depend on the situation.
* If one person stops with the project and drops out, you may give a choice between joining another pair and writing a slightly longer research proposal or continuing alone and writing a slightly shorter proposal.
* If a student misses too many lectures or student presentations (see Assessment forms for details) with a justified reason, they should be given a substitute assignment. Students are then asked to go through the slides of the missed sessions and hand in a summary of 2 or 3 articles of their own choice that were presented in the original session. That way they still get more or less familiarized with the topics covered in that session.
* There have been no rubrics developed for the assessment of the presentation and the written research proposal. However, the assessments are discussed with students throughout the course to make sure they understand how they are being graded. Furthermore, there is only one assessor in our case (also the lecturer) so all assessments are aligned with the same standards. In order to make the grading even more transparent (especially handy in case of more than one assessor), rubrics may indeed be developed for the assessments of the presentation and the written research proposal. The exact criteria in the rubrics will depend on the position of the course in the curriculum and this will vary per school.
* Many students find diving into the literature and working on their own research proposal a refreshing method to familiarize themselves with Nanotechnology. Some find it scary, however. This approach should be stimulated even with hose students because it makes them go outside of their comfort zone and that is when they learn the most.
* The students are also required to summarize two scientific articles about nanotechnology topics that are non-related to their topic of choice for the research proposal (see Assessment Form for the written research proposal). This ensures the students also read literature outside of their topic of choice. The lecturer needs to briefly check that these are relevant to nanotechnology and written in own words and not, for example, just a copy-paste of the article abstracts. There is no feedback provided on the summaries unless they are really poorly written and need to be rewritten.
* If you come across an interesting ahead-of-print article in the literature concerning a topic that someone is working on for their proposal, send it to them. Students are typically very excited when they receive an ahead-of-print article and appreciate the gesture. This will often also give them additional inspiration for their proposal.
* Sometimes students will have a tough time coming up with an original proposal. Help them out by asking questions and sharing some initial ideas but always leave enough room for them to discover for themselves to which extent an idea makes sense or not.