2017-02-28

Physics Education Research (PER) at Uppsala University

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Background

The Physics Education Research (PER) group at Uppsala is unique in Sweden, possibly in the Nordic countries, with a profile that involves both deep knowledge of physics as a research endeavour and as an educational programme, as well as the discipline of educational science in terms of theoretical, philosophical and methodological underpinnings. The research focus is on what it takes to learn and teach physics in higher education, principally for the profession of physics but also including teacher education, centred on conceptual understanding in the context of social resources, such as mathematics, language, representations, and interactive artefacts. It has a particularly strong basis in the methodologies of educational science research, including phenomenography, the variation theory of learning, discourse analysis, social semiotics, complexity theory, socio-cultural theory, and cultural-historical activity theory (CHAT). Members of the group have been successful in obtaining substantial research funding in the extremely competitive environment of the Educational Science division of the Swedish Research Council, with two current projects and 7 previous projects stretching back to 2003. Since its inception 7 doctoral degrees have been awarded, and there are currently 6 doctoral students. In the past three years over 90 publications in refereed journals and peer-reviewed conferences have been authored or co-authored by members of the group. PER at UU belongs to a strong and well-developed international network of physics higher education research groups, including South Africa, Germany, USA, Canada and Australia. A recent network is emerging in Sweden as experienced researchers and recent PhDs are gaining positions to establish PER at other Swedish universities, Lund and Stockholm as well as Oslo.

Given this unique research history and the strength of the work being produced, it is the strong recommendation of the panel that funding should be made available to ensure that it can continue in the face of two encroaching situations, one long-term and one short-term, which we come to below.

Setting PER in Context

Before reporting on our considerations, we would like to draw attention to the distinctions between three areas in which higher education is intertwined with physics. First, there is academic development (also called pedagogical development or staff development) which, in Sweden at least, is mandatory at all institutions of higher education for supporting the practices of teaching, in particular for new appointees and the on-going practices of curriculum renewal and evaluation. Second, there is the emerging field of the Scholarship of Teaching and Learning (SoTL), under which umbrella teachers of physics study and report on aspects of their own and/or their colleagues' teaching and/or their students learning. SoTL

is generally directed at improving individual and local practices, and should be considered by all those who teach. Thirdly, there is Physics Education Research (PER)[1], generally (though not necessarily exclusively) oriented to studies of systems, approaches, and tools used in teaching and learning in higher education.

These three areas are distinguished by the staff who engage in them and their qualifications, the work they engage in, and the audience they direct their work towards. Academic development is generally carried out by experienced university teachers, who have specialised in educational and communicative aspects of teaching, and might come from a variety of disciplines and interact with staff either from the whole university or from specific faculties. SoTL is carried out principally by active teachers in various disciplines who have added some educational investigative approaches to their disciplinary knowledge, and they report and publish their findings to a local community of university teachers as well as a global SoTL community. Physics educational research is generally carried out by researchers who have taken the route from traditional areas of physics research to physics education research via a PhD or equivalent rigorous training, possibly via an extended and creative SoTL engagement in collaboration with experienced education researchers; their aim is to develop intellectual knowledge and tools for better understanding the theoretical underpinnings and practical potentials of physics education.

The three areas are, we would claim, distinct, but they have great potential for interaction to the benefit of all three. Communication and collaboration between the practitioners of the three areas can enhance the teaching at a practical and theoretical level. The distinctions are not necessarily unique to physics, but the growing fields of Discipline-Based Educational Research can, in principle, be established in any academic discipline.

Physics Education Research Contexts: examples from the United States

Physics Education Research is a well-known and highly regarded field of within physics departments internationally. In the United States, the first reported PhD in the field was in 1978 at the University of Washington. Since the early era of only having select institutions involved (including University of Washington, University of Maryland, Kansas State University, and University of Nebraska), PER has grown to a national movement. Roughly 100 institutions of higher education currently boast research groups in physics education, with dozens offering PhDs in the field. Many of the leading and “top-10” institutions in the U.S. host physics education research programs, including but not limited to Harvard University, Cornell University, University of Illinois, University of Colorado, University of Maryland, and University of California. In 1999, the American Physical Society (APS) endorsed the research field in its statement: “Research in Physics Education.” In 2005, APS launched a journal in its main, longstanding line of *Physical Review*, and articles in PER are now appearing in *Science*, *Nature*, *Proceedings of the National Academies of Sciences*, and other leading interdisciplinary journals. In 2013, the APS created a representative unit to oversee the field, the Topical Group in Physics Education Research. There are several, longstanding conferences and associated proceedings where members of the U.S. and international communities gather and publish peer-reviewed works regularly. In parallel to the growth of PER, other fields have been developing research programs within their disciplines, these include but are not limited to: astrophysics, biology, chemistry, geosciences, mathematics, computer science, engineering. Each of these discipline-based education research (DBER) communities hosts its own publication streams, conferences, and organizational structures. Building on this early work, the American Association for the Advancement of Science in collaboration with the Association of Public and Land-grant Universities is now supporting these discipline-based communities in and emerging STEM DBER-Alliance. Commensurate with the breadth and growth of the field of physics education

[1] A proper term in Swedish would be *fysikutbildningsvetenskap*, rather than *fysikens didaktik*.

research, substantial funding is provided from the federal government (National Science Foundation, US Department of Education US Department of Energy) and private foundations (e.g. Alfred P. Sloan Foundation, and the Helmsley Charitable Trust, and Howard Hughes Medical Institute).

The two groups most similar to the Uppsala PER group in the United States are the PER groups at University of Colorado (PER@C) and University of Maryland (UMD PERG). The PER@C group is directed by three tenure line faculty (Finkelstein, Pollock, and Lewandowski). It hosts two research faculty (Dancy, and Perkins), eight postdoctoral researchers, and six graduate students currently. It is among the best funded groups in the country with roughly $ 2.5M USD/ year in funding. It is also among the best published groups in the field. The group is known for its work in theory (drawing from sociocultural traditions and applying them to the disciplines), the study and development of technologies used in teaching physics (PhET Interactive simulations, and modeling affordances of online learning environments), studies of student reasoning (studies of knowledge structures, attitudes and beliefs, interpretations, modeling approaches in experimental physics), and applying these to curricular applications (from introductory and lower division courses to upper division, quantum mechanics, electricity & magnetism, statistical mechanics and labs.) The success of the group has led to campus-wide initiatives (studying and promoting institutional change to scale and sustain the successful PER-based efforts). The PER group has been instrumental in developing a campus-wide movement in DBER, where efforts in educational research and transformation are running in 12 different disciplinary units. The Center for STEM learning coordinates and links among these efforts and has led to recognition of the University of Colorado by the Association of American Universities, and the U.S. White House.

Similar to both the Uppsala PER and the Colorado PER groups, the University of Maryland UMD PER Group is known for its work in both theory, culture, and educational transformation. It is among the longest standing of the PER groups in the US, directed by Professor Edward (Joe) Redish. The group currently is led by three tenure line faculty in physics, several affiliated faculty in other disciplines, two postdoctoral fellows and eight graduate students. The scale of the UMD PER Group is similar to that of Colorado with multi-million dollars in grants in recent years that support a wide array of studies from the cognitive structures that physics students use to address problems, to thinking about how mathematics is used in physics teaching and learning, to leading an interdisciplinary project to develop an introductory physics course for biology majors and premedical students. The efforts in building new course content has been determined by extensive negotiation with biologists and students. No matter the study, the UMD PER Group draws from common methodological tools that privilege studying how students are thinking in authentic, situated environments. UMD PERG is a destination of the top graduate students and postdoctoral researchers in the field, and has been recognized with many awards from campus, and national organizations such as the American Physical Society, American Association for the Advancement of Science, the American Association of Physics Teachers, and the National Science Foundation.

Physics Education Research at UU

Earlier in this report, we outlined three fields of scholarship that are readily related to physics education: physics education research (PER), scholarship of teaching and learning physics (SoTL-physics) and academic development, and we emphasised that we are concerned primarily with the first of these, PER. We have compiled a list of references for the 93 publications authored or co-authored by the senior researchers in the group, from 2014, 2015 and 2016 (appendix 1), which include papers written together with doctoral students from the group, and papers written with local, national and international collaborators. The number of doctoral theses has grown with the maturing of the group, totalling 7, with 3 in the last three years and there are currently six doctoral students in various stages of their work.

The scale of productivity and quality is as high as any of the leading PER groups in the world (the quality aspect is exemplified by the group having articles receive Outstanding Paper awards in 2016 from the European Journal of Physics, Physics Education and the International Journal for Lesson and Learning Studies).

The work of the physics education research programme rests on three theoretical and methodological pillars: the variation theory of learning, language and conceptual understanding, and the significance of social semiotics. In large numbers of the recent (and earlier) publications these can be seen, and the on-going research projects with external funding specifically link the three together. In addition, complexity theory and identity theory have been added to the theoretical repertoire when research issues demanded. With that foundation, research has ranged over a wide variety of physics education situations, as well as furthering the foundations themselves. These methodological approaches allow for research that is relevant and on the leading edge of what is being investigated currently in the global physics education research community.

Recent research by the group has been conducted in a wide array of areas but all output focuses on how students learn and the conditions and tools that support or inhibit learning of physics. Work has been conducted in traditional areas of PER, for example investigating aspects of conceptual understanding that go beyond traditional forms of algorithmic mastery (e.g. Haglund, Andersson & Elmgren, 2015). The group has considered how tools shape student learning, for example on the roles and impacts of interactive devices (e.g. Gregorcic, 2016), and the intellectual tools we deploy, such as learning physics through a second language (e.g. Airey, 2014), or the metaphors and analogies that are used in teaching (e.g. Airey & Berge, 2014). More foundational research has focussed on learning physics in the light of social semiotic resources (e.g. Fredlund, Linder & Airey, 2014), and representations used in learning and teaching physics (e.g. A. Linder, Airey, Mayaba & Webb, 2014). In these and other studies, work has been deeply grounded in the physics knowledge that is addressed - including electricity and magnetism, thermodynamics, astronomy and astrophysics.

The publication list confirms that the most work by the PER group is directly related to physics in higher education, but it can be seen that there are also contributions that lie outside this programme - research oriented to school physics (e.g. Haglund, Jeppsson, Hedberg & Schönborn, 2015), collaboration with university physics teachers outside the PER programme (e.g. Moll, Nielsen & Linder, 2015), and even research that tackles subject areas that are linked to, but separate from physics (e.g. Patron, Wikman, Edfors, Cederblad, & Linder, 2015). Physics in higher education is thus importantly and valuably connected to educational enterprises beyond the department, but can only do so from being grounded in the disciplinary field within higher education -- that is by occurring within the physics department.

In the Quality and Renewal report from 2011 the PER group was evaluated by both the physics and the education panels. The physics panel, admitting its lack of experience of PER, stated that the unit has “a unique research focus in Sweden” (p 310). The education panel refers to the publication record in “internationally recognised journals”, funds obtained in “national and international contexts”, and that “the theoretical sophistication and methodological approaches of the group have important implications for the general field of science teaching at all levels of education”. It assessed the research of the group at the level “internationally high standard” and says it has “potential to become world-leading” (p 143). Since 2011, the group has received further external funding and produced three more doctoral theses, one of which was awarded best thesis of the year within the physics department. In our estimation, the group has become one of the world's leading groups in the field, as can even be seen in Professor Linder being awarded the medal of the International

Commission on Physics Education in 2014 for his “many contributions to Physics Education research” pointing to “its range, depth and impact, as well for its international scope”.

In Sweden there is no organisation comparable with the American Physics Society in the sense of the support given to PER, as described in the previous section; there are organisations concerned with physics at the professional level and with physics (and other STEM subjects) at the level of school education, but nothing that specifically lends support or infrastructure to physics education at the level of higher education. This puts the onus on individual universities, departments and researchers to establish PER, to connect to those international efforts in PER, and to find the necessary funding.

In summary, the programme of the PER group is consistently directed towards fundamental issues that concern learning and teaching physics in higher education, using a number of theoretically sophisticated and methodologically sound and consistent approaches, with what in 2011 was reported as “potential to become world-leading” having now been achieved. At the same time, it is open to the inclusion of research on related issues. The work of the group not only informs the practices of physics education and supplies intellectual tools to address its challenges but it also contributes greatly to the theoretical aspects of the fields of Discipline-Based Educational Research.

Long term situation

The long term situation to be faced is the retirement of Cedric Linder in 2020. Talking to Linder’s colleagues at Uppsala, we are struck by the sense of collegiality and shared commitment to the work of the group, a willingness to work hard at maintaining it and even extending its influence. A search should be initiated for a person with similar interests in research pertaining to teaching and learning physics in higher education, well developed international networks, and strong leadership qualities, who will be able to lead the group into a new and equally productive phase, and maintain the group’s, department’s and institution’s unique standing in Sweden, and its potential to maintain world-leading status.

Short term situation

The short term situation to be faced is that the high and middle level of experience (docent and potential docent) is likely to disappear to permanent positions at other universities, as is already happening. This potentially leaves one supervisor (Prof Linder) with at least 4 doctoral students who will not have graduated before he retires. There is even the threat that with current researchers moving on to academic positions elsewhere and no new post-docs coming along to a shrinking group, by the time Prof Linder retires the group will be too severely weakened to survive.

The opportunities here are twofold. First, the immediate creation of tenure track positions in line with the research profile of the group would offer the experienced staff who are currently employed on grant funding or in temporary post-doc positions the opportunity to stay in the group. This investment would ensure that by the time of Linder’s retirement there is a continuation of doctoral supervision, and leading up to that there is potential for renewal through new external research funds. The second opportunity is that researchers at the middle level of experience - new post-docs and more advanced doctoral students, for example - will be able to participate in activities within the physics department at-large and take part in the education of physics teachers, but decidedly without weakening the commitment to acclaimed physics education research.

A number of scenarios for a viable future for PER at UU

Staffing Infrastructure for PER at UU

For the long term situation, a recruitment process for a full professor should be initiated by 2018, with a profile similar to the current profile – research into physics education at the university level, focusing on issues pertinent to learning and teaching physics in higher education with a range of theoretical underpinnings and methodological approaches. In order to maintain continuity, a position should be created that overlaps with Prof Linder's tenure by 3-6 months. In order for this to be viable, the short-term situation needs to be resolved.

For the short-term situation to be resolved, the current loss of more senior group members, currently employed on soft money, to permanent positions elsewhere needs to be rectified, or at least discouraged. In the immediate future, at least two tenure track positions should be created to enable the group to stabilise and to give the opportunity of appointing new post-docs on non-permanent, research grant funding.

Building Local and Regional Networks

Now that former group members are moving to senior permanent positions elsewhere, with remits and funding to establish PER within physics and astronomy departments in Lund and Stockholm as well as the existing presence at Kristianstad, it is time to establish a formal Scandinavian network and seek funding to support a minimal infrastructure. This could ameliorate the vulnerability of rather small groups, by establishing collaborative supervision and courses. The PER group at Uppsala, with its hitherto unique status and its extensive experience, would be a natural hub for Scandinavian or European networks within which collaborations could develop. Such a network could be established by providing modest funding to the PER group at Uppsala to build regular meetings to convene and interact with the other groups.

A further collaboration that could be strengthened is that with the computer science education research group, which has a similar profile of deep knowledge in both the discipline and educational sciences and research into issues of learning and teaching in the computer sciences with related methodological approaches. While appropriately independent, and housed within distinct disciplinary units, having the ability to share research approaches, lines of inquiry, and creating the potential for cross-disciplinary collaborative work will enhance the capacity of the broader faculty at Uppsala. Such a collaboration would act as a model for further departments in the faculty, and even elsewhere at UU, to establish disciplinary educational research in their specialisations, with Uppsala potentially placed at the hub of national initiatives in the field of Discipline-Based Educational Research.

In keeping with the recommendations of the 2011 Quality and Renewal review at UU, an effort should be made to employ and develop the expertise of the group in collaboration with both the education department and the physics department. The education panel recommended “the group should continue to be supported at departmental levels and develop closer links with the Department of Education” and the physics panel recommended that its work would be strengthened if it was more closely related to the educational practices of the rest of the department. There are already initiatives of this kind on a small scale, but the work could be scaled up and established with increased funding of the group. There are opportunities for genuine research collaborations to occur within the Department of Physics, involving the students’ learning and the teaching practices within the department, seen now as a laboratory for investigation. Further, such collaborations offer an organic way to disseminate the intellectual tools concerning learning and teaching practices developed in such research to the practitioners of the department, and material for series of seminars.

Recommendations

1. [immediate] At least two tenure track positions[2] be created to maintain the viability of the group in the short term. There are two very good post-docs who would be able to apply for these and fill them in competition with others.

2. [short term] Form a group to write a research programme for the recruitment of a replacement professor for Prof Linder, emphasising the salient aspects of the group's current profile and the group's history.

3. [medium term] Formulate a programme of activities to bring about possibilities of the physics education research group reaching out to other interested groups in both the physics department and the education department, to the extent that is mutually beneficial.

4 . [medium term] Establish PER at UU as the hub for a national and international network with the profile of the group, kicking off with an international conference to celebrate the work of Prof Linder and an ensuing book.

5. [long term] Establish PER at UU as a model for initiating specific disciplinary higher education research for other disciplines, with the essential feature of employing experienced and competent researchers in the fields.

[2] Biträdande universitetslektor

Appendix 1: Publications from Diva, 2014-2016 (incomplete)

Airey, J. (2016). *Seminar on Parallel Language Use in Higher Education* 25 Seminar on Parallel Language Use in Higher Education, January 2016, Bergen

Airey, J. (2016). *Changing to Teaching and Learning in English*. University Teacher Development Programmes In Science and Health. Invited speaker 29th April 2016 Department of Science Education University of Copenhagen.

Airey, J. (2016). *Undergraduate Teaching and Learning in English*. Plenary speaker 2016 PED Conference, Jönköping School of Engineering

Airey, J. (2016). EAP, EMI or CLIL?: (English for Academic Purposes, English Medium Instruction or Content and Language Integrated Learning). Routledge Handbooks in Applied Linguistics, Milton Park: Routledge, pp 71-83

Dolo, G., Haglund, J. & Schönborn, K. J. (2016). *Infrared cameras support inquiry-based science education in a township school in South Africa*. Paper presented at The 8th International Conference on Multimodality (8ICOM), Cape Town, South Africa, 7-9 December

Etkina, E., Gregorcic, B. & Vokos, S. (2016). Organizing physics teacher professional education around productive habit development: A way to meet reform challenges. *Physical Review Special Topics : Physics Education Research,*

Etkina, E., Gregorcic, B. & Vokos, S. (2016). A theory-guided research agenda for physics teacher education. *In:* D. L. Jones, Lin Ding, and A. Traxler (Eds.) *2016 Physics Education Research Conference Proccedings: A Methodological Approach to PER*, pp 116-119

Euler, E. & Gregorcic, B. (2016). *Fostering Multimodal Communication in Physics Learning Through the Inclusion of Digital Sandbox Modeling Alongside Laboratory Experiments*. Paper presented at 8th International Conference on Multimodality

Gregorcic, B. & Bodin, M. (2016). Algodoo: A Tool for Encouraging Creativity in Physics Teaching and Learning. *Physics Teacher. 55*, no 1, pp 25-28

Gregorcic, B., Etkina, E. & Planinsic, G. (2016). A New Way of Using the Interactive Whiteboard in a High School Physics Classroom: A Case Study. *Research in science education*,

Gregorcic, B. & Haglund, J. (2016). *Using conceptual blending to analyze student inquiry and embodied engagement in a technology-enabled collaborative learning environment*. Physics Education Research Conference 2016

Gregorcic, B. & Haglund, J. (2016). *Conceptual blending: analysis of a computer-supported collaborative learning activity in physics.* EARLI SIG meeting on Conceptual Change

Gregorcic, B. & Haglund, J. (2016). *A conceptual blending analysis of student immersive engagement with an interactive whiteboard.* Physics Education Research Conference 2016

Gregorcic, B. & Haglund, J. (2016). *Using conceptual blending to interpret student embodied engagement in a computer-supported learning environment*. FND 2016, Forskning i naturvetenskapernas didaktik

Gregorcic, B. (2016), Interactive Whiteboards as a Means of Supporting Students' Physical Engagement and Collaborative Inquiry in Physics. In: L.-J. Thoms & R. Girwidz (Eds.) *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning Mulhouse: European Physical Society*, 2016, 101-108

Haglund, J., Andersson, S., & Elmgren, M. (2016). Language aspects of engineering students' view of entropy. *Chemistry Education Research and Practice*, Vol. 17, no 3, 489-508

Haglund, J., Jeppsson, F., Melander, E. & Pendrill, A-M. (2016). Infrared cameras in science education. *Infrared physics & technology*, Vol. 75, no March, 150-152

Haglund, J. (2016). Värmekameror i fysikundervisningen: Övningar från mellanstadiet och uppåt. In K. Stolpe och G. Höst (Eds.) Från forskning till fysikundervisning: Bidrag från konferensen i Malmö 14-15 mars 2016, 35-39 p.

Haglund, J. & Hultén, M. (2016). *Introduktionen av begreppet energikvalitet i svenska läroplaner*. Paper presented at FND 2016, Forskning i naturvetenskapernas didaktik, Den 9-10 november 2016, Högskolan Dalarna, Campus Falun

Haglund, J., Jeppsson, F. & Schörnborn, K.J. (2016). Taking on the heat: A narrative account of how infrared cameras invite instant inquiry. *Research in science education*, Vol. 46, no 5, 685-713

Melander, E., Haglund, J., Weiszflog, M. & Andersson, S. (2016). More than meets the eye: Infrared cameras in open-ended university thermodynamics labs. *Physics Teacher,* Vol. 54, no 9, 528-531

Netzell, E., Haglund, J., Schönborn, K. J. & Jeppsson, F. (2016). *Värmekameran: En laboration med fokus på elektriska kretsar.* Popular science discussion, in LMNT-nytt, ISSN 1402-0041, no 1, 24-27 p.

Samuelsson, R., Haglund, J., & Elmgren, M. (2016). *Användning av värmekameror vid öppna laborationer.* Paper presented at Forskning i Naturvetenskapernas Didaktik, November 9-10, 2016, Falun

Samuelsson, R., Haglund, J., & Elmgren, M. (2016). *Hot vision – affordances of infrared cameras in education*. Paper presented at The 8th International Conference on Multimodality

Airey, J. (2015). Social Semiotics in Higher Education: Examples from teaching and learning in undergraduate physics. *SACF Singapore-Sweden Excellence Seminars, Swedish Foundation for International Cooperation in Research in Higher Education (STINT) , 2015*, pp 103

Airey, J., (2015). From stimulated recall to disciplinary literacy: Summarizing ten years of research into teaching and learning in English. In In: S. Dimova, A-K Hultgren, C. Jensen, (Eds.) *English-Medium Instruction in European Higher Education* Berlin: De Gruyter Mouton , 2015, pp 157-176

Airey, J. (2015). Changing to Teaching and Learning in English, Invited speaker, Meeting of Industrial Engineering and Management, Uppsala,

Airey, J. & Linder, C. (2015) *Social semiotics in university physics education: Leveraging critical constellations of disciplinary representations.* 11th conference of the European Science Education Research Association (ESERA 2015), August 31 - September 4, 2015, Helsinki, Finland

Andersson, S., Haglund, J. & Elmgren, M. (2015). *Same goal, but different paths: Learning, explaining and understanding entropy.* Paper presented at 5:e utvecklingskonferensen för Sveriges ingenjörsutbildningar, Uppsala universitet, Uppsala, 18-19 november

Bossér, U., Lundin, M., Lindahl, M. & Linder, C. (2015). Challenges faced by teachers implementing socio-scientific issues as core elements in their classroom practices. *European Journal of Science and Mathematics Education,* Vol. 3, no 2, 159-176

Edfors, I., Wikman, S., Johansson Cederberg, B. & Linder, C. (2015). University students' reflections on representations in genetics and stereochemistry revealed by a focus group approach. *NorDiNa: Nordic Studies in Science Education, 11,* no 2, pp. 169-179

Forsman, J., Van den Bogaard, M., Linder, C. & Fraser, D. (2015). Considering student retention as a complex system: a possible way forward for enhancing student retention. *European Journal of Engineering Education, 40,* 3, pp 235-255

Fredlund, T., Linder, C. & Airey, J. (2015) A social semiotic approach to identifying critical aspects. *International Journal for Lesson and Learning Studies,. 4,* 3, pp.302-316

Fredlund, T., Linder, C. & Airey, J. (2015) Towards addressing transient learning challenges in undergraduate physics: An example from electrostatics. *European journal of physics*, Vol. 36, no 5

Fredlund, T., Linder, C. & Airey, J., (2015) Enhancing the possibilities for learning: Variation of disciplinary-relevant aspects in physics representations. *European journal of physics, 36*, 5.

Gregorcic, B (2015). Exploring Kepler's laws using an interactive whiteboard and Algodoo. *Physics Education, Vol*. 50, no 5, 511-515

Gregorcic, B. , Etkina, E. & Planinsic, G. (2015). *Using Interactive Whiteboards to Support Student Investigation and Communication.* Paper presented at AAPT Summer Meeting 2015, College Park, MD, USA

Gregorcic, B. , Etkina, E. & Planinsic, G. (2015). *Interactive Whiteboard: A Catalyst for Student Use of Gestures.* Paper presented at AAPT Summer Meeting 2015, College Park, MD, USA

Gregorcic, B. , Etkina, E. & Planinsic, G. (2015). *Students' hand gestures in a virtual hands-on environment.* Paper presented at AAPT Summer Meeting 2015, College Park, MD, USA

Haglund, J., Andersson, S. & Elmgren, M. (2015). Chemical engineering students' ideas of entropy. *Chemistry Education Research and Practice,* Vol. 16, no 3, pp537-551

Haglund, J., Jeppsson, F., Hedberg, D. & Schörnborn, D. (2015). Thermal cameras in school laboratory activities. *Physics Education*, Vol. 50, no 4, 424-430

Haglund, J. & Andersson, S. (2015). *Infrared cameras in inquiry-based thermodynamics laboratory exercises in university physics.* 11th Conference of the European Science Education Research Association (ESERA), Helsinki, Finland, 31 Aug-4 Sep

Haglund, J., Elmgren, M. & Andersson, S. (2015). *Chemical engineering students' conceptions of entropy.* 11th Conference of the European Science Education Research Association (ESERA), Helsinki, Finland, 31 Aug-4 Sept

Haglund, J., Jeppsson, F., & Schörnborn, K. (2015). *IR cameras provide disciplinary affordance to thermal phenomena.* The Sixth Conference on the Foundations and Frontiers of Physics Education Research (FFPER), Bar Harbor, ME, June 15-19

Haglund, J., Jappsson, F. Hedberg, D. & Schörnborn, K. (2015). Students' framing of laboratory exercises using infrared cameras*: Physical Review Special Topics : Physics Education Research,* Vol. 11, no 2,

Hedberg, D., Haglund, J. & Jeppsson, F. (2015). Metaforer och analogier inom termodynamik i kemiläroböcker för gymnasiet. *NorDiNa: Nordic Studies in Science Education*, Vol. 11, no 1, 102-117

Hill, M., Manjula, S., O'Byrne, J., Airey, J. (2015) Developing and Evaluating a Survey for Representational Fluency in Science. *International Journal of Innovation in Science and Mathematics Education, Vol. 22,* no 5, pp 22-42

Jeppsson, F., Haglund, J. & Schörnborn, K. (2015). *Personal embodied experiences in thermodynamics education*. 11th Conference of the European Science Education Research Association (ESERA), Helsinki, Finland, 31 Aug-4 Sept

Jeppsson, F., Haglund, J. & Tamer, A. G., (2015). Varying use of conceptual metaphors across levels of expertise in thermodynamics. *International Journal of Science Education*, Vol. 37, no 5-6, 780-805

Larsson, J. Airey, J. (2015). *The "physics expert" discourse model – counterproductive for trainee physics teachers' professional identity building?,* Conference of the European Science Education Research Association (ESERA)

Larsson, J & Airey, J. (2015). *The competing discourse models future physics teachers' meet during teacher training.* Paper presented at International Science Education Conference ISEC 2014, National Institute of Education, Singapore, 25-27 November 2014

Lindahl, M. & Linder, C. (2015). What's natural about nature? Deceptive concepts in socio-scientific decision-making. *European Journal of Science and Mathematics Education, Vol*. 3, no 3, pp 250-264

Linder, C. (2015) *Viewing the representations used in physics teaching in new ways.* Keynote presentation at the 'Från forskning till fysikundervisning' conference, Malmö, 14-15 March

Linder, C. & Linder, A. (2015) *Categories of influence: the case of light and sound in physics* 11th conference of the European Science Education Research Association (ESERA 2015), August 31 - September 4, 2015, Helsinki, Finland

Melander, E., Haglund, J., Weiszflog, M & Andersson, S. (2015). *To see the invisible: open-ended university thermodynamics labs with infrared cameras.* Paper presented by 5:e Utvecklingskonferensen för Sveriges ingenjörsutbildningar (5th Developmental Conference for Sweden's Engineering Education), 18-19 November, 2015, Uppsala

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