DEVELOPING OUTDOOR PHYSICS PROJECTS USING THE ACTIVITY THEORY FRAMEWORK

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ABSTRACT
This paper presents the conceptualisation, implementation and evaluation of methodology of "outdoor physics" a project in science teacher education at Umeå University, Sweden (see http://outdoorphysics.educ.umu.se). Activity Theory was used as the theoretical framework for project development. The fundamental constructs of this theory: collaborative activity, motivation, object and context of learning were taken into consideration in the development of outdoor cases and methodology of the project. Prospective science teachers took active part in all stages of project activities. They developed specific cases for outdoor study, tested these both by themselves and with students in schools and evaluated their outcomes. The various cases of outdoor physics were part of teacher students' research projects presented at the end of their undergraduate studies. Professional development of prospective teachers of science participating in the project is the main outcome of the current stage of the project, which benefited from international collaboration with colleagues from Russia (KSPU, Petrozavodsk) and some European countries (OutLab project). We expect that the knowledge acquired by prospective teachers in outdoor physics activities can also lead to new pedagogical approaches in their future professional work.

KEYWORDS
Outdoor environment, methodology, physics learning, website, teacher students of science

INTRODUCTION

From the start of our project we assumed that outdoor activities could allow for better acquisition of knowledge by students, as the activity could be experienced with different senses and therefore have a more personal character for them. Teaching physics outdoors allows students to investigate physical phenomena in the natural settings of their daily life. Students can be trained to see the problems of physics in all reality around them and not restrict themselves to technical applications as they most often do. Students can learn the logic of the laws of physics that govern nature while being in nature.

Working in the field of teacher education in Sweden, we have experienced that students of both sexes are interested in outdoor activities. More than half of those who attempted questions related to outdoor activities in the examination papers of teacher education at Umeå University, during the last eight years, were female students. Outdoor courses have higher enrolment of female students as well (Markström, Cedergren, 2005). However, research in Swedish schools shows, that teenage girls have less positive expectations from outdoor activities than boys (Forsgren & Johansson, 2004).

Research also shows that a variety of natural settings can be effectively used for students' investigations outdoors such as schoolyards, playgrounds, gardens, zoos and amusement parks (see for example, Nilsson, Pendrill, Pettersson, 2006). Physics field experiences can be found both in natural settings and urban environments. The pedagogical potential of a "physics trail" in a city has been explored by Foster (1989). Slingsby (2006) expresses his conviction that "the future of school science lies outdoors".

In the “Outdoor physics” project, prospective teachers worked with physics activities in different forms and on different occasions, such as in physics course assignments, school practice, diploma/examination work and in their master degree courses. The website developed as part of the project (http://outdoorphysics.educ.umu.se/, see its initial page in Figure 1) had a two-fold function. On one hand it was a mediating tool for teaching/learning physics and contained suggestions for outdoor activities that could be used as sources of inspiration. It contained also interactive computer models and visualisations that supported students’ understanding of physics. On the other hand, it presents results of students’ and teachers’ work, their ideas and recommendations. The website is targeted at teacher educators, school teachers, and prospective science teachers.

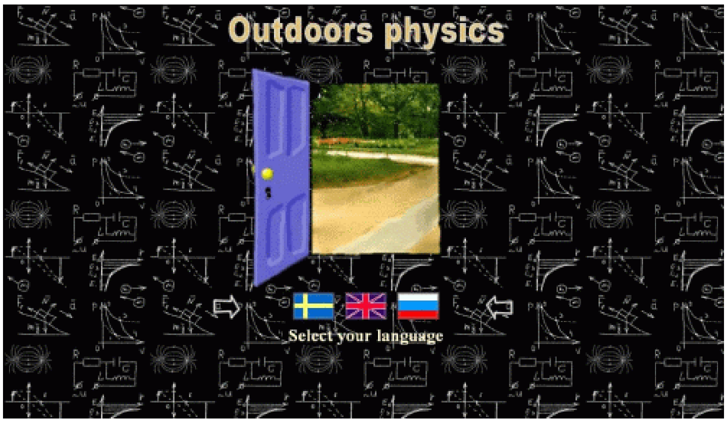

Figure1. Entrance to the project website

The learning tasks or cases presented in the above shown website are organized with respect to the level of difficulty, field of physics and natural objects used in the activity. We have attempted to present each case as an open and authentic problem with various possible solutions and offered only few hints for either the conduct of the practical activity or explanation of the results. Hyperlinks are provided to examples of other similar activities available on the Internet or of students’ practical work in schools with more detailed description of activities.

Situated outdoors the work of our project was framed within activity theory as our conviction was that we should motivate and challenge students’ thinking in physics. The theory helped us to make some methodological deliberations about particularities of teaching and learning in outdoor context that are presented in this paper. We now describe the use of activity theory and value-base of the project in the text below.

THEORETICAL FRAMEWORK

The importance of the context as an active component of the learning process that interplays with learner’s and teacher’s activities was suggested by Vygotsky (1978). Latin root of the word context *contexere* means ‘to weave together’. It can be briefly defined as “the interrelated conditions in which something exists or occurs” (www.merriam-webster.com/dictionary). Sweetser and Fauconnier (1996) explain that human cognition has an inherent property to contextualize, to access information differentially in different contexts. Edwards (2003) talks about ‘contextual nature of knowledge production.’ It can be argued that without context there is no knowledge or knowledge processing. Usually, one of the goals for placing science teaching in real world contexts is that it will lead to more engagement of students with learning process and therefore produce more solid knowledge. Following this line of thought, we placed the study of laws and properties of nature directly in natural settings and in the context of active social interactions between students and teachers.

According to Leont'ev (1981), the first and most fundamental form of human activity is external, practical collaborative activity that is idealised later on in human thought. Another important claim of

Activity Theory is that human activity (on both the interpsychological and the intrapsychological plane) can be understood only if we take into consideration mediating artefacts (technical and psychological tools) that mediate any activity. In “Outdoor physics”, investigation techniques or processes of science (also called process-skills or skills of scientific inquiry: observing, measuring, classifying, hypothesizing, etc) and different kinds of physics models are artefacts that have particular significance.

The *content* of human activity is determined first of all by its *object*. When doing outdoor physics, the objects of students’ activities are natural or human made objects with their properties reflected in scientific principles, laws, and theories of physics. Thus, the content of learning is the acquisition of knowledge (embodied in learning objects) about properties and laws of nature. The learner performs actions on the learning objects, transforming the objects in intellectual and/or practical ways and changing him or herself (the mind) in that process.

According to Activity Theory, goals and motives are considered the basic (key) components of learning activities. Leont’ev (1981) emphasised that the motive (oriented towards and defined by the object) determines the sense of the concrete activity. These relations, applied for the case of learning activities, are illustrated in the figure 2 below.

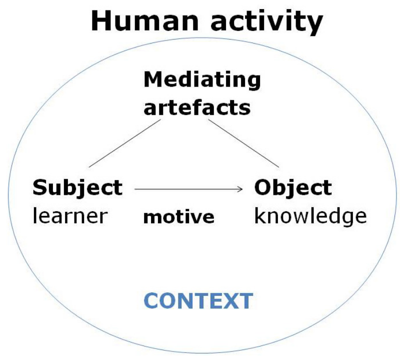

Figure 2. Activity Theory model of learning activity

Learning activity cannot be developed without developing specific learning motives that need students to be conscious about them. The motives of students of science studies could just as well be in pursuit of liberal[1] as well as humanistic[2] educational values. The opportunities provided in “Outdoor Physics” which satisfied liberal values of science education were of particular focus in our project and are discussed in the following text.

Liberal values and motives in studying physics

Current academic and political discourse about science teaching is dominated by utilitarian, cultural and humanistic motives. However, incumbent students in different educational levels have a broad variety of interests. In our experience some prospective teacher students in teacher education appear to be interested in learning “for the sake of enjoyment of learning and knowing”, a feeling they in turn hope to transmit to their future students. Historically this is what “liberal education” is concerned with “education that enlarges and disciplines the mind and makes it master of its own powers, irrespective of the particular business or profession one may follow” (http://www.webster-dictionary.net).

[1] Directed to general intellectual enlargement and refinement; not narrowly restricted to the requirements of technical or professional training. (Oxford English Dictionary: http://dictionary.oed.com/)

[2] “that animates students’ self-identities, their future contributions to society as citizens, and their interest in making personal utilitarian meaning of scientific and technological knowledge” (Aikenhead, 2006, p. 2).

The ideals of liberal education can be seen in the OECD forum curriculum recommendations for increasing the interest, motivation and competence in science studies amongst students (OECD, 2006). These include among others:

- Transmitting the excitement of science from the teacher to the student.
- Exposing students to the *joy* of discovery.

These recommendations emphasise liberal values of learning science just for the joy of its learning. Some students might experience the excitement of discovering scientific explanations of the structure of the Universe, learn about quarks, global warming or about laws of physics that can explain phenomena around us, which could be enough to be highly motivated to study science. However, showing students the possibility of loving science just for its beauty, logic and intellectual challenges no longer seems to be common among teachers. The OECD (2006) attributes this problem to the fact that many teachers themselves do not have a sufficient level of comfort and confidence about science and maths.

Just as physical activities shape the body, intellectual activities shape the mind. Learning physics demands hard work and can provide real intellectual gratification in the form of understanding. But, it is not possible for everybody to get success in science, in the same way that not everybody can succeed in sport or music. The teachers can challenge and generate an interest in science studies for some students, but not all. Outdoors physics activities provide good opportunities for fascinating students about explanatory power of physics laws. Anecdotal evidence collected in our project shows that the best memories of their schools physics for many prospective teachers was when their teachers organised outdoor lessons like throwing stones from a bridge, launching a water rocket, or shooting from a rifle.

Our experience shows that conventional teacher education provides prospective teachers with limited skills to develop their future students' abstract and logical thinking. Few prospective teachers have interest in developing methods of advancing students skills of problem solving and theoretical thinking in science education, reflected by the content of their examination projects. We see great motivational potential of "Outdoor physics" in this aspect. Outdoor teaching provides opportunities for introducing students to experiences and intellectual challenges of working with authentic physics problems. The students get "exposed to the *joy* of discovery" as they learn to identify solvable physics problems and their solutions though scientist-like work. We will try to describe our experiential and theoretical methodological inferences about "outdoor physics" in the text below.

METHODOLOGY IN "OUTDOOR PHYSICS"

We utilise Activity Theory to reflect on the methodology of outdoor activities. The experiences of our project indicate that outdoor physics activities seem to naturally demand the use of cooperative learning and many of them cannot be done individually. Collective activities in turn naturally foster communication, group discussions and decision-making. Thus, collective practical activity takes central place in physics learning in outdoors. There are also other methodological considerations that arouse from the project in light of Activity Theory perspective.

Identifying and delimitating the object of learning activity in outdoor context

We experienced that organising physics teaching in the outdoor context is much more demanding than indoors. Phenomena and objects in real life contexts do not provide obvious "hints" (explicit suggestions, as in a laboratory manual) of the physics that can be discovered and studied in them. These can be seen from multiple perspectives and through different conceptual eyeglasses. Teacher guidance is often needed in the process of indentifying potential *learning objects* (objects of learning activity). In contrast to laboratory settings, studying physics (physical phenomena) outdoors demands elimination of "noise" in the form of insignificant or disturbing features to be able to construct models suitable for explanations of the phenomena observed[3]. What is this noise in any particular case? What should be

[3] The author is thankful to Richard Gunstone for discussing with him this analogy.

taken out of consideration in order to build a model that helps understand a phenomenon? Answering these questions posits scientific reasoning skills and the ability to construct models.

It is also the case that insignificant features ("noise") that can be eliminated from consideration in one case can be important for understanding the physics related to the object or phenomena in another. For example, in the case of a warm air balloon, mechanical, thermal and chemical effects have very complex interplay, but depending on what we want to study, certain features become more important than others. So, the students learn to "eliminate noise" from complex reality of outdoors in order to formulate "solvable problems", i.e. they learn to build and study models of physics in reality. Using the terms of Activity Theory we can say that the students learn to identify *object* and *content* of their learning activity.

Planning the study of phenomenon like the resistance of air can be often more difficult than planning measurements of the object like the height of a tree. The task of what to measure is often more visible and explicit in the study of an object (a tree) than it is in the study of phenomenon (resistance of air). While working hands-on, an appropriate model needs to be created that "reflects" the phenomenon being observed. This demands that students learn to manage variety of cognitive artefacts and tools of modelling.

Considering complexity of the learning objects (studied phenomena) in outdoor context, it is possible to mention a couple of other project findings concerning the "openness of problems" and the role of doing and overcoming mistakes. Usually, outdoor cases do not have only one solution. Often there are more unknowns than givens in possible physics equations, and such outdoors physics problems can not be solved simply by "substituting values in formulae". Cases of physics outdoors provide opportunity to investigate genuine problems and practice scientific inquiry. The students learn to try out their ideas, make mistakes and accept that doing mistakes is a necessary part of learning. Thus, one of the difficult tasks for the students is to formulate "solvable" physics problems, find out an appropriate model and theoretical base that can be used in particular outdoor experiments. Often they have difficulty in understanding in which direction to search for answers. So, probing, making mistakes and overcoming them (typical features of any scientific activity) become a natural part of learning.

Many experimental tasks outdoors have a creative aspect as well i.e. they do not explicitly provide a way or algorithm towards their resolution. This demands inductive and creative reasoning, choice of an appropriate model or planning of an experiment. The same task often can be solved based on the same chosen model with help of different experiments. Opportunity of finding out different (experimental) solutions, discussing them and choosing the most appropriate one in the given conditions has great potential for learning in physics.

Thus activities in the outdoor environment often demand of their learners much longer time and deliberation while engaged in respective observations and experiments. This can be seen both as a pedagogical advantage or disadvantage. We, however, see an extension of didactical time, the time of engagement in activities, as a positive factor giving rise to richer opportunities for assimilating new knowledge and skills. Learning takes time!

Exploration of authentic problems an important part of learning content

Authentic problems are genuine problems or questions of interest that arise in practically existing situations e.g. the study of different and effective ways of dealing with and eliminating slipperiness on roads and pavements. There could be different approaches for constructing and solving authentic physics problems outdoors. By authentic problems we identify in the project certain kinds of tasks. For example, 1) tasks without a single right answer: open ended problems allowing for deeper studies, for example hot air balloon when Archimedes law, thermal conductivity, convection flows, type of fuels and combustions can be consequently included into consideration; 2) tasks varying with changing environmental circumstances: for example weather conditions; 3) tasks that preliminary demand definition of what should be measured: for example what is the height of a birch tree: its stable trunk, its leaves and branches, criteria that should be discussed in advance as well as a choice of criteria of what accounts for an acceptable answer.

In the exploration of authentic problems knowledge of basic physics is a necessity. Students depart from known laws of physics and learn to work in real situations. They conduct tests with their own bodies or available technical devices and study how physics works demonstrating also the validity of the principles of physics. The universality of some laws can be demonstrated by varied actions in various situations.

New tools and new roles of the tools mediating learning

Mental and manipulative skills serve as important tools in the teaching culture of science. In our project the outdoors provided for new tools to be used effectively in new ways. For example, physical artifacts of large dimensions like cable drums, cars, barrels, etc could also be used as tools for stimulating learning. We departed from the hypothesis that "size does matter" when students' had the possibility to explore physical phenomena outside their classroom walls. For example, in the study of torque there is a "traditional" physics experiment that is conducted with a sewing spool as shown in Figure 3 below. If the thread leaves the spool from the bottom of the axle when gently pulled, would the spool move forward or backward? We adapted this experiment to the outdoor environment using a rope and a large sized cable drum, as shown in Figure 3.

Figure 3. Changing scale in experiments outdoors

Useful apparatus for data collection outdoors become digital photo and video recording. Teacher students in our project came up with the advantages of such recording of data as having multiple reproductions of the observed phenomena as also the possibility of different speeds of replay of video and the ability to collect data over time. Such records provided opportunities for various occasions of technical discussions within various students' groups.

In conducting activities outdoors, different parts of the human body can also be found useful for conducting estimations or measurements. Such knowledge has been in use by the military for ages when they needed to estimate distances and observe something over time. In such cases, any observation depends not only on objective factors but also the subjective. The "observer" can himself or herself influence the nature of data collected. Humans as data collecting devises have limitations in a variety of ways. For example, uncertainty of measuring speed of sound propagation, by seeing flash and hearing sound of distant explosion, depends on individual reaction time. The physical size of a person's body when used in measuring can also be a source of error. Parallax phenomena, own body heat, reaction time, bodies inertia and other factors can sometimes be easily understood when experiments are done with bigger size object or using student's body as a part of measuring device. These factors contribute to the understanding of a general principle of measurement, that of the observer's role, one which is often forgotten in laboratory conditions. To get a feeling from bodily experience of what it means to make measurements as exact as possible can be found of great methodological value for the students.

Working outdoors gives many possibilities to feel laws of physics e.g. inertia, thermal phenomena, static-equilibrium and various optical phenomena with ones own body. Such experiences enlighten students that as physical bodies human beings also obey the laws of physics just as unanimated bodies do. Such an opportunity gives perspective of the necessity of thinking about the laws of physics when for example one is navigating road traffic.

Disposable materials like soft drinks plastic bottles become natural tools for learning outdoors. Launching a water-rocket is probably one of the most popular science exercises conducted outdoors in schools around the world. The Internet search engine Google offers hundreds of thousands results upon searching for “water rocket”. While conducted in reality, students are challenged to change different parameters in launching such a rocket (like proportion of water and air in the PET bottle) and have opportunity to observe how they influence the rocket’s flying capacity. The above examples bring fresh perspectives to use of tools (mediating artefacts) in the learning of physics.

Taking measurements and estimations outdoors
As mentioned earlier science process-skills such as taking measurements and making estimations are important mediating artefacts of physics learning activity. Conducting measurement outdoors can be more demanding than when conducted indoors. The environment, bigger scale of the object, changing weather like wind, humidity, and sunshine - all can change rapidly and, hence, influence the precision of measurement. This aspect makes the reproducibility of experimental conditions and results far more problematic than in a corresponding laboratory setting. For example the measurement of temperature of the soil will now depend on additional factors as the place and the size of the hole itself. Likewise the flatness of terrain could be an important factor in the measurement of shadow size.

Outdoors can just as well provide richer opportunities for reflecting on precision, errors and uncertainties in taking measurements. The importance of considering uncertainties becomes apparent and more obvious in such circumstances. When different groups of students measure the same object using the same method or different methods and get the same or different results – this occasion provides opportunity for discussion of general principles of methodology of measurement in science.

Skills of making estimations are very important in the practice of physics. This was underlined by many famous physicists e.g. Richard Feynman and Yakov Zeldovich. In conducting experiments outdoors students are forced to choose apparatus and measuring devises which have parameters that seem appropriate for the respective measurement being made for example the use of a smaller or greater scale. Therefore, the need arises to think ahead and estimate what values and magnitudes measured in a physics experiment can be expected. It is only then, that students have opportunity to note whether their predictions correspond to the reality of the experiment and have opportunity to discuss the nature of the discrepancies they might have encountered. So, taking measurements outdoors present both practical and intellectual challenges to the students. Activity Theory perspective draws our attention to the importance of working with tools of doing physics such as measurements and estimations. Finding an attractive way of discussing precision and errors in measurements has always been a challenge for physics educators and work in outdoor settings provides good opportunities for this.

Evaluation of the project
The development of our project was mainly done within practicing teachers’ routine duties and teacher students’ study time. The teachers involved in the project conducted self-evaluations of the activities (Popov, Engh, 2007). The technical and pedagogical aspects of ICT support for project’s outdoor activities were examined by Andersson & Holmström (2008). They analysed the project website and conducted a study based on interviews with six teachers who made use of it.

The results of these studies show a positive attitude of both teacher students and practicing teachers towards physics studies conducted outdoor with an interest in trying out and experimenting with these methods and tools in their future physics education. Availability of data-base of “outdoor cases” and methodological ideas on the project’s website were highly appreciated. Suggestions and recommendations were given of how to improve usability of the material presented. There was a need to eliminate some technical errors in order to facilitate navigation on the website and improve access to the project's data. In general, the students' and teachers' evaluations of the outdoor physics project showed a positive appreciation of the activities and satisfaction with our methodological approach.

Experiences of implementing outdoor physics teaching in other countries (e.g. Russia, Italy, and Romania with whom we collaborate) also show increase in student motivation to work with physics content, and to explore new tools, contexts and objects for studying physics.

CONCLUSIONS

When well organised, teaching physics outdoors develops learner's abilities to observe, to ask, to presume, and verify one's presumptions, and to conduct a critical analysis of data. These are the skills of critical thinking that are also important for physicists and physics teachers' professional activities. Learners need guidance and collaboration in acquiring investigation techniques and critical thinking skills. The role of the teacher as organiser and facilitator of this work is very important. Therefore, we do not consider, for example, our website as offering self-instruction for learners, but we assume that it will be the teacher who guides students' work with suggested cases and monitors the inquiry process based on their background and capabilities. The complexity of the real world situations demanded that the teacher will be more of a researcher and partner for the students rather than a possessor of the right answers.

The natural environment provides genuine opportunities for meaningful learning based on combination of minds-on and hands-on activities, but also requires additional preparation and carefully designed pre and post field work to make outdoor learning productive. In spite of these logistical issues our experiences show that outdoor physics activities can lead to real empowerment of prospective science teachers, giving them more control over, and understanding of, the science learning processes. They gain confidence of using new mediating artefacts of learning and have more open-minded approach meeting new objects of the study. Using words of Edwards (2003), 'It is also a real world version of learning.' The accumulated experiences acquired by our teacher students through an outdoor physics teaching approach will hopefully lead to innovative pedagogical practice in their future science education work.

Outdoor physics is a pedagogically and scientifically demanding work, though it has great pedagogic potential. We argue based on the evidence of our project work that physics education activities outdoors can be an effective and important complement to classroom-based physics learning. It can trigger students' thinking and give them deeper understanding of concepts and methods in physics. Such an approach seems to create new learning opportunities for different categories of students from the bright ones to those who need special encouragement and help. We are interested to increase our knowledge about this through the future research. We hope that methodological aspects emerged in our work with "outdoor physics" project presented in the paper can lead to further empirical and theoretical development of physics teaching methodology in outdoor context.

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