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Introducing Nanoscience to Students at University – Five years of experience with 'Nano1' – a Research-Based Introduction to Nanoscience

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Introduction – Nanoscience & Research-Based Teaching

Introducing new students to their chosen field of study is difficult, as the students have to *learn* about their chosen field of study and *integrate* into the new university setting (Biggs & Tang 2011*b*, Dolin 2013, Johannsen et al. 2013). In multidisciplinary fields of study the challenge is considerable, as the students have to learn about and familiarize themselves with several disciplines (Dolin 2013, Rienecker, Müllen, Dolin, Musaeus & Mørcke 2013). In some cases, the students do not have the knowledge needed to perceive the scientific substance of their chosen field of study. The students that enroll on the nanoscience education at the University of Copenhagen have to face the challenge of integration, while learning the course matter of the undergraduate degree programme in nanoscience, which is primarily taught as physics, chemistry, and biology. To help the students take charge of their progress towards becoming a nanoscientist, an introduction course named 'Nano1' is included in the nanoscience degree programme. The Nano1 course was redesigned in 2010 as a research-based course predominantly consisting of a laboratory project. Here, the course rationale is detailed, and the course analyzed using a constructivist framework.

Research-based teaching at the undergraduate level has been successfully implemented in chemistry courses (Dintzner et al. 2011, Kharas 1997, McKenzie et al. 2012, Newton et al. 2006, Tomasik et al. 2013, 2014), with a genuine research outcome reported in several cases (Kharas 1997, Newton et al. 2006). While all reported cases are examples of active learning (Prince

& Felder 2006, Weaver et al. 2008), various forms of inductive learning are applied, typically starting with a guided-inquiry approach that to varying degrees move towards open ended discovery learning as the course progresses (Prince & Felder 2006). One report highlights the necessity of this progression, as the students need to learn how to perform research, before being asked to undertake an independent research project (Newton et al. 2006). All reports highlight the exceedingly positive student response to active learning and research-based teaching (Biggs & Tang 2011*b*, Dolin 2013, Prince & Felder 2006, Tomasik et al. 2013, Weaver et al. 2008). As student motivation is an important aim of an introduction course, an active learning approach in the form of research-based teaching was an obvious choice when redesigning the Nano1 course.

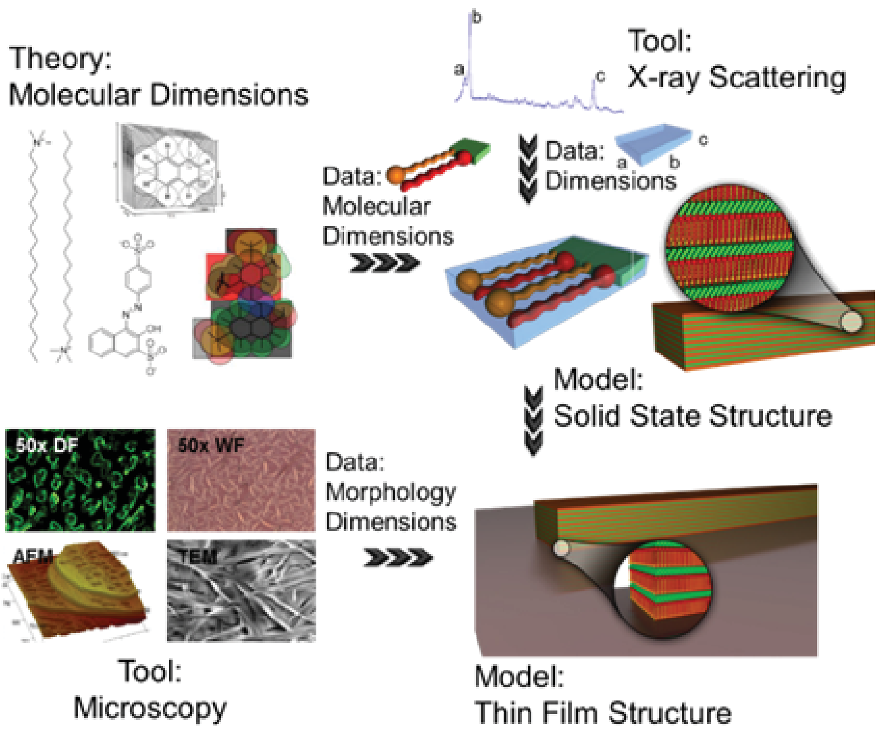

Fig. 3.1. The part of the Nano1 research project working with the structure of matter and molecular dimensions.

Nanoscience is hard to define. Nanomaterials are defined as to materials with one or more dimensions between 1 nm and 1000 nm. At the University of Copenhagen, nanoscience is defined as research using tools that measure on the nanoscale, typically research also involving nanomaterials. In addition, nanoscience at the University of Copenhagen is strongly rooted in the parent disciplines of chemistry, physics, biology, and medicine with regard to both education and research. In order to focus on nanoscience and nurture the student's identity as nanoscientist, the Nano1 course focuses on the tools and dimension of nanoscience rather than discipline related content.

The research project Nano1 revolves around is based on the work of Faul (Gaun et al. 2002), which described the fabrication and investigation of a series structured nanomaterials. These materials can be processed into films, allowing for three kinds of samples to be investigated using the tools of nanoscience: solid samples, samples in solution, and film samples. Furthermore, the constituents of the materials have dimensions and properties that are highly relevant in nanoscience, which allows for introduction of several important concepts. Figure 3.1 shows the relationship between the different aspects of the Nano1 research project concerned with structure. This part of the course, representing roughly half of the scientific content, involves five important nanoscience tools. In total, the students use no fewer than eight different nanoscience tools in the five weeks in the laboratory.

Theoretical Framework – Constructivism

Constructivism in language and education is based on the works of Vygotsky and Piaget, both working in the beginning of the 20th century (Dolin 2013, Glassersfeld 2005, Pritchard & Woollard 2010). Starting as field of epistemological philosophy the constructivist idea has moved into to field of teaching and has found support in cognitive biology (**?**Pritchard & Woollard 2010). The fundamental concept in constructivism is that a person perceives a subject based on previous knowledge, that is, a new concept cannot be transmitted from a teacher to a learner (*positivism*), but the learner has to build an understanding of the new concept based on previous experiences and knowledge (*constructivism*). Schools has arisen within constructivism as to whether the process of learning is exclusively a social phenomenon (*social constructivism*) or whether the process takes place exclusively within an individual (*radical constructivism*) (Glassersfeld 2005, Pritchard & Woollard 2010), but for a teacher the truth is most likely found on the middle ground. The different settings for learning automatically engage students in a manner that can be associated with either form of constructivism: the classroom is a social setting, group-work is a social setting, while reading a textbook or completing set problems takes place within the individual.

In the context of a university introduction course, three key concepts from constructivism can be considered: *i)* Bruner's spiral curriculum, *ii)* Vygotsky's Zone of Proximal Development, and *iii)* the general concept of 'scaffolding' in instruction (Pritchard & Woollard 2010). In summary: Bruner's Spiral curriculum suggests that important concepts should be introduced and re-introduced frequently throughout an education, Vygotsky's Zone of Proximal Development is the scope of new concepts a student is capable of learning if instructed, and 'scaffolding' is the general means employed by the instructor to enable the students to pass through/encompass the zone of proximal development:

> "*...the teacher need to construct a hypothetical model of the particular conceptual worlds of the students they are facing. One can hope to induce changes in their [the students] way of thinking only if one has some inkling as to the domains of experience, the concepts, and conceptual relations the students possess at the moment.*" (Ernst von Glassersfeld (2005))

Vygotsky's Zone of Proximal Development in particular will be detailed below and used as a model throughout the text, while Bruner's spiral curriculum and scaffolding is simply adopted as valid concepts in e.g. curriculum planning and the design of teaching activities.

Rationale – Course Design

When redesigning the Nano1 course in 2010 the two major concerns were: How to integrate the students into the nanoscience community, a community constituted primarily by university students, while all instructors and researchers are chemists, physicists, and biologists. And how to teach a complex and undefined multidisciplinary field of study to a diverse group of students.

A theoretical solution did not present itself, and it was decided to plan a research-based laboratory course involving the largest possible number of nanoscience related tools, concepts, and techniques. The goals of the Nano1 course was defined, and are:

- to give the students a common frame of reference to build their further studies on
- to put rudimentary practical and leaning skills in place for the students to use in their further studies

- to introduce the students to the multidisciplinary field of research that is nanoscience

Table 3.1. Concepts the students have to use in the Nano1 course. The evaluation is indicated behind each concept, the exam paper (ex) is summative while the students receive formative feedback on their laboratory group report (lr) and individual lab book (lb). The oral presentations are concluded by one general feedback session.

Declarative knowledge	Functioning knowledge	Both
Molecular dimensions (**lr/ex**)	Laboratory safety (**lb**)	Chemical synthesis (**lb/lr**)
bond lengths and angles (**lr/ex**)	Documentation (**lb**)	Elemental analysis (**lr**)
atomic radii (**lr/ex**)	Solid and solution handling	Mass spectrometry (**lr**)
Functional groups (**lr/ex**)	Laboratory glassware	Optical spectroscopy (**lr/ex**)
Intermolecular forces(**lr/ex**)	Data analysis (**lb/lr**)	Optical/electron microscopy (**lr/ex**)
Electrostatic forces(**lr/ex**)	Word processors (**lr/ex**)	Atomic force microscopy (**lr/ex**)
Hydrophobic interactions (**lr/ex**)	Spreadsheets (**lr/ex**)	X-ray scattering (**lr/ex**)
Qualitative and quantitative analysis (**lr/ex**)	Scientific writing (**lr/ex**)	Primary literature (**lr/ex**)
	Scientific oral presentations	Information gathering (**lr/ex**)

To meet those goals a course was designed were the students attend lectures and tutorials aimed exclusively at ensuring that the students have the skills needed to perform the research-based laboratory part of the course. The lectures cover concepts the students are to use actively in their research, and all concepts are accessed with at least one round of formative feedback. The concepts that are intended learning outcomes of Nano1, divided into declarative and functioning knowledge where possible (Biggs & Tang 2011*b*), are listed in table 3.1. The form of the feedback is indicated in table 3.1.

Student Integration

While off-topic here, the course design was strongly focused on student integration. The Nano1 course is the first nanoscience course the students face, and is one of two courses the student take in the first quarter of the first year of university. The students arrive from high school and have to start integration on several levels (Johannsen et al. 2013):

- Practically and socially outside university
- Socially within the year group

- Professionally in a new discipline
- As a university student

The Nano1 course aims at helping the student in the process of adapting to university. The course is designed to force the students to interact within the year group, to force the students to employ several beneficial techniques for university learning, and to give the students a shared experience within the year group and within the field of study.

Learning

Teaching in a constructivist view has to start by adopting the viewpoint of the students. When receiving new students at university the constructivist approach dictates that the status of the student is evaluated in order to map what the student knows and can perceivably learn. The students come with a background within a given discipline, seeded in primary school and cultured in high school. Learning requires that the lessons are structured according to the areas of a discipline where the students have a proficient understanding (Pritchard & Woollard 2010). From this starting point, a lesson may enable the student to learn, and expand the part of the discipline where the student demonstrate a proficient knowledge. This process can be visualized by using Vygotsky's Zone of Proximal Development, see figure 3.2 (Dolin 2013, Pritchard & Woollard 2010). For the most efficient

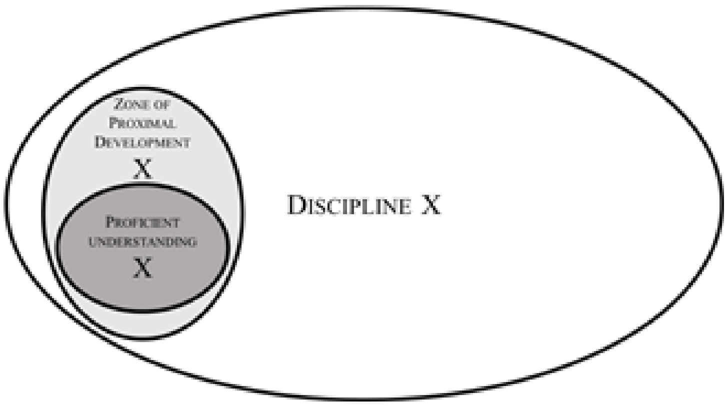

Fig. 3.2. Vygotsky's Zone of Proximal Development, or in context of university learning, a visual representation of what the student know, what the student are able to learn in a given timeframe, and what the student should learn in a given discipline (chemistry, physics, biology, medicine or more specific organic chemistry, inorganic chemistry, theoretical chemistry etc.).

learning to take place the students should have similar backgrounds, in order for their background knowledge and zones of proximal development to overlap. If this is the. case, then each lesson can challenge the students at the highest possible level, maximize learning, and cover the discipline at the most rapid pace. This can also be understood as a steep learning curve, which employed will alienate all the students that have a background less suited for studying the specific discipline (Dolin 2013). The best possible candidates are produced in this manner, but this form of teaching is ill suited to a mass university.

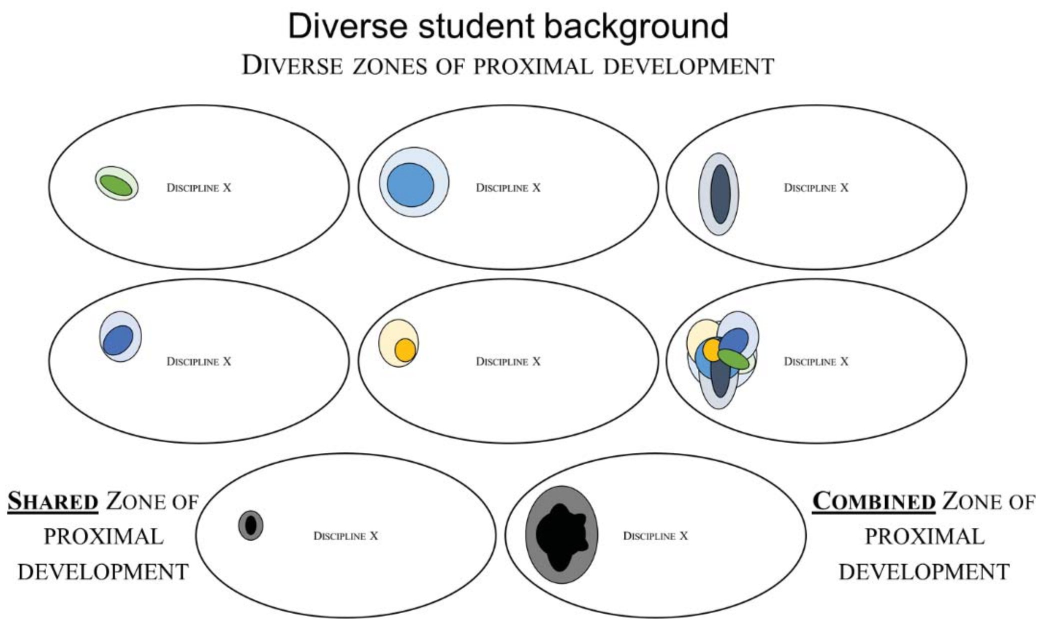

Fig. 3.3. Vygotsky's Zone of Proximal Development for a typical student group enrolled at the nanoscience education at the University of Copenhagen, where the students are strong in multiple but different disciplines. Here, three groups are weak in discipline X and two groups are strong. Constructivist lessons can build on either the shared knowledge or the combined knowledge of the student group.

Vygotsky's Zone of Proximal Development can be used as a strong visible representation of student knowledge, student learning potential, and the content matter the student has to master at a certain level at university. Each student or group of students will come with different knowledge and expand that knowledge differently. By using a visual representation of the differences in knowledge and progress, a qualitative evaluation/analysis of student learning is feasible. Moreover, conceptually, course planning can take the differences in student background into account by mapping out the student knowledge using Vygotsky's Zone of Proximal Development as a graphical representation of student knowledge.

In the nanoscience education, the challenge of student background is multiplied. A much more varied student group is accepted compared to the traditional disciplines. Figure 3.3 shows a graphical representation of the diverse student group. Ideally, the first courses the students are met with should homogenize the student group to the extent that they have equal chances to learn in the following courses. This can be done using a classic lecture format provided scaffolding based on the *shared zone* of proximal development, or in an active setting, where the students are engaged at the extent of their *combined* capabilities, the difference in area of a discipline covered is shown in figure 3.3. While time consuming for instructors and teaching assistants, the learning outcome of the second approach is highly favorable.

In the Nano1 course, two types of teaching/learning activities are in place: the facilitating series of lectures and the laboratory project. Both are aimed at the combined zone of proximal development shown in figure 3.3, where the lectures relies on peer instruction and small group discussions during the laboratory project to compensate for the differences in student background.

Teaching a Multidisciplinary Field of Study

In nanoscience, the problem of a diverse student background mirrors the problem of teaching a multidisciplinary field of study. While nanoscience is defined as pertaining to matter and materials defined by having at least one dimension measured on the nanometer scale, the field of study is located at the point where multiple traditional disciplines overlap or interact, see figure 3.4. Essentially, basic nanoscience does not exists. Rather, basic nanoscience is the combination of advanced physics, chemistry, biology, and medicine. In a course introducing first year students to nanoscience, their background does not include the concepts needed to comprehend the nature of nanoscience, see figure 3.4. Furthermore, the instructors the students meet are not nanoscientist, but are heavily rooted in chemistry, physics and biology, and are as such not familiar with the scaffolding needed to aid the first year students in becoming nanoscientist from a nanoscientist's perspective. The instructors can only help the nanoscience students from a biologist's perspective, chemist's perspective *etc*. In introducing nanoscience to the students, different means have to be applied. If the first year students cannot *learn* the multidisciplinary aspects of nanoscience until later in the education, they have to be familiarized with nanoscience in a different manner. Nano1 uses the tools of nanoscience as the means to introducing the students to nanoscience by having them *do* nanoscience.

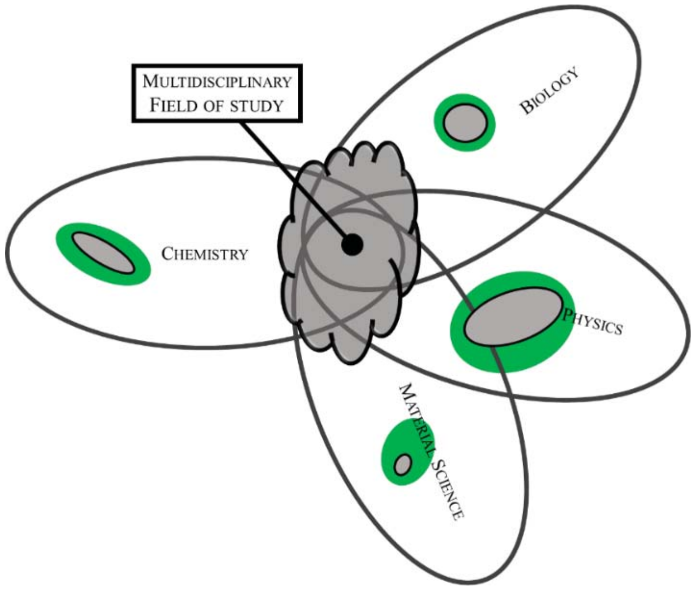

Fig. 3.4. The problem of teaching a multidisciplinary field of study illustrated using Vygotsky's Zone of Proximal Development in various disciplines.

Nano1 – Introduction to Nanoscience

The Nano1 course have run successfully for five years, with positive student feedback, successful research outcomes (Marco Santella et al 2015), and a clear progression in student learning outcomes as the course has evolved. A detailed account of the course will be given elsewhere. (Thomas Just Sørensen. A Research-Based Laboratory Course for First Year Undergraduate Teaching, Manuscript in preperation)

While building on the strengths of the individual student, the research-based Nano1 course also caters to peer-instruction based on the individual strength, and this approach to teaching allows for covering a wide scope of very advanced material that will be new and challenging to all students. Furthermore, by adopting a research-based approach, multiple techniques and concepts relevant for the chosen discipline can be introduced actively to the student, touching down on important formulas or concepts that the students will have to work with for an extended period of time. The research-based course allows the student to work hands-on with nanoscience and actively do research, neither of which they would do prior to their third year under different circumstances.

Returning to the desired learning outcomes of Nano1, as listed in table 3.1, they fall into two categories: discipline-related concepts and secondary skills. The latter of the two are easily taught as all the students have a working experience with computers and the internet, and as such, a common background easily addressed by lectures and tutorials. The former is more difficult, due to the issue outlined in figure 3.3. In Nano1, this is tackled as the research project, through peer instruction and numerous contact hours, makes it possible to teach based on the common zone of proximal development. The issue of the distance between the student's discipline-dependent zones of proximal development and the multidisciplinary nature of nanoscience is dealt with by letting the student work towards a simple functional proficiency in several nanoscience related techniques. In the lab, the students perform experiments, which they are fully capable of comprehending. They then independently perform data analysis on a level they understand, while subsequent advanced data analysis is performed by following a recipe. The results are designed to lie within the limits of the student's zone of proximal development, enabling the students to explain the results. Using the SOLO taxonomy the several levels of understanding is mapped as zones of proximal development in figure 3.5 (Biggs & Tang 2011*b*). While the students will not be able to learn or reflect on nanoscience during the Nano1 course, they will be able to *do*, *explain* and *apply* various aspects of nanoscience. The greatest challenge in planning and executing the Nano1 course is to match the teaching to the student group's version of figure 3.5.

Evolution – Lectures and Tutorials

he first iterations of the course ran with a pure positivistic approach by choice, which was partially successful in that the students in general came with a solid background in chemistry and physics. The second iteration, following on from the success of the first, was a complete failure of the transmissive lecture format; possibly do to a vastly different student group. The

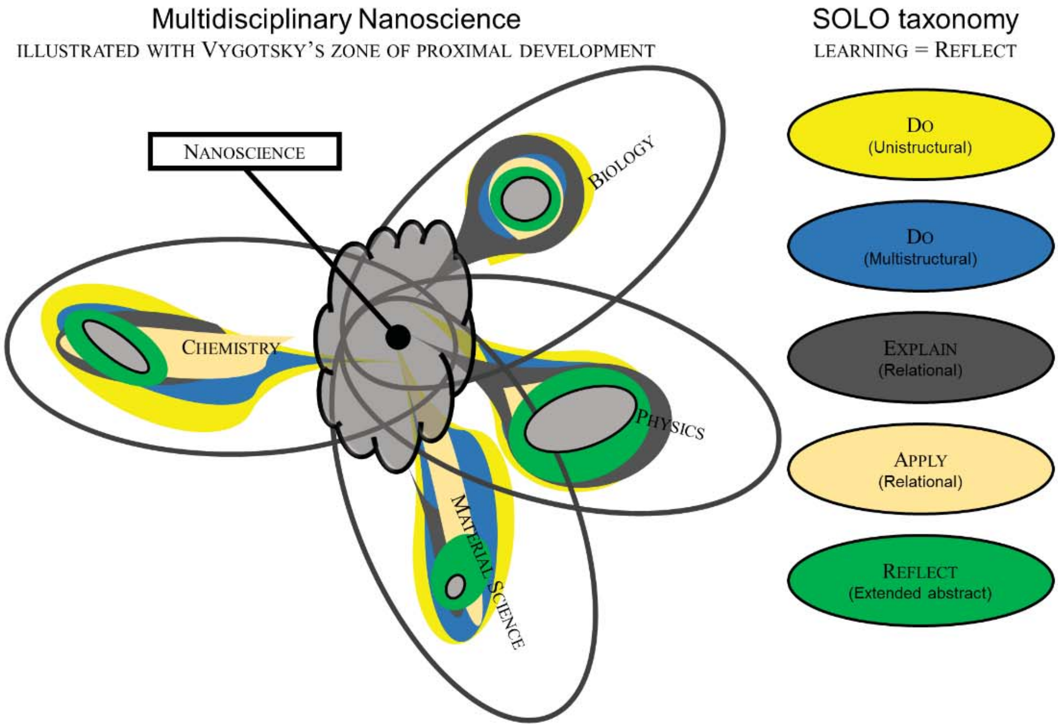

Fig. 3.5. A typical map of the discipline dependent zones of proximal development at various levels of understandings of a first year nanoscience student at University of Copenhagen.

failure suggested a more student-centered approach to the lecture part of the course. The research part of the course is intrinsically student-centered.

To make the lecture course more student-centered, the first task is to investigate where the students are when they arrive at university. They all come from a high-school background, where they have focused on various disciplines, but they will all have had mathematics and a minimum of two of the following: physics, biotechnology, geoscience, and chemistry. They do not have any knowledge of nanoscience and they do not have overlapping competencies within any area of science besides mathematics. The five iterations of Nano1 has shown that the students have poor secondary skills, as they have not been trained to use word processors nor spreadsheets professionally, and the student have not had experience in independently researching a subject using the internet, libraries, and other available sources of knowledge.

The initial assumption was that a transmissive approach to lecturing, where the content of each lectures gives a condensed account of the theory behind each applied technique, would fulfill the goals of Nano1. The idea was that the student would thus be taught the skills listed in table 3.1, and able to actively apply the information in the relevant part of the research project. This assumption was proven to be flawed and a radically different approach had to be adopted. Where the initial idea was to *expose* the students to the theory behind listed skills at a very high level during the lectures, the focus was gradually shifted towards that the student *learn* the basic concepts of each technique, ensuring that all students have a working knowledge of the techniques they are to actively use in the research project.

In the latest, fifth, iteration of the course the appropriate level for lectures has been found, where the diverse student group all are able to explain the foundation of the techniques they have actively used. This is evident from the exam papers.

Evolution – Laboratory Research Project

The research project has worked perfectly in the execution of the experiments in all five iterations of the course. The first two iterations suffered from poor documentations, but a clear focus on this aspect throughout the course has made the student lab books acceptable with respect to reproducibility. In most other aspects, the quality is still poor, which serves to highlight the difficulty in keeping a proper laboratory account. An experience the students take with them into the remainder of the degree programme.

The biggest challenge in this course is to achieve a high quality in the written laboratory report (based on the laboratory experiments). The students repeatedly fail to produce high quality work despite the 100+ student hours they have to write the report. The reason for the lack of quality has been identified. I reason that it is partly due the fact that the students have to do the data analysis in the writing process. And partly due to the general lack the secondary skills i.e. the ability to operate spreadsheets and word processors. By ensuring that data analysis is performed prior to the time allocated to writing the report, time to sort out the secondary skills should be available. It is clear from the exam papers that the secondary skills are in place after having written the laboratory report.

It has previously been noted that the students like to be able to perform a model experiment/model analysis prior to performing the research based task (Newton et al. 2006). Therefore, in the sixth edition of Nano1, a written formal data analysis guide and a model data set will accompany each experiment, with the result shown in the form of a graph or table. Furthermore, the data analysis will be integrated within the 'experiment time' in the course schedule, rather than appearing as several congregated blocks of 'data analysis time'. In this manner the data analysis should be in place when the writing process starts, and the use of spreadsheets should be reinstated, thus allowing the writing process to be focused on scientific writing and using word processors. This is a clear step towards a guided-inquiry approach away from discovery learning where this course started (Prince & Felder 2006, Weaver et al. 2008). However, attention to the student learning outcomes clearly indicates that in teaching first year students this is a better format. The course could be repeated at a later stage in the education, where a more open discovery learning approach can be used.

Discussion

As student integration is essential, we start by considering the effects of the Nano1 course on student integration. A research-based course gives unique handles to nurture student integration. Working in groups, directly experiencing nanoscience tools, working with postgraduate nanoscience students (as teaching assistants), and working on an individual and novel research project are all factors that work well towards student integration within the year group and the discipline. A key aim in the Nano1 course is to instill the students with an identity as nanoscientists. As each year group is directly involved in a nanoscience research project, using the tools of nanoscience on an unexplored system, they are given a common identity within the year group. As each year group has been through similar although not identical, but progressive research project based exclusively on the work of previous year groups, the experience can be used to give the students across year groups a shared identity. Furthermore, the successful research projects result in publications with student authors, making the students published researchers, which effectively integrate the students in both of the two communities present at universities: the research community and the educational community (Ulriksen 2009). Nano1 allows the students to be part of the research community from the first year, rather than in the third year where they perform research as part of their bachelor projects.

Concerning student learning, the Nano1 course have changed in focus and means over the five iterations. The analysis presented here based on constructivism in general and Vygotsky's Zone of Proximal Development in particular, highlight the difficulty in teaching nanoscience to first year students. However, the analysis also shows how nanoscience can be taught to a diverse group of first year students by using a research-based active learning approach. The analysis suggests that enrolling a more homogenous student group would enable more ambitious levels of student learning to be achieved.

The experience from creating, implementing, and developing Nano1 show that research-based teaching is feasible, and that the research part of such a course is readily planned and implemented. The support structure in the form of lectures and tutorials is essential for student learning, but are much more difficult to plan. Only by using a constructivist approach can the optimal format for student learning be realized. Nano1 was developed iteratively, which worked well because the vast benefits of research-based teaching compensated for the less than perfect lectures. Based on the experiences with Nano1 an iterative approach to develop research-based courses is suggested, unless the student group is very well known. As presented above, the student knowledge and their potential for learning is very complex (figure 3.5), consequently, detailed course development may be in vain if even small changes in student population occur.

Conclusion

Introducing nanoscience to first year university students remains a challenge. By using Vygotsky's Zone of Proximal Development as a visual representation of student knowledge and potential for learning, the course 'Nano1 - Introduction to Nanoscience' was analyzed. The analysis shows that, with appropriate scaffolding, students can be introduced efficiently by using a research-based form of active learning. Furthermore, the analysis using zones of proximal development visualizes the advantage of a student centered active learning approach over a traditional lecture format. The same method of visualization allow for a clarification of the issues inherent in teaching and learning multidisciplinary fields of study, and further allows for a mode of action to be selected in introducing multidisciplinary fields of study: By selecting a few points within the multidisciplinary core, in which the students are able to either *do* research or *explain* research-based results, a multidisciplinary field of study such as nanoscience can be introduced to the students in an actively learning setting early in a university degree programme.

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All contributions to this volume can be found at:

http://www.ind.ku.dk/publikationer/up_projekter/2015-8/

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