Theory and practice in lab work – a complex interplay

We propose an empirically based research project with the aim to investigate the complex *interplay* between learning of theory and learning of practice in computer programming through laboratory work. Computer science students need to learn both the theoretical foundations and the practical skills required to program a computer. In the present proposal, we refer to this as *learning of theory* and *learning of practice*, respectively. The aim for the project is to gain insights about what is required in order that students' learning of practice and learning of theory during lab sessions can support each other mutually. Previous research has shown that learning in the laboratory is problematic, in that neither the learning of theory nor the learning of practice during lab work is satisfactory (e.g., Eckerdal, 2009; Hofstein & Lunetta, 2003; McCormick, 1997; Séré, 2002; von Aufschnaiter and von Aufschnaiter, 2007). In the past, research about learning during lab sessions has mainly focused on *either* the role of theory *or* the role of practice in laboratory work, whereas our focus will be on the interplay between them.

Objective and goals

Specifically, we will study lab-based teaching and learning of computer programming at upper secondary schools and in higher education. Although we focus on a particular subject area, some of the results of our project may be transferable to other subject areas within the field of science and technology (Eckerdal, 2009; Hofstein & Lunetta, 2003; McCormick, 1997; Séré, 2002; von Aufschnaiter and von Aufschnaiter, 2007).

The overarching research question for our project is:

- *How can we understand, describe and develop learning and teaching in lab work, with particular focus on the relation between students' learning of theory and their learning of practice?*

Based on this question, we formulate the following specific research questions that reflect different levels of abstraction and different objectives:

- **Q1**: On a **theoretical level** and with the objective to better understand learning during lab work:
  How can the interplay between students' learning of theory and their learning of practice in lab work be described?
- **Q2**: On an **empirical level** and with the objective to understand students' learning in specific lab situations:
  What is the relation between students' learning of theory and their learning of practice in some concrete lab sessions?
- **Q3**: On the **level of contribution to educational practice,** with the objective to enhance lab-based teaching and learning:
  What implications do the answers to the previous questions have for teachers who design lab exercises, for lab-based education in general and for teacher training in disciplines where lab work constitutes an important element of the education?

Survey of the field

As this application has a cross-disciplinary character, this overview is structured into three sections, each focusing a particular sub-field.

Research on learning to program. Beginners' courses in programming are taught both at upper secondary school and at universities in Sweden, and are, at both levels, regarded as hard to learn (see for example Kinnunen, 2009; Greening 1998). Despite the extensive body of knowledge concerning learning of programming (e. g. students' understanding of key concepts, Eckerdal (2009), Sorva (2008); students' ability to read and debug code, Lister et al. (2009); introduction of new ways of teaching, Beck and Andres (2004), Linn (2005); misconceptions, Fleury (2001); teachers' understanding of their teaching, Berglund et al. (2009)), the problem persists.

About theory and practice. Bransford et al. (2000; with reference to Ericsson et al., 1993) say that "learning is most effective when people engage in 'deliberate practice' that includes active monitoring of one's learning experiences". This requires that students can discern the meaning of the practice they perform and the theory that relates to this practice. Any practice (drill, following procedures) does not necessarily lead to good understanding.

In educational contexts the use of the concepts of theory and practice is not unproblematic. In Western culture there seems to be an accepted agreement that theory and practice are opposite parts of a dualistic opposition; knowledge is regarded as either theoretical or practical (Gustavsson, 1996; Molander, 1997; Saugstad, 2006). The dichotomy between the two concepts is reflected not only in the differentiation between practical and theoretical knowledge but also in the differentiation between theory oriented and practice oriented educational programs. In vocational training, e.g. in teacher training, the placement part (VFU) has been seen as practical and the university located part as theoretical (Carlgren, 2003; Selander, 2003, 2006). The aim of practical elements in educational settings is to help students connect the observable with the theoretical descriptions of phenomena (Millar, Le Maréchal & Tiberghien, 1999). There is however no clear link between a theoretical instruction and a lab or field trip. Research has been able to show positive effects of deliberate strategies to develop a lab or an excursion in a way that ensures that students see the link between the lab activity and the theoretical analysis presented by the teacher. The importance of the relationship between theory and practice has only recently been problematised in the world of education (McCune and Hounsell, 2005; Saugstad, 2006; Eriksson, 2009). Recent studies also point to the need of further research in the field (von Aufschnaiter and von Aufschnaiter, 2007 ; Eckerdal, 2009).

Lab work in educational research. To our knowledge, there is virtually no previous research about the relation between students' learning of theory and learning of practice in computer science lab work. In other subject areas with lab work, the problematic nature of this relation is recognized, but little explored. For example, von Aufschnaiter and von Aufschnaiter (2007) write about physics students' learning in the lab: "we do not yet know under exactly which circumstances students are more likely to connect theory to practice, which activities are more likely to result in a 'better' understanding and which are not".

According to educational research about laboratory work in natural science education (Helldén et al., 2005) there are a number of factors that affect learning from lab other than the task itself. Students' understanding of the purpose of the lab and its context has been found very important (Harlen, 2001). Where and when the lab takes place is another important factor. If students may work with the same lab in different settings, e.g. in a leisure environment and in school, the result from the lab will be quite different (Newman, Griffin & Cole, 1989). Based on recordings of students' conversations with each other during lab sessions in zoology, Wickman (2002) has shown that students made very few generalizations based on what they saw in the lab. They took much more attention from what they had read in the course books or picked up during lectures. This should however not be interpreted as if the students lack the ability to make their own generalizations (Wickman & Östman, 2002a). Learning from lab could rather be described as a "change of discourse" (Wickman & Östman, 2002b). According to White (1996) teachers pointing out possible links with other subjects and disciplines has proven to be an important part of learning in the laboratory. A clearly pronounced link helps students understand the purpose and point of the lab. The central role of the teacher is pointed out also in research about laboratory work with computers in mathematics (Engström, 2006). The quality of the task given to students, how the task is presented and to what extent the students are given the opportunity to explore the full potential of the software is mentioned as important factors for learning in lab situations.

As shown above, previous educational research has shown the complex relationship and mutual dependency between theory and practice in students' learning in the laboratory. The students need to learn both theory and practical skills. The way theory and practice scaffold each other is an example of learning efficiency for higher cognitive processes. Previous research from natural science and mathematics has pointed to the lack of understanding on how theory and practice relate in students' learning. The present project aims to fill this gap.

Project description

Theoretical framework. Our research framework will be phenomenography and variation theory (Marton & Booth, 1997; Marton & Tsui, 2004). Phenomenography is a qualitative research approach. The objective is to understand and describe the *variation* in how a phenomenon is experienced by a group of persons, for example students. Data are typically collected via semi-structured, individual interviews. These interviews are transcribed and then analyzed in an interpretative, iterative process, where the researchers look for common themes in the collection of interviews. In a phenomenographic analysis, the goal is to identify and describe *qualitatively different ways* in which students experience a phenomenon related to the subject matter. For example, we have made phenomenographic investigations of students' notions of the concepts of "object" and "class" in object-oriented programming (Eckerdal, 2009).

The immediate result of a phenomenographic study is a so called "outcome space" consisting of *categories of description* of qualitatively different ways of experiencing a phenomenon, within a group of students, as interpreted by the researcher. These qualitatively different ways of experiencing are furthermore organized hierarchically, in a way that exhibits a "logical" relationship between the different categories of description. To explain this briefly, but over-simplified, we can think of the hierarchy as an ordering of the categories of description with respect to how well they correspond to the established "expert" notion of the phenomenon. Phenomenographic outcome spaces are of direct use for education. They provide an empirical basis for teachers' reflection on how to create possibilities for students to get a more complete understanding of the corresponding phenomena.

Variation theory is a further development of phenomenography, with a potential to give even stronger implications for teaching. In variation theory, the phenomenographic outcome spaces are subject to a closer analysis, to pin-point precisely in what ways the qualitatively different categories of description differ. What different aspects of the phenomenon are in focus in one category of description but not in another? The different aspects that constitute these critical differences between the categories of description are said to correspond to different *dimensions of variation*. Variation theory says that in order for a student to "see" the phenomenon in a new and more complete way, it is necessary for the student to become aware of an additional dimension of variation or of some relation between dimensions of variation that the student had not discerned before. From this perspective, a challenge for the teacher is to use carefully planned *patterns of variation* to create possibilities for students to get this kind of new insight.

Furthermore, variation theory discusses the space of learning that is opened in a learning situation in terms of the *intended object of learning*, the *enacted object of learning*, and the *lived object of learning*. The intended object of learning is the object of learning as seen from the teacher’s perspective and the lived object of learning is the object of learning as seen from the student’s point of view, i.e., the actual outcome of learning. Finally, the enacted object of learning, briefly explained, is a researcher’s description, from a particular theoretical perspective, of what the possibilities are for seeing a certain object of learning in a certain learning situation.

Implementation, setting and research methods. The analytical separation between the intended, enacted and lived object of learning will be used as the structural backbone of the proposed project. We will collect and analyze data with the purpose to describe these three objects of learning and their interrelations in the context of specific lab sessions in introductory programming courses on upper secondary school and university level. We aim to answer the following sub questions:

- What are students’ learning opportunities (the enacted object of learning) and learning outcome (the lived object of learning) in these lab sessions?

- What are the differences between students' actual learning opportunities and the learning opportunities the teachers' intended to provide them with (the intended object of learning) in the lab?

In addressing these sub questions, we will focus on both theoretical and practical objects of learning. The answers to the sub questions will provide a basis for answering our empirical research question concerning the relation between learning of theory and learning of practice in some specific lab sessions (research question Q2, p 1). The insights gained from these empirical investigations will then be used as a basis for an answer to our theoretical research question about the relation between learning of theory and learning of practice in lab work (research question Q1, p 1). Finally, we will discuss the implications for educational practice of these empirical and theoretical results (research question Q3, p 1).

Data collection. The project will collect data from students and teachers in upper secondary school as well as from university level. It is likely that a study involving both these levels can help to chisel out how theory and practice relate to and interplay with each other. We have a very good basis for selecting teacher informants, since the applicants from Stockholm University/KTH have a large network of contacts with teachers in upper secondary school and the partners from Uppsala University have a corresponding network of contacts with university teachers. When the teachers have been selected, groups among their students will be selected as student informants.

Intended object of learning: For the project, we will select a few topics that are typical elements of an introductory programming course, and that are commonly trained via exercises in the computer lab. Each teacher informant in the project will be interviewed about how he/she has designed these lab exercises: what are the intended objects of learning in the exercise and how does the teacher motivate the design of the exercise, in view of these learning objects? Both learning of practice, learning of theory, and the interrelation between these different learning objectives, will be addressed in the interviews.

Enacted object of learning: Data for investigation of the enacted object of learning will be collected in the form of (a) the material provided by the teacher as input for the students (written instructions, ready-made software to use in the lab, etc.) and (b) video recordings of lab sessions.

Lived object of learning: After each lab session, we will use the video recording for a "stimulated recall" interview with students about their learning experiences during the session. Particular emphasis will be on finding out what the students focussed on during the lab session.

Analysis. For the analysis, all interviews will be transcribed. These transcripts and the video recordings will form the basis for analysis and conclusions.

Intended object of learning: The interview transcripts will be read with the purpose to identify each teacher informant's intended objects of learning for each of the lab exercises in focus. Moreover, we will use content analysis to analyze the motives given by the informants for how they designed the exercises. The goal is to broadly categorize teacher's ways of thinking about design of exercises in introductory programming courses, in relation to common practice-oriented and theory-oriented learning objectives in that subject area.

Enacted object of learning: The collected data as discussed above (learning material, provided by the teacher, and video recordings) will be analyzed from a variation theoretical point of view. Phenomenographic outcome spaces from previous research in computer science education will provide a basis for identifying dimensions of variation in this subject area. In our analysis, we will investigate the learning material and the video sequences to look for dimensions of variation that could be possible to discern during each lab session. Finally, for each such dimension of variation, we will make an argument about whether and how practice-oriented and theory-oriented learning objectives for the lab exercise relate to this dimension. This will serve as a description of the enacted object of learning. This is based on the variation theoretical analysis proposed by Eckerdal (2009), according to which both practice-oriented and theory-oriented learning goals can relate to dimensions of variation.

Lived object of learning: The investigation of the lived object of learning will be based on an analysis of the transcripts of "stimulated recall"-interviews with students, from a variation theoretical point of view. As mentioned above, the particular emphasis of those interviews will be on finding out what the students focussed on during the lab session. This is a way of getting at what the students came to "see" during the interviews. Although we can never be sure that what they say is what they actually saw, a stimulated recall session has the potential to help students to remember what caught their attention during the lab session. The goal for the analysis, related to the lived object of learning, is to identify (a) aspects of the object of learning that came into focal awareness for the students during the lab session, and (b) what it was that made them become aware of these aspects. Regarding (b), we will both consider the learning material and the interactions that took place during the lab session (student-student, student-teacher, and student-artefact interaction).

Concluding analysis. The analyses described above will focus on the three analytically separated objects of learning: intended, enacted and lived, respectively. By putting these results beside each other in a concluding analysis, we aim to provide a nuanced description of the interplay between learning of practice and learning of theory in introductory programming, and of what factors that can enable (or hinder) an alignment between intended, enacted, and lived learning objects in that context. More precisely, at this point we will have analyzed data from a pool of different lab sessions. By identifying and describing what characterizes the cases where we see a relatively good alignment between the three objects of learning (and vice versa), we will shed light upon how the learning of theory and the learning of practice have interacted in the different cases. This connects back to our overarching research question and has a potential to inform teaching practice in lab-based programming education.

Close link to teachers' practice. In the spirit of "scholarship of teaching and learning", we will involve the teacher informants more closely in the project in continuous dialogue. To provide additional input for our analysis, we will use the video recordings for "stimulated recall" interviews where we ask the teachers about their experiences of these lab sessions, and ask them to reflect upon the learning outcome. Moreover, at various stages in the project we will arrange meetings where we discuss implications for teaching. After these meetings, we will once again interview each teacher about his/her view on learning objectives and design of lab exercises, in relation to practice-oriented and theory-oriented contents in introductory programming courses. The aim is to see how the teachers' participation in the project has developed their way of seeing these things.

Time schedule. The project spans over three years according to the following plan:

Spring 2012	Pilot study - including video documentation (students in lab), interviews (teachers and students). Focus groups (involved teachers). Tentative analyses. Planning of main study in interaction with advisory board .
Autumn 2012	Main study: Data collection (class room activities): video documentation and interviews (students and teachers). Meetings with involved teachers (focus groups). First analyses.
Spring 2013	Complementary data collection. Summarising meetings with teachers. Further analyses of collected data and occurring textbooks and lab instructions. Meeting with advisory board.
Autumn 2013	Further analyses. Deskwork. Focus groups with involved teachers (briefing and discussions). Dissemination (first results): papers presented at regional and national conferences.
Spring 2014	Further analyses. Deskwork (reports, articles). Dissemination: papers presented at national and international conferences. A national/Nordic conference, including advisory board.

Autumn 2014 Deskwork (reports, articles). Discussion with advisory board. Dissemination: Publications in journals and international conferences and doctorial thesis (Lennart Rolandsson).

Significance

Previous research has pointed to a need for—and lack of—research on the complex relation and interplay between learning of theory and learning of practice in laboratory-based learning (Eckerdal, 2009; Hofstein & Lunetta, 2003; McCormick, 1997; Séré, 2002; von Aufschnaiter and von Aufschnaiter, 2007). Our project has the aim and potential to make significant contributions to a more nuanced understanding of this relation. Our particular focus will be on laboratory-based learning in introductory computer programming education. We also expect the general findings to be transferable to laboratory-based teaching and learning in other subject areas. The aim is to reach insights about how lab exercises can be designed in such a way that learning of theory and learning of practice during the lab session support each other mutually.

The case of learning through computer lab exercises is a particular instance of learning activities in general. This is one of the main forms of learning activity in natural science and technology domains and also increasingly common in social and human sciences due to the access to digitally stored social and historical data. We expect that the general insights from our project, concerning the interplay between practice-oriented and theory-oriented learning in lab contexts, will be transferable to subject areas other than computer science.

Results such as the ones we envisage have potential to contribute to a better learning outcome for students in computer programming. This adds to the satisfaction of learners and teachers. Moreover, there is a potential for economic gains, both directly, in reducing the dropout and re-examination rates, and indirectly, in providing the labour market with better-qualified staff. Due to the important role of computer science in modern society, the training in this field is a significant educational task. We expect the results to have an impact on teacher training, by providing deeper insight into the interplay between learning of practice and learning of theory, and, consequently, an improved basis for the design of lab exercises in Computer Science. It can be noted that this is a young area, where the didactics knowledge base for teacher training is comparatively small. The relative importance of new contributions is consequently large.

Preliminary results

Eckerdal (2009) used variation theory to investigate the relation between learning of practice and learning of theory in introductory programming courses. A main finding was that theory-oriented and practice-oriented subject matter can relate to the *same* dimensions of variation. This indicates that such dimensions of variations are keys to understanding the interplay between learning of theory and learning of practice. This will be further explored in the proposed project.

According to Rolandsson (ongoing) upper secondary school education in programming is mainly focused on practice. Educational settings are mainly aligned for an individual constructive pedagogy with student-computer interaction. The majority of Rolandsson's teacher-informants explicitly declare that they are typically concerned during class with fundamental syntax in programming languages and that they rarely address theoretical aspects of programming. Nevertheless, the teacher-informants are aware that students in programming should learn strategies and structures for deeper understanding, which is also emphasized in computing education research (Linn & Dalbey, 1989; Robins et al., 2003), and which would require a theoretical underpinning.

Eckerdal and Thuné have very recently received a grant from *Forum för ämnesdidaktiska studier* at Uppsala University for a small pre-study during Autumn 2011, to try out and fine-tune the methodology proposed for this very project.

The project’s relevance for Educational Sciences

This is a practice -based research project where upper secondary school teachers and teachers at university will be actively involved in different phases of the project. The study will also result in suggestions concerning teaching methods in programming courses. The project's relevance for Educational Sciences can be summarized as follows:

- The project will develop understanding of teaching and learning of theory and practice in lab situations.
- The focus of this project - teaching and learning programming - is a neglected research area in Sweden and internationally.
- This project is a rare example of practice- based research involving teachers in upper secondary school and at university level.
- The project opens up for comparison of teaching strategies in programming courses in upper secondary school and at university level (content, context and tradition).
- This study will result in suggestions, developed in cooperation between teachers and researchers, concerning lab-based teaching methods in programming courses. developed in cooperation between in service teachers and researchers

Collaborating institutions

The proposed project is a collaborative effort between Stockholm University (SU)/Royal Institute of Technology (KTH)[1] and Uppsala University (UU). The partners at SU/KTH contribute expertise in teacher training and related research, focussing on the teacher profession, in particular on secondary school level. The partners at UU have specialised in student centred investigations of learning in Computer Science on university level, using phenomenography and variation theory. Since the present project includes both teacher- and student-centred aspects, in secondary school as well as at university, the collaboration is essential for success.

Both collaborating partners have strong networks in research in programming and computing. At SU, organized seminaries have been arranged to achieve trust between teachers and the educational research in programming. With the help of Teknikum (www.utep.su.se) important relations have been established between the domains of educational science, computing educational research and practicing teachers, which has meet a considerable interest all over Sweden.

Stockholm University, Royal Institute of Technology and University of Gävle have since 2008 enacted a research school with 12 doctoral students, for enhancing the important didactic questions concerning technology education and the decreasing numbers of students attending courses in natural sciences. One of the project participants, Lennart Rolandsson, has been financed through this school.

Uppsala Computing Education Research, UpCERG, is internationally highly recognized within the field of research of computer science, including programming. The group has presented over 60 reviewed publications (in journals and at conferences) 2006 – 2009, and has co-authored these publications with approximately 60 researchers from many different research groups from many countries.

At both universities there are established contacts with individual researchers, research groups, teachers and other actors relevant to the project. In terms of research contacts e.g. Graduate School TUFF (SU), Centre for Technology Education (SU), Technology Education Research Unit (Goldsmiths College, London).

An international advisory board, consisting of internationally recognised researchers within education and computer science, will be connected to the project.

- Pang, Ming Fai, Associate Professor in Education, the University of Hong Kong and Visiting Professor at Gothenburg University (2010). Prof. Pang will contribute with his world-leading competence in phenomenography and variation theory.

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[1] Co-applicant Inga-Britt Skogh is expected to become affiliated with KTH during 2011, as visiting professor in "*teknikens didaktik*"/Engineering Education Research (the application process for this position is ongoing). Ph.D. student Lennart Rolandsson is affiliated with SU during his ongoing studies towards the licentiate degree.

- Wickman, Per-Olof, Professor and Director of Science Education at the Department of Education in Mathematics and Science at Stockholm University will contribute with his competence in research about laboratory work in science education.
- Petre, Marian, Professor in Computing, The Open University, UK. Prof. Petre will contribute with her methodological competence in empirical studies, as well as program design and computer science.
- Carsten Schulte, Professor in Computer Science Education, Freie Universität Berlin. Prof Schulte will contribute with his competence on high school education in computer science.

The international advisory board will meet in Uppsala once every year, to serve as a sounding board and vehicle for quality insurance. During the meeting, the plans for the coming year will be settled in detail. The last meeting will be arranged as a national/Nordic conference, aiming also to disseminate the results from the project. We also plan to do two academic visits, to work closely with members of the advisory board, for one month.

Work distribution within the project

Anders Berglund (30%) is senior lecturer at Uppsala University and holds a PhD in Computer Science with specialization in Computer Science Education. Berglund is engaged in the computing education research community, both at national and at international level. In this project he will be particularly involved in the student oriented parts of the project and will focus his efforts on the analyses of data from the students, as well as in the theoretical underpinnings of final results.

Anna Eckerdal (50%), lecturer at Uppsala University, earned her PhD in Computer Science with specialization in Computer Science Education in March 2009. Eckerdal has long experience in teaching programming at upper secondary school as well as at university level. Eckerdal is engaged in the computing education research community, both at national and at international level. In this project she will, together with Michael Thuné and Anders Berglund, in particular be involved in the student oriented parts of the project. Eckerdal will, as the principal investigator, also be responsible for coordinating the project group meetings, and for assembling the results of the project.

Inga-Britt Skogh (10%), associate professor in pedagogy at Stockholm University and Head of Graduate School Technology Education for the Future has extensive experience of teachers education in technology and related research. In this project she will, together with Lennart Rolandsson, in particular be involved in the teacher oriented parts of the project.

Lennart Rolandsson (75 %) is upper secondary school teacher in computer science, and PhD student at the Graduate School Technology Education for the Future. He plans to defend his licentiate thesis in August 2011. Rolandsson has 15 years of experience from secondary school and vocational education for telecom industry, and is the initiator of PROLÄR, a national network for programming teachers. In this project he will, together with Inga-Britt Skogh, in particular be involved in the teacher oriented parts of the project. Rolandsson will also be responsible for the meetings with the group of teachers.

Michael Thuné (10%) is professor of Scientific Computing at Uppsala University and responsible for the computing education research area at the department. He has a long career as university teacher. In recent years, he has engaged in computer science education research. In this project he will, together with Anna Eckerdal and Anders Berglund, in particular be involved in the student oriented parts of the project.

Shares of Project costs

The funding applied for from the Swedish Research Council amounts to 100 % of the total costs for the project, per year.

Ethical Considerations

The proposed project is such that the principles of research ethics issued by the Research Council for Human and Social Sciences (March 1990; revised April 1999)—and referred to by the Swedish Research Council (VR) in the publication "*Vad är god forskningssed?*" (Gustafsson et al., 2005) are applicable. We will adhere to these principles. For example, informant participation will be voluntary, and the researchers will not collect data from informants that are in a dependency relation to them. With respect to confidentiality, data will be safely stored, and results will be presented in such a way that individuals cannot be identified.

References

Beck, K., & Andres, C. (2004). Extreme Programming Explained: Embrace Change (2nd Edition): Addison-Wesley Professional.

Berglund, A., Eckerdal, A., Pears, A., East, P., Kinnunen, P., Malmi, L., et al. (2009). Learning Computer Science: Perceptions, Actions and Roles. European Journal of Engineering Education (34), 327 - 338.

Bransford, J. D., Brown, A. L. & Cocking, R .R. (2000). How people learn: Brain, mind, experience, and school. Washington, DC: National Academy Press.

Carlgren, I. (2003). Teoretiska praktiker och praktiska teorier. I A. Bronäs & S. Selander (Red.), Till frågan om teori och praktik i akademisk yrkesutbildning. Ett diskussionsunderlag. Stockholm: DidaktikDesign Lärarhögskolan i Stockholm.

Eckerdal, A. (2009). Novice Programming Students' Learning of Concepts and Practice. Uppsala, Sweden: Acta Universitatis Upsaliensis

Engström, L. (2006). Möjligheter till lärande i matematik. Lärares problemformuleringar och dynamisk programvara. Studies in Educational Sciences 81. Stockholm: HLS Förlag

Eriksson, Å (2009). Om teori och praktik i lärarutbildning. En etnografisk och diskursanalytisk studie. Göteborg Studies in Educational Sciences 275. Göteborgs universitet.

Ericsson, A. K., Krampe, R. T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. Psychological Review, 100(3), 363-406.

Fleury, A. E. (2001). Encapsulation and Reuse as Viewed by Java Students. In proceedings of ACM SIGCSE Bulletin.

Greening, T. (1998). Computer Science: Through the eyes of potential students. Paper presented at the Proceedings of the ACSE 1998 Conference, Brisbane, Australia, 145–154.

Gustafsson, Bengt – Hermerén, Göran – Petersson, Bo (2005), Vad är god forsknings-sed? Synpunkter, riktlinjer och exempel. (Vetenskapsrådets rapportserie nr. 1). Stockholm: Vetenskapsrådet.

Gustavsson, B. (1996). Bildning i vår tid. Om bildningens möjligheter och villkor i det moderna samhället. Stockholm: Wahlström & Widstrand.

Harlen, W. (2001): The assessment of scientific literacy in the OECD/PISA project. I H. Behrends, H. Dancke, R. Duit, W. Gräber, M. Komarek & A. Kross, red.: Research in Science Education – past, present and future (s. 49–60). Dordrecht: Kluwer Academic Publisher.

Helldén, G., Lindahl, B. and Redfors, A. (2005). Lärande och undervisning i naturvetenskap - en forskningsöversikt. (Vetenskapsrådets rapportserie nr. 2). Stockholm: Vetenskapsrådet.

Hofstein, A., & Lunetta, V. N. (2003). The Laboratory in Science Education: Foundations for the Twenty-First Century. Science Education, 88(1), 28 - 54.

Kinnunen, P. (2009). Challenges of teaching and studying programming at a university of technology - Viewpoints of students, teachers and the university. Doctoral dissertation, TKK Research Reports in Computer Science and Engineering A, TKK-CSE-A4/09, Department of Computer Science and Engineering, Helsinki University of Technology, 2009.

Linn, M. C. and Dalbey, J. (1989). Cognitive consequences of programming instruction. In E. Soloway & J.C. Sphorer (Eds.), Studying the novice programmer (pp.57-81). Hillsdale, NJ: Lawrence Erlbaum.

Linn, M. (2005). Designing computer learning environments for engineering and computer science: The scaffolded knowledge integration framework Journal of Science Education and Technology, 4(2), 103 – 126.

Lister, R., Clear, T., Simon, Bouvier, D. J., Carter, P., Eckerdal, A., Jackova', J., Lopez, M., McCartney, R., Robbins, P., Seppälä, O. and Thompson, E. (2009) *SIGCSE Bull.* 41(4).

Marton, F., & Booth, S. (1997). Learning and awareness. Mahwah, New Jersey, USA: Lawrence Erlbaum Associates.

Marton, F., & Tsui, A. (2004). Classroom Discourse and the Space of Learning. Mahwah, NJ, USA: Lawrence Erlbaum Ass.

McCormick, R. (1997). Conceptual and Procedural Knowledge. {International Journal of Technology and Design Education, 7(1 - 2), 141 - 159.

McCune, V. & Hounsell, D. (2005) The development of students’ ways of thinking and practising in three final-year biology courses. Higher Education, 49, 255-289.

Molander, B. (1997). Praktiska och teoretiska kunskapstraditioner. Utbildning och demokrati, 3, 7-18.

Millar, R., Le Maréchal, J.F & Tiberghien, A.(1999). Mapping the domain. Varieties of practical work. I J. Leach. & A. Chr. Paulsen, red.: Practical Work in Science Education. – Recent Research Studies. Dordrecht/Roskilde, Kluwer Academic Publishers/Roskilde University Press.

Newman, D., Griffin, P & Cole, M. (1989). The construction zone: Working for cognitive change in School. New York, Cambridge University Press.

Robins, A., Rountree, J., & Rountree, N. (2003). Learning and Teaching Programming: A Review and Discussion. Journal of Computer Science Education, 13(2), p.137-172.

Saugstad, T. (2006) Aristoteles tankar om yrkesutbildning. (E. Insulander, övers.). I A. Bronäs & S. Selander (Red.), Verklighet, verklighet. Teori och praktik i lärarutbildning (s.58-73). Stockholm: Nordstedts Akademiska Förlag.

Selander, S. (2003). Praktiskt förnuft – förnuftig praktik. Om yrkesskicklighet och institutionell kompetens. I A. Bronäs & S. Selander (Red.), Till frågan om teori och praktik i akademisk yrkesutbildning. Ett diskussionsunderlag (s 7-17). Stockholm: Lärarhögskolan i Stockholm.

Selander, S. (2006). Kunskapsformer, topiskt tänkande och tolkningspraktiker. I A. Bronäs & S. Selander (Red.), Verklighet, verklighet. Teori och praktik i lärarutbildning (s.25-40). Stockholm: Nordstedts Akademiska Förlag.

Séré, M.-G. (2002). Towards Renewed Research Questions from the Outcomes of the European Project Labwork in Science Education. Science Education, 86(5), 624 - 644.

Sorva, J. (2008). Students’ Understandings of Storing Objects. Australian Computer Science Communications, 127 - 136

von Aufschnaiter, C. and von Aufschnaiter, S. (2007) University students' activities, thinking and learning during laboratory work. EUROPEAN JOURNAL OF PHYSICS, 28(3):51-60

White, R.T. (1996). The link between the laboratory and learning. International Journal of Science Education 18(7), 761–774.

Wickman, P.O. (2002). Vad kan man lära sig av laborationer? I H. Strömdahl, red.: Kommunicera naturvetenskap i skolan. Lund: Studentlitteratur.

Wickman, P-O. & Östman, L. (2002a): Induction as an empirical problem: how students generalize during practical work. International Journal of Science Education, 24, (5), 465–486.

Wickman, P-O. & Östman, L. (2002b): Learning as Discourse Change: A Sociocultural Mechanism. Science Education, 86 (5), 603–623.