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Big Ideas in Science Education in Teacher Training Program

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Abstract

New curricula from primary school to higher education include performance assessments of achieved skills. The study investigates if it is possible to respond to this by focusing on some core ideas regarding content and design of learning situations. It was made on pre-service primary school teacher students in science and technology. It shows how the achievement of useable knowledge is enhanced by close relations between teachers and students in combination with open and visible processes of the learning.

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Keywords: science learning; teacher learning; student learning; big ideas; core concepts; qualitative assessment

1. General introduction

In Sweden, new curricula on all levels from compulsory school (Skolverket 2010, *Swedish National Agency for Education*) to higher academic education focus on training students to use achieved knowledge. Thus, the knowledge requirements are formulated as criteria for assessing the performance of the students when they are using their achieved skills. This wider perspective increases the expectations on the students and their teachers to be more efficient both in teaching as well as learning. The knowledge requirements may be interpreted as students are supposed to be able to use their achieved knowledge on the highest order of thinking in Bloom's revised taxonomy (Anderson et al. 2001). As learning usually appears when students are in their growth or learning zone and not in their comfort or panic zones (Luckner & Nadler 1997; Brown 2008) it has become necessary to design learning situations where all students develops according to their potentials. Collective participation is important for

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intellectual development in general (Freire 1970; 1975) but is also useful for professional development of teachers (Garet et al. 2001). The consequences for teacher training obvious; it is not only necessary for the becoming teacher to know the core content of a subject but it is also necessary to have usable achieved skills and an understanding of this knowledge and this knowledge should be transferable (Hendricks 2010).

To be useful, knowledge preferably should be possible to use in different situations as performances of achieved skills. At these occasions knowledge gained is surfaced and shown by the user by performances in different situations. The achievement of skills is often result of processes with a dialectic relation between practice and reflection of the student, also often including the teacher, where more or less chaotic situations transform to structured theoretical and practical knowledge (Doll, 1993). Within teacher training programs at Södertörn University there has been a process of development of courses in science and technology (Mattsson & Lättman 2004, Mutvei & Mattsson, 2014a, Mutvei & Mattsson, 2014b, Mattsson & Mutvei 2014).

2. Science and technology at school

Usually science in schools is delimited in different subjects with concepts, methods, and language far from the ordinary well-known world of the student. From our experience teaching often concentrates on definitions of concepts, examples that should be learned, and calculations based on formulas learnt by heart and not constructed by mind, thus, giving the student the impression of a static presentation of a world unknown in real life. Outside school, science contains a large number of perspectives and investigates and describes a world without borders. Science is to large extent built on curiosity, not only about the object studied, but also about the role of the researcher and the process of personal transformation during the enquiry. Similarly the teacher, often together with the student, has to find the generative questions which help both into the process of deeper understanding and transformation (Freire 1975). The objective of this activity is to develop personal ways of finding starting points for further development and acquisition of skills based on background and experiences. This may be described as an intercultural interaction between teacher and student.

The pre-service teacher education has to adapt to this intercultural interaction and several aspects of learning, including theoretical knowledge and theories about how this may be achieved. The knowledge requirements in the primary school curriculum are almost identical in biology, chemistry, and physics, thus, it is at school possible to train the skills of the students with an integrated approach (Mutvei & Mattsson, 2014a). Similarly the becoming teachers may be trained in a similar way during their own studies. Here we used a science and technology course for pre-service teacher students were the content is based on essential parts of the new curriculum for the compulsory school, year 4–6 (9–13 years old) and tried to identify learning problems in the different subjects.

2.1. Biology

In biology it is necessary to have an evolutionary perspective as most processes on different levels have developed over long periods of time due to random variation and natural selection. If these fundamentals are unclear for the students they often achieve teleological views and think there is an intention or purpose behind the properties or characteristics of individuals, populations, species, clades, communities, biotopes, or bioms. These problems were recently demonstrated by an evaluation of science teaching in primary school by the Swedish Schools Inspectorate (Skolinspektionen 2012).

One way of overcoming this is to discuss every biological subject out of an evolutionary perspective. The human digestive system is a part of the core content in biology in the Swedish curriculum for compulsory school: “Organ system of the human body. Names of organs, appearance, location, function and interaction” (Skolverket 2011). The understanding of the specific location, function and interaction of the different organs may be promoted by studies based on questions how animals in general through evolutionary processes achieved the ability to utilize hydrocarbons, fats and proteins.

2.2. Chemistry

The core content of chemistry in the curriculum includes: “Contents of food and the importance of nutrients for health” (Skolverket, 2011). This gives the opportunity to study how the main types of chemical compounds, carbohydrates, fatty acids and amino acids are used as energy sources and building material in the body simultaneously in biology and chemistry. These parts of the core content in chemistry are easily included in the study by using this perspective.

2.3. Physics

Teachers in chemistry often make envious remarks towards teachers in physics, claiming that processes in chemistry rarely are directly observed as they are in physics. This is a misunderstanding; it is often easier to see the results of, e.g., the action of forces but it is impossible to see the forces themselves. Further, everyday observations are often contrary the law of in physics; as objects never are moving at a constant pace, they are always retarding but we can´t see the force responsible for this.

The core content in physics includes “Forces and motion in everyday situations, how they are experienced and can be described, such as when cycling” (Skolverket, 2011). The visualization of forces and Newton’s laws of motion may be one fundamental challenge in physics.

2.4. Technology

The core content of technology in the curriculum includes “Everyday objects consisting of moving parts and how these are linked together by means of different mechanisms for transferring and reinforcing power” and “How common solid and stable constructions are built, such as houses and bridges” (Skolverket, 2011). Here, studies of everyday objects like doors and simple constructions may help the students to understand the wide use of technology in society.

3. Objectives

The aim of this study was to investigate how to develop pre-service teacher training courses in science and technology in order to respond to the challenges of the curriculum for year 4–6. This is done by focusing on the following research questions.

- Which are the big ideas corresponding to the core content in the syllabuses of the subjects?
- Which are the main obstacles delimiting the achievement of knowledge requirements in the subjects?
- Which are the differences in the process of the achievement of new knowledge among the students?
- Which role does teacher–student interaction play in the learning process?
- Is it possible to use the higher studies of the becoming teachers as models for learning usable in school?

4. Material and methods

4.1. General

This study was made within a teacher training program during a 20 week course in biology, chemistry, physics, and technology with six students (age 22–37). The design of the learning situations and the implementation of the course was made by a team of four academic teachers, mostly working in pairs when teaching.

For evaluation of the quality of the learning outcome the 4 R´s of Doll (1993) were used; *rigor*, *recursion*, *richness*, and *relations*. The analyses were primarily based on the students and the teachers own written and oral reflections. The quality assessed by these criteria, was presumed to show the level of understanding of specific aspects of the different subjects and the achievement of skills of the students. Within the different subjects parts of the core content were selected for this study out of their potential to present or expose the main concepts of each subject and thus could be used as foundations for further studies within each subject.

An integrated study of the students' development during one month of the course was also included. This was done as a student thesis aimed to examine how to measure students' knowledge development by using a self-made measure instrument based on William Doll's postmodern curriculum (Doll, 1993). The measure instrument was built from Doll's categories: Richness, Recursion, Relations and Rigor. Each category was divided by three levels of thinking and each reflective task was judged by two persons. The study was based on process-hermeneutics and was focused on analyzing the students' written and oral reflective thoughts collected over three lessons. Observations were made each lesson for control of validity (Stenhols, 2014).

4.2. Biology

We used a simplified model, a short paper tube representing a general animal. It had an outer surface representing the skin, a hollow cavity as a simple stomach and between them a narrow piece of paper tissue representing the body. The model made it possible to discuss differences between outer and inner parts of a body and their different ways of communicating with the surroundings. The students should find out how small units of carbohydrates, fats, and proteins are transported from the outside of a body to the inside of a cell. This approach combined an evolutionary perspective with everyday life. What happens today is a function of an evolutionary process and may be better understood with an evolutionary perspective. To understand the human digestive system as a long term adaptation to land-life of multicellular organisms is easier, compared to learn its components by heart which gives no understanding. The main performance assessments of the students were made on projects by the students presented as a combination of different media.

4.3. Chemistry

As described above the human digestion is a good area for studies in evolutionary biology but it also have interesting connections to chemistry. Thus, it is possible to study how the main types of chemical compounds, carbohydrates, fatty acids and amino acids are used as energy sources and building material in the body simultaneously in biology and chemistry. Which chemical transformations are necessary before uptake and transport in the body and what is needed before they are stored? We also included studies of chemical processes in cocking to reveal the secrets of the chefs. This approach includes automatically most essential parts of chemistry in primary school. Here one of the performance assessments was made on an oral presentation prepared partly by the biological projects.

4.4. Physics

In physics we focused on forces, especially gravity as it is a characteristic of all matter. "Forces and motion in everyday situations, how they are experienced and can be described" is a part of the core content in physics in the curriculum. Thus, we investigated forces and their consequences in different situations related to the mass involved by enquiry based learning in daily life situations coupled to theoretical discussions and tried to make the concepts visible. For example, we used chairs on wheels to investigate relations between forces and movements when pushing each other. We repeated the supposed experiment of Galilei at the leaning tower of Pisa and made Foucault's pendulum. We discussed a movie about Einstein and Eddington and the proof of the principle of relativity and how matter shapes space. An amusement park was used for investigations and performance assessment of exploratory skills.

4.5. Technology

Technology was to some extent integrated with physics, as we used visits to the National Museum of Science and Technology in Stockholm for getting knowledge of both subjects. The core content of technology in the curriculum includes "Everyday objects consisting of moving parts and how these are linked together by means of different mechanisms for transferring and reinforcing power." and "How common solid and stable constructions are built, such as houses and bridges". Construction became the main theme. In order to experience this, the students built cars which were used to study friction and develop improvements of the cars to reduce this force. They also constructed and built houses with electric light, houses which were assembled to a town with electric power supply. To each house they also produced construction drawings with explanatory words and concepts and a technical report. One part of the performance assessment was made on these drawings and reports and included peer assessment; further a more theoretical paper written by the students about technology in daily life focused on sustainability was assessed.

4.6. Assessments of learning outcomes

In addition to the regular assessments of the student skills according to the syllabus of their program, we also assessed the learning outcome for the participating students and teachers related to the aims of this study. The rubrics based on the syllabus as the knowledge requirements often were more specific. Further, the assessments of student performance had to be neutral in relation to this study. It wouldn't be fair if the teachers' assessments were influenced by factors outside their course. Thus, parts of the assessments in relation the objectives of this study were based on anonymous student reflections and open teacher reflections assessed by a participating observer, parts by common reflections made by students and teachers in cooperation. In both cases rubrics focused on the quality of *rigor*, *recursion*, *richness*, and *relations* were used. The following areas were assessed: the usefulness of achieved knowledge within and outside the subject; the quality of achieved skills and their relation to the dialectic relation between practice and reflection; the process from chaos to structured knowledge; the quality and importance of the teacher/student relation; the importance of the basic ideas for the learning processes; the appearance of personal development of students and teachers; the identification and use of generative questions; and finally the variation in acquisition of skills for further personal development.

5. Results

5.1. General

The major findings are related to the teacher/student relation. The cooperative enquiry where the curiosity of the teachers to understand the learning processes of the students and to deepen the teachers own knowledge together with the students ambition to get guidance in their search for meaning and understanding of the studied area promote development of several skills of all participants. As the teachers also openly demonstrates their ignorance in some fields and also show how they deal with this in order to develop their own knowledge and skill, also the students discovers the power of good learning processes and the necessity of investments in work and time. The close and open relations between teachers and students also reveal misconceptions and can thus be eliminated by common activities. As described by Freire (1970) this relation also makes enquiry a collective process with individual gains and this demonstrates that knowledge is not easily achieved. Although chaotic situations are distressful, many students realize how these may be used as starting points for achievement of knowledge of high quality supporting the view of Doll (1993). It may also be noted that skills achieved through studies within a specific subject often surfaced also in performances in many other different situations demonstrating the problems of artificial borders between subjects. We also found support for a view where few but central concepts thoroughly used, promotes a general understanding of the theoretical framework within a subject.

The study of the students' development showed an increase of knowledge for about one half of the students. One criterion, Rigor, showed a low rate of acquired knowledge development. The result does not support the premises of this study. The tests of reliability fail to support the claim that the measure instrument should be reliable enough to be used to measure knowledge. (Stenhols, 2014).

5.2. Biology

One main result directly related to biology was the problem for the students to have an evolutionary perspective on the human body and its organs. It was hard for them to understand why it could be beneficial to understand the development of the different parts of the human digestive tract produced or designed by natural selection on groups of ancestors. For most students it was easier to accept the importance of understanding the evolutionary background for general human behavior. For example, it was easy to present evolutionary explanations for why humans prefer to act in and belong to groups rather than being alone, but hard to explain how cooperation between bacteria living in the digestive tract of different groups of land living animals have originated.

5.3. Chemistry

In the beginning of the course the students claimed the importance of knowing the theory and background before doing experiments. The experiments were often regarded as demonstrations of scientific principles rather than inquiries aiming at deeper understanding. In chemistry this was even more pronounced compared to the other subjects but here we also saw a more prominent shift during the course. At the end the students demanded introductory experiments before presentations of theory or facts when new areas were introduced.

5.4. Physics

One challenge in physics was to make physical concepts like force and gravitation visible. The use of the own body to percept forces, actions and reactions clearly made these concepts understandable. If two students pushed each other on wheel chairs it was quite obvious for them that it was impossible to decide who pushed whom. Similarly, simple experiments like jumping on one spot and comparing the sensation when falling down with the sensation when doing long jumps when running. Jumping gave the sensation of falling due to gravity while jumping when running omitted the feeling of gravity and reproduced a feeling of free fall. Although the gravitational forces give similar results in both cases most students had different sensations. This showed to be a good example how hard it is to identify similar concepts.

5.5. Technology

One important result in technology was the problem to visualize technology in everyday life. The students' own reflected experiences of these were limited. They had to study a door to understand how it is connected to the wall and had hard to describe it as they didn't had words for this, although they understood how it worked. For example, the word "hinge" was unknown to all of the students. On the other hand, the practical activities like constructing cars and trying to reduce the friction to make the run longer distances or building models of houses, rapidly increased the understanding of how cars or houses should be built.

5.6. Assessments of learning outcomes

The assessment of the learning outcome for the participating students and teachers focused on the quality of *rigor*, *recursion*, *richness*, and *relations*. Based on these concepts the usefulness of achieved knowledge within and outside the subject could be recognized to some extent. The achieved skills were clearly related to the dialectic relation between practice and reflection. This was mainly shown in the process from chaos to structured knowledge together with the quality and importance of the teacher/student relation.

There were some differences between the judgments of the evaluators of the learning outcome based on the 4 R's but this could be due to differences in experience in using the method.

The development of the students' knowledge, as in most courses, was quite obvious, but the layout of the course also promoted personal development of both students and teachers. The assessments also show the importance of the basic ideas of the learning processes like use of generative questions, mainly due to the variation in acquisition of skills for further personal development of all participants.

6. Discussion

Conclusions of importance from the study are how the achievement of useable knowledge of high quality is enhanced by close relations between teachers and students in combination with open and visible processes of the teachers own learning (Freire 1970; 1975). Here the teachers by teaching together demonstrated their own visible learning as good examples of how powerful dialogues and discussions in combination with open enquiries are in the process of learning. Garet et al. (2001) made a point of the importance of focus on duration, collective participation and core features rather than type of activity to improve professional development of teachers. To recognize this may help to overcome the paralyzing effect of being in the panic zone (Luckner & Nadler, 1997). This was further enhanced by the participation of an embedded active observer. In combination this design helped to widen the views of the students and makes their own and the other students' learning visible to everyone in the group. Thus, the teacher´s own visible learning is a powerful requisite for augmenting the learning of the students.

As the impact of background and earlier experiences for the learning also was pronounced, the importance of the intercultural perspective was visible. The acknowledgement of cultural differences increased the number of perspectives and deepened the understanding of the ongoing processes in learning situation. Further, the study implicates focus on few concepts as a road to deeper understanding and useable knowledge in science learning. This may also have been improved by the examples from different fields of science and technology used more or less simultaneously during one semester. Inquire based approach starting with experiments demonstrating a small concept followed by theoretical discussion, increased knowledge. Using conceptual ideas will increase the student ability to use their knowledge for explaining other phenomena in nature. This also indicates the possibility for the teacher students to reach higher levels in Bloom's taxonomy (Anderson et al., 2001), although it hardly is possible for students at school.

In this perspective it was possible to observe the achievement of transferable knowledge on several levels. Some of the students changed their learning strategies and simultaneously their teaching models during the course. In the beginning of the course they demanded lectures before doing anything, later they become more curious and wanted to make inquiries of their own when new study areas were introduced. In this way there was a transfer of knowledge of how to work not only of subject content. This may be contrary to the findings of Hendricks (2010) about situated learning but here actually designed learning situations similar to those of the primary school teachers'.

Although the focus was on few areas in each subject the students reached an acceptable level of general knowledge in each subject. The examples used were always treated as examples of the theories they exemplified not as something to remember by heart. This view is in concordance with Alters & Nelson (2002) who shows that too many details make the theory invisible.

The study of student development during three learning situations showed relatively low degree of development but this part of the study was only of one month's duration. This may partly be due to how the assessment was made. The assessment tool used seemed quite simple, to evaluate development out of four well defined criteria. But as two different persons, one with some experience of the theory and the other without any earlier experience we may have overestimated the method. One criterion, *Rigor*, showed a low rate of acquired knowledge development. The reason behind that could be in the nature of the theory behind *Rigor* itself, and the students' understandings of it. This instrument for assessment needs to be altered to be possible to serve as a reliable tool for measurement. Further research is needed in order to reveal if the instrument and Doll's 4R theory are useful as curriculum and measuring tool for knowledge development (Stenhols, 2014).

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References

Alters, B. J. & Nelson C. E. 2002. Teaching evolution in higher education. *Evolution* 56: 1891–1901.

Anderson, L.W., Kratwohl, D.R., Airasian, P.W., Cruikshank, K.A., Mayer, R.E., Pintrich, P.R., et al (Eds.) 2001. *A Taxonomy for learning, Teaching, and Assessing. A Revision of Bloom's Taxonomy of Educational Objective.* Longman, New York.

Brown M. 2008 Comfort Zone: Model or metaphor? *Australian Journal of Outdoor Education* 12(1), 3-12.

Doll, W. E., Jr. (1993). *A post-modern perspective on curriculum.* New York: Teacher College Press.

Freire, P. (1970). Pedagogy of the oppressed. New York & London: Continuum.

Freire, P. (1975). Education for critical consciousness. New York & London: Continuum.

Garet, M. S., Porter, A.C., Desimone, L., Birman, B.F. & Yoon, K.W. (2001). What Makes Professional Development Effective? Results From a National Sample of Teachers. *American Educational Research Journal*, 38, 915-945.

Hendricks, C.C. (2010) Teaching Causal Reasoning Through Cognitive Apprenticeship: What Are Results From Situated Learning? *The Journal of Educational Research*, 94:5, 302-311, DOI: 10.1080/00220670109598766

Luckner, J. L., & Nadler, R. S. (1997). *Processing the experience: Strategies to enhance and generalize learning* (2nd ed.). Dubuque, IA: Kendall Hunt.

Mutvei, A, & Mattsson, J.-E. (2014 a) Performance assessment of practical skills in science in teacher training programs useful in school. In Constantinou, C. P., Papadouris, N. & Hadjigeorgiou, A. (Eds.) E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning Part 11 (co-ed. Millar, R and Dolin, J.) (pp. 3-12) Nicosia, Cyprus: European Science Education Research Association. ISBN: 978-9963-700-77-6. http://www.esera.org/publications/esera-conference-proceedings/science-education-research-for-evidence-/

Mutvei, A, & Mattsson, J.-E. (2014 b) The impact of performance assessment on science education at primary school. In Constantinou, C. P., Papadouris, N. & Hadjigeorgiou, A. (Eds.) E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning Part 10 (co-ed. Dillon, J. and Redfors, A.) (pp. 34-41) Nicosia, Cyprus: European Science Education Research Association. ISBN: 978-9963-700-77-6. http://www.esera.org/publications/esera-conference-proceedings/science-education-research-for-evidence-/

Mattsson, J.-E. & Lättman, H. 2004. Chaos and order in teaching and research. *Acta Univ. Ups. Symb. Bot. Ups*. 34:1, 245–255. Uppsala.

Mattsson, J.-E, & Mutvei, A. (2014) Aim: To practise scientific methods. Result: Personal development.. In Constantinou, C. P., Papadouris, N. & Hadjigeorgiou, A. (Eds.) E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning Part 13 (co-ed. Avraamidou, L. and Michelini, M.) (pp. 188-195) Nicosia, Cyprus: European Science Education Research Association. ISBN: 978-9963-700-77-6. http://www.esera.org/publications/esera-conference-proceedings/science-education-research-for-evidence-/

Stenhols, M. (2014). Dolls 4R: Ett mått på kunskapsutveckling?– En studie om bedömning av studentens kunskapsutveckling. (Student paper). Södertörns högskola.

Skolinspektionen (Swedish Schools Inspectorate) (2012) "Min blev blå" – men varför då? *Skolinspektionens rapport* 2012:2.

Skolverket (Swedish National Agency for Education). (2011) *Curriculum for the compulsory school, preschool class and the recreation centre 2011*. Stockholm: Skolverket.