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# Towards Meaningful Learning through Inquiry

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**Abstract**

The purpose of this study is to develop and implement a study module including scientific inquiry based experiments in the context of the physical phenomenon of friction, and to assess the learning outcomes. The aim is to describe the levels of students' understanding after instruction as well as to study where learning is situated on the continuum between meaningful and rote learning. This study is a qualitative case study and the participants of the study are sixth graders from a countryside school. The students studied the issue of friction by doing experiments in collaborative small-groups, following the principles of scientific inquiry. The data was collected firstly, by asking the students prior to the teaching intervention to explain what happens in a picture which shows someone slipping, and secondly, by using an open-ended questionnaire after the teaching intervention. Before instruction, students only used their prior experiences and perceptions in their explanations, whereas after it they also utilized the scientific knowledge and concepts which they had learned during the intervention. After instruction, the students' answers reflected deeper understanding of the phenomenon, and of the five types of learners found, one type reaches the level of meaningful learning. The finding of five types of learners reflects the complexity of students' understanding.

**Keywords:** Meaningful Learning, Deep Approach to Learning, Scientific Inquiry, Experimental Learning.

## Introduction

Learners, who develop well-organized knowledge structures, are learning in an active, sensible and meaningful way, whereas those who are learning primarily by rote are not developing these structures. Generally their knowledge includes many misconceptions. The discovery/inquiry - reception and meaningful - rote dimensions, do not describe simple dichotomies but are rather more the nature of continua. Any learning that occurs is not simply meaningful or rote; it is, instead, more or less meaningful or more or less rote. (Ausubel & Robinson, 1969: 44-45; Mintzes, Wandersee & Novak, 1998.) While hands-on experience is important, it is also important to carefully clarify the meanings of words (or concept labels) and prepositional statements. Much of this could be done by didactic or reception instruction, provided that it is integrated with appropriate experience. It is important to make the distinction between the learning approach and instructional approach. With regard to

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instruction, both reception instruction and inquiry (or discovery) approaches can be either very rote, or very meaningful learning experiences.

According to Gomes, Borges, and Justi (2008), investigative activity is a complex task that calls for a combination of a chain of skills and processes. Using experiments, the main goal of this kind of activity is to produce knowledge by means of experiments through setting up hypotheses. Many science educators argue that inquiry should focus on the thinking practices through which students understand and construct scientific ideas. These practices cannot be formalized into one method. Science in a school context cannot fully duplicate what scientists do; however, science education should involve not only the development of comprehensive and abstract knowledge, but also of process skills and contextual knowledge. The use of scientific inquiry and the respective educational materials associated with it has been studied in several science disciplines: physics, chemistry and biology. Inquiry-based education has the potential of enhancing students' meaningful learning, conceptual understanding, and their understanding of the nature of science (see e.g. Asay & Orgill, 2010; Apedoe, 2008; Gott & Duggan, 1995). Inquiry type experiences in the school science laboratory are especially effective if conducted in the context of, and integrated with, the concept being taught (Hofstein, Shore & Kipnis, 2004; Kipnis & Hofstein, 2008). Tobin (1990) has suggested that in the laboratory, meaningful learning is possible if students can personally choose the equipments and materials needed for constructing their knowledge of the phenomena.

Hofstein et al. (2004) found that by applying the inquiry method, students' involvement in experiments improved their ability to ask better scientific questions. The type of questions changed. Students' questions related more to the actual inquiry and they were well aware of the learning process and cognitive development; learning cooperatively helped them to construct their knowledge. Sriwattanarothai, Jittam, Ruenwongsa, and Panijpan (2009) also noted that after undergraduate students had participated in the inquiry-based laboratory work, they had better conceptual understanding of the issues studied. In their study the experimental work had been carried out before the lecture; the students experienced that this made it easier to fully understand the concepts.

Tang, Coffey, Elby, and Levin (2009), based on their research in the context of environmental education, claimed that a productive approach towards teaching scientific inquiry would not begin by introducing students to decontextualized steps. According to them, teachers should instead start by noticing, bringing out, and building upon the productive, sometimes nascent inquiry abilities that they have observed in students. Apedoe (2008) highlights the amount of guidance and scaffolding provided by teachers; it is an important component of an inquiry-based learning environment that can be enhanced. However, Brown, Abell, Demir, and Schmidt (2006) found that teachers may view classroom inquiry as time consuming and unstructured. Although teachers valued inquiry, they perceived limitations of time, student motivation and student ability to be problematic.

*Perspective of The Research*

Our study focuses on how well students understand the physics concept of friction after having performed scientific inquiry. Many studies, on applying scientific inquiry instruction, have emphasized the significance of prior knowledge on students' science learning. For example, Jones, Carter, and Rua (2000) noted that students drew on many different prior experiences when forming a response, thus each student's learning was unique. Students that regard science as a body of knowledge to be discovered by empirical means, have more rote strategies for learning science than those with a more constructivist view who regard science as a creative and inventive endeavour (Wallace, Tsoi, Calkin & Darley, 2003). Edmonson and

Novak (1993) found three groups of students that corresponded respectively to a positivist epistemology, a constructivist epistemology, and a mixed epistemology. Positivist oriented students tended to be rote learners, while constructivist oriented ones used meaningful learning strategies. O'Neill and Polman (2004:236-237) have concluded that science education should encompass fewer phenomena so that these could be studied more profoundly. Superficial treatment of many topics leads to knowledge and skills which are quickly forgotten.

The Finnish national core curriculum for basic education recommends that education in environmental and natural studies relies on an investigative, problem-centred approach; the starting point is the students' existing knowledge, skills, experiences, phenomena and events connected to the students' environment and the students themselves. With the aid of experiential instruction, the student develops a positive, affirmative relationship with nature and the environment. However, in many primary schools (the lower level of the comprehensive school), laboratory experiments typically used; continue to emphasize confirmatory exercises that require students to follow explicit procedures in order to arrive at expected conclusions. Thus we need models which show how to implement scientific inquiry methods in school.

This study examines the position of scientific inquiry based learning, in the everyday context, on the continuum between meaningful and rote learning. A deep approach to scientific inquiry learning should lead to understanding and skilfulness. A central feature of sciences is their ability to change and enrich interaction with the surrounding world (Pugh 2004:182-183), and we ask to which extent students, who are engaged in scientific inquiry, realize this possibility.

This study attempts to answer the following research questions:

1. How does our study module influence primary school students' understanding of the scientific concept of friction?
2. What is the position of the students' learning on the continuum between meaningful and rote learning?
3. How do the students experience inquiry-based education?

## Material and method

### *Aim and Participants*

The main goal of this study is to develop and implement a study module and assess the learning outcomes of the study module, including inquiry-based experiments, in the context of primary school physics in Finland. The participants of this study are 25 sixth graders (one class, ages 12-13) from a countryside school. The experiments were carried out in a normal school class not on equipped laboratory; this is the general case in Finnish science education at the primary school level. One student was absent from the experimental work but took part in the post-examination at the end of the intervention. As a part of their obligatory studies all students answered all questions according to their abilities.

### *Intervention*

The intervention was planned based on theories about the inquiry method in science education and consisted of three parts, each taking 45 minutes. In the intervention, students studied the physics content of friction by doing experiments in collaborative small-groups. Two of us developed and carried out the intervention as part of professional development, following studies on Science and Technology pedagogy.

During the first phase of the intervention, students were introduced to the general scientific meaning of the phenomenon of friction, through a story of a family's day; thus the context of the education was everyday situations. Images and a concept map were also used to introduce friction. The intention was to activate students' prior knowledge of friction and to attach new knowledge to their earlier constructions. The second phase, the experimental part, contained three different inquiry type experiments to be done by the students. They worked in small groups. First they were given the problem, for which they developed a hypothesis founded on their present understanding; students then made predictions, and planned an experiment to test them. Equipments were made available, but the students personally planned the use. The students made notes of each step of the inquiry type experiment and after getting the teacher's approval for their plan, the group was allowed to perform the experiment. Each group performed all three experiments. They investigated friction in terms of the influence of surface material, weight, and contact area. In the last part of the intervention the students compiled the inquiries, everything from hypotheses to conclusions, and compared and scrutinized the results.

The students were therefore personally involved in the following components of the inquiry method: identifying problems, formulating hypotheses and making predictions, designing an experiment to answer predictions, gathering and analyzing data and drawing conclusions about scientific problems or science phenomena. The hypothesis indicates students' prior knowledge, the essential element of the education which follows the constructivist framework. For a more extensive discussion of inquiry approaches see for example Grandy and Duschl (2005).

*Data Collection and Analysis*

The data was collected in two ways. Students took part in examinations on the day previous to and the day after the intervention. In the pre-examination phase, the students firstly explained what happened in the picture which depicted a person slipping. Secondly they explained how the situation could be avoided, whereby the students were asked to write as many proposals for improvement as possible. After intervention, the data was collected using an open-ended questionnaire. Students answered ten questions: what is friction; which factors influence the strength of friction; in what circumstances and how does one try to a) increase and b) decrease friction; why a lady with high shoe heels slips more easily than if she uses sport boots; what the differences in the braking distance of cars depend on (cars in the figure); why a pencil does not make a mark on the plastic ruler; why there are differences in the tracks of skiers and what are the reasons for this phenomenon; why soccer goal keepers use gloves; why formula cars' tyres are changed from smooth to ribbed when it starts raining; exemplify in which phenomena friction is a) useful, b) harmful. Finally, the students were asked how they had experienced this inquiry type learning method; the task was to judge the usefulness of studying physics by choosing one alternative out of three (rather useful, rather useless, useless) and to give reasons for their choice.

By using open questions, we wanted to study students' understanding of friction both before and after the teaching intervention. The data, i.e. students' explanations in the answers, were analyzed qualitatively. Hereby the authentic text of the students was preserved as far as possible, i.e. no correction of errors has been made to the excerpts used in this study. The analysis was data based, however the theory sensitized the researchers to look for meanings from the data. Four themes were found from the students' explanations: how the students explained the phenomenon, how they processed knowledge, which concepts were used, and their ideas about the instruction. Based on students' way of explaining and the concepts they used, the way students process knowledge was revealed. Finally, they were categorized to five learner types. The learner types are based only on the intervention used in this study, and cannot be generalized when relating to learner types in other contexts.

## Results

*Description of the Explanations*

The explanations in the pre-examination do not show a deep understanding (for discussion see for example Chin and Brown 2000:119-121; Biggs, 1988:186) of the phenomenon of friction. No student used the concept of friction in the answers, or gave an explanation for it. The students used circular arguments: the man slips because it is slippery on the yard. The answers, although correct as expressed in everyday language, were not enough to explain the phenomenon. The students had lots of suggestions as to how to avoid slipping: the use of sand and salt, removing the ice, walking another way, shoe studs to prevent slipping, and walking more carefully.

In the following we report, one by one, the explanations students gave to the questions in the post-examination. This gives an idea about how well the students were able to explain the questions. The first question of the post-examination “what is friction”, should reveal how well the students were able to define the concept of friction as taught during the first step of the intervention. The answers were divided into two groups. Either the students defined friction as a reactional force affecting motion or as the rubbing together of two objects. It was interesting that especially the girls gave the first definition of a reactional force. For example, one girl said that friction was “a force that counteracts movement and the beginning of movement”. It seems to us that this type of answer indicates rote learning, because it repeats the textbook and the student has not given any of her own explanations or descriptions. Boys mainly answered that friction is the rubbing together of two objects. Such an answer might hint at a deeper understanding, especially as it is given using the student’s own descriptions.

The second question “which factors influence the strength of friction” had formed the background for the experimental work and could be answered drawing on the results of the students’ own inquiry and reflections. Most students answered correctly. Here we would like to note that still the day before, before the last step of the intervention, i.e. before the comparison and scrutinizing of the results, almost all students kept to their prior assumption that the contact area influences the strength of the friction.

In the third question “in what circumstances and how does one try to a) increase and b) decrease friction”, students could suggest phenomena other than those discussed during instruction. However, most of the examples given had already been discussed. Boys often connected the increase of friction to car tyres. Only in answers to question b) did some students give their own examples: skin-tight suits in ski jumping, skiing and swimming, and the shaving of swimmers’ body hair to decrease friction.

The fourth question “why a lady with high shoe heels slip more easily than if she uses sport boots” was designed to reveal the understanding of friction in every day contexts. This question where knowledge had to be applied, contrary to question two, showed that some students had difficulties in applying knowledge. One boy answered: “*Because shoes with high heels have such a small area of support compared to sports boots*”. The superior results of question two may partly be associated with rote learning. However, most students had given an explanation which was based on the differing contact area materials: “*The boots have a patterned rubber sole; whereas the heels of high heel shoes are smooth and made of plastic and so it is more slippery.”* Especially girls seemed to be well acquainted with the smooth material of high heel shoes. However, a statistically significant majority of students (17 students out of 25) had given an explanation using the difference of the contact area materials.

In the fifth question students should discuss “what the differences in the braking distance of cars could depend on”. Students mostly explained the differences by referring to different material on the road surface or in the tyres. Almost all girls, but only a part of the boys, linked their answers to their knowledge about friction and used the concept they had learned in their answers.

> *[in winter]one car might have winter tyres with high friction, because the ribs and spikes make the tyres rough; another might have winter tyres too, but well worn and thus smoother and so not keeping such a good hold; a third might still have summer tyres*

The girls usually concentrated on one factor that influenced the braking distance, whereas, the boys did not bother to describe and compare different situations. Their answers were short, for example: “*from the tyres, the asphalt surface, the weight of the car*”. Almost all boys gave descriptions based on their everyday knowledge: “*From the break blocks and tyres. If the break blocks are worn, the car will be slower to stop; if the blocks are new the car will stop quickly. The same thing concerns the tyres.”*

To investigate how well students understand friction in new circumstances, we asked in question six “why a pencil does not make a mark on the plastic ruler”. Many students gave the reason that the friction between the pencil and the ruler was too small, but did not say why. We had expected that the students mention the smooth, hard surface of the ruler. One student tried to explain the phenomenon by using the concept of contact surface:

> *Because the core of the pencil is so thin there will not be much friction between the pencil and the ruler.*

In question seven we asked the students to describe “differences in the lengths of tracks made by the skiers Päivi, Saara, and Matti, and to explain the reasons for this phenomenon”. Only eight students used the concept of friction. Many students gave more than one reason.

> *Matti used the biggest amount of adhesive ointment, which increases friction. Saara used rather little ointment, whereby there was not much friction. Päivi used very little ointment and then the friction was really small. So this all is because of friction, which can be decreased or increased with the amount of adhesive ointment.*

In question eight we asked “why soccer goal keepers use gloves”. Explanations of two kinds were given. Either, when using gloves it is easier to catch the ball or, your hands do not hurt so much. The last reason was given by five girls but only by one boy. The boys were more acquainted with soccer playing and thus seemed to be able to apply their knowledge better.

> *Because if the goalkeeper does not wear gloves there is little friction between the bare hands and the ball, because both are smooth. .. But if he uses gloves, then because they are coarser there is more friction between the gloves and the ball, so he does not drop the ball.*

Question nine, “why do they change the formula cars’ tyres from smooth to ribbed when it starts raining?” was difficult. A typical answer was: “*Because the road surface becomes slippery in rain, more friction between the road and the tyres is needed.”*Such answers are correct but do not explain the significance of the ribs in the tyres. Only one girl and two boys gave a correct explanation: "*Ribbed tyres steer the water to the sides and thus enlarge the friction and grip/adherence.*"

Question ten, "exemplify in which phenomena friction is a) useful, b) harmful" allowed the students to use their imagination. They found many more positive than negative examples and they also found their own examples, especially positive ones. They mentioned Frisbee throwing, swimming, sports, and locks. One student wrote about the negative effects: "*if the surfaces rub against each other it might start a fire*".

Most students thought that it is useful to study physics because their knowledge increases. Six students mentioned that it is possible to explain every day phenomena with the help of what they learn in physics. For example one student wrote: "*Because it is good to know why the hinges of the door are stuck*".

*Categories of The Explanations- How The Students Explained The Phenomenon*

According to Vosniaudou (1997:46-51), functional knowledge, intuitive conceptions and scientific knowledge form the grounds for acquiring information. Functional knowledge is defined as primordial reactions to the environment, as for example reflexes, and other sets of elementary actions. Intuitive conceptions reflect every day experiences and phenomena. A composition of intuitive conceptions and scientific knowledge forms synthetic explanations. When parts of scientific knowledge are melded into everyday experiences, the result can include both acceptable and unacceptable insights: ... *Because the heels are small and shaky and there is not much friction but the sport shoe is flat-bottomed and thus has a lot of friction.* Scientific knowledge is based on the knowledge and concepts accepted by the scientific community. Students' explanations, given in the post-questionnaire after intervention, are categorized as scientific, synthetic or intuitive explanations (Figure 1). By scientific, we here mean scientific explanations typical to school.

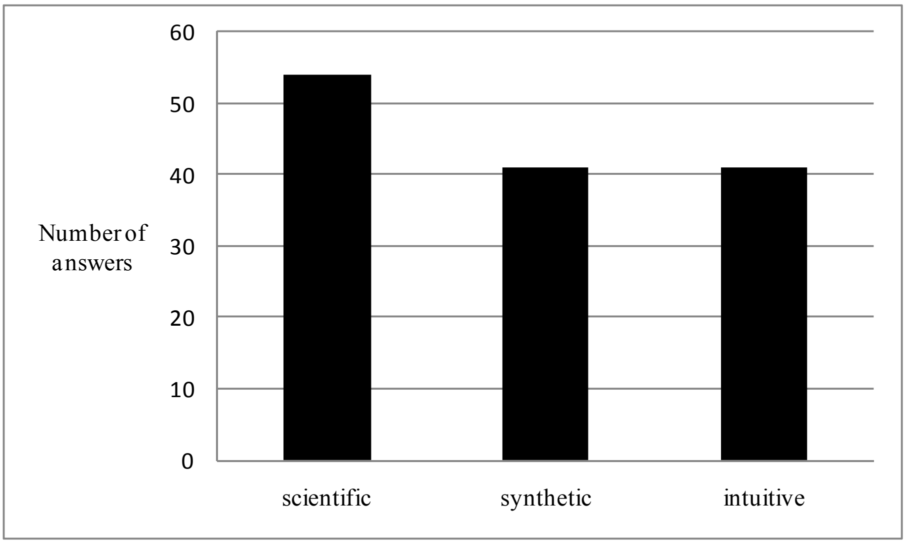


**Figure 1.** Categories of students' explanations/answers.

Around 40 % of the explanations were scientific (54 out of 134). In the pre-examination phase, all the explanations were intuitive and were based on previous knowledge, observations and experiences. In the post-examination, the students used intuitive explanations mainly in the question concerning familiar situations wherein they had their own experiences. When the students referred to their own experiences, they did not use concepts or knowledge that they had studied in the intervention phase.

The students used synthetic explanations for all other questions except the soccer question for which the explanations were either intuitive or scientific. Particularly in the skiing question, the students had applied scientific knowledge in a wrong way. They used scientific facts but not their own experiences, which might have lead to a more correct explanation. The finding of the use of synthetic explanations, agrees with the finding of Vosniadou (1997) who claims that the construction of knowledge is not a straightforward process which, when increased, automatically develops understanding of the phenomena. Knowledge when applied wrongly, may change correct knowledge which has been based on experiences. The explanations being dependent on the context, in this case the question, agrees with the findings of Linn and Songer (1993).

The scientific explanations were either exact and also included every day experiences (question 4 and 8) or, the students used scientific concepts clearly without a deep understanding of the phenomena. In the latter cases, the explanation was factual but the student's own thoughts were not apparent. Although the explanation is scientific, it does not necessary mean that the student has understood the phenomena.

*Processing Information- The Way Students Processed Knowledge*

Another theme of analysis was the way the students process information. Here, in conformity with Chin and Brown (2000:119-121), the participants were split up according to how their answers could be categorized into being surface and deep approaches. Students taking the surface approach gave 1) no answers, 2) evasive answers, or 3) short answers without discernment: *Ribbed tyres adhere better than smooth ones. The smoother the surface the smaller the friction.* Students taking the deep approach 4) tried to give or gave productive, cause related answers. The majority of the students' explanations were placed at levels 3 and 4, 70 explanations were placed at level 3, and 60 explanations at level 4. There were 10 explanations at the first and second levels. There were also differences between the questions. Typically, the explanations at the level 4 were connected to the questions concerning familiar situations to the students.

> *That they could get a good grip of the ball. The hand shoes are adhesive and have a rough surface and there is lots of friction and for example one gets a good grip.*

*Concepts Used by The Students*

The third theme focuses on the language used in the explanations; although scientific understanding can occur even when using everyday language, it is of interest to study the extent to which students change their use of everyday language towards the direction of using scientific concepts. Before intervention, the students used intuitive and everyday language while afterwards they still explained familiar situations through everyday language, but used scientific concepts to explain less familiar ones, irrespective of whether they understood the phenomena or not.

> *The car A had (perhaps) new tyres that were more adhesive or perhaps the road of car A is dry and the roads of cars C and D are slippery. The car B probably has worse tyres than car A or the road is more slippery than for the car A. The car C probably has very bad and worn-out tyres or then the road is really slippery.*

*Perceptions about Usefulness of Physics*

The last theme concerns students' own conceptions about the usefulness of studying physics through scientific inquiry. Most students considered its use in that physics is fun, you learn new things, and get knowledge which is necessary for the future. Only six students stated that they would like to use their new knowledge for a better understanding of phenomena in their everyday world.

*Learner Types*

Based on the way the students process information, it was possible to observe five different types of learners. Each participating student was classified as belonging to one of the types according to his/her way of processing information. Belonging to a certain type does not necessarily tell us anything about the student's learning, or approach to learning in general; it is solely based on the learning results from the present learning situation. The types are: 1) those who explain insignificantly; 2) those who camouflager their ignorance; 3) those who apply learned knowledge in familiar situations; 4) those who strive for a deep understanding; and 5) those who have reached a deep understanding. These learner types can be placed on the continua of rote-meaningful learning (Figure 2).

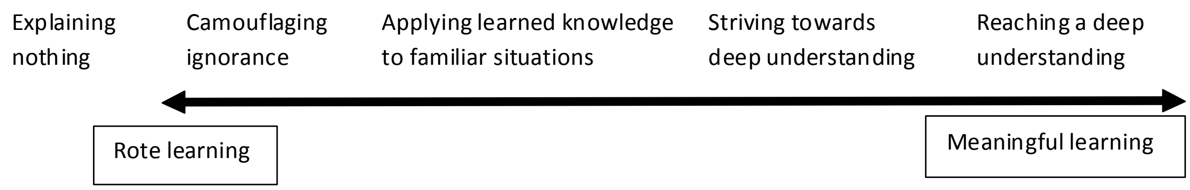


**Figure 2.** Learner types in the continua of rote-meaningful learning

The first type of learners is those that do not give any sensible answer, not even occasional facts learned by rote. These students had not been able to use to advantage information presented during the intervention. Either they could not take in the information or they could not use it in a new context. These students did not use scientific concepts and without exception they took a surface approach to learning.

Students who try to cover their ignorance are those that rely on concepts and definitions that they have learned by rote. They use scientific concepts, but their explanations are primarily either intuitive or synthetic. These students have not actually understood the phenomena behind the concepts and have a surface approach to learning.

Those who can apply their new knowledge in familiar situations form the third type of learners. These learners already approach meaningful learning; they try to connect new and prior knowledge to meaningful entities, thus they try to apply scientific concepts to their everyday experiences. Their answers can already show a deep understanding of the phenomena.

Students, who almost always use scientific concepts and try to apply what they have learned, form the fourth type. The process, however, is not always straightforward, the new knowledge sometimes contradicting their everyday knowledge. The amount of synthetic answers is therefore especially large in this group although they have revised their knowledge and strive to more comprehensive concept hierarchies through which they can explain and understand still more phenomena.

The answers of students who have reached a deep understanding, show that they fulfil the criteria for meaningful learning. They have been able to comprehend less familiar phenomena and can explain these in a meaningful way combining their prior knowledge and experience to the new, without experiencing any conflict.

One girl and three boys did not explain anything thus belonging to the first category (Figure 3). On the other end of the continua of rote-meaningful learning were four girls and one boy (Figure 3).

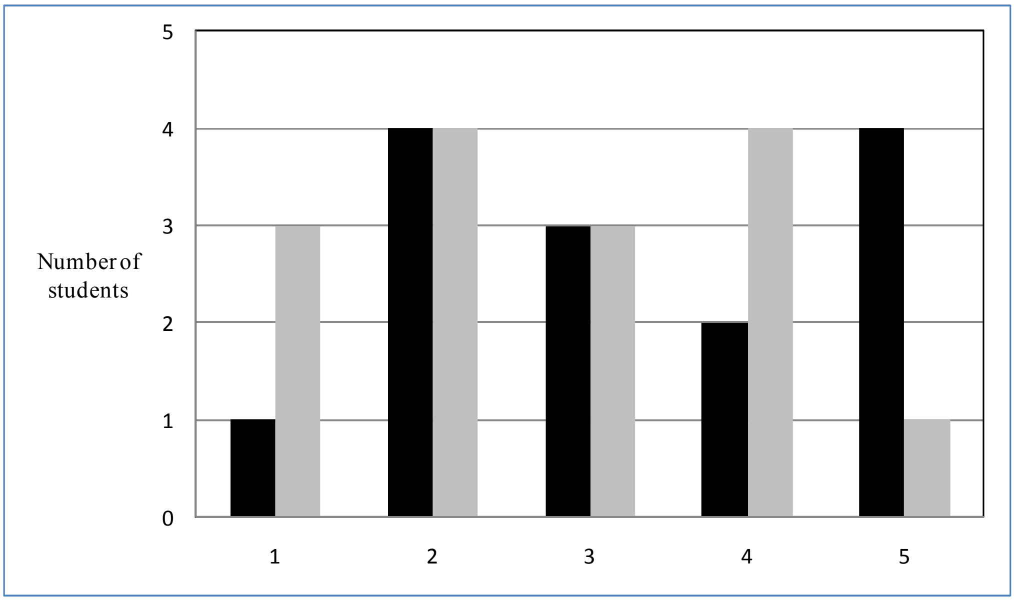


**Figure 3.** Learner types (1-5). Black boxes stand for girls, gray for boys.

*Transformative Experience*

The way students described the usefulness of scientific inquiry, provided an opening for study on how they possibly intent to use their new knowledge in explaining their own everyday experiences. The aim of science education is to expand the student's understanding of phenomena in the surrounding world and to help him/her explain them in a better way. All participants apparently did not achieve this aim. Eight students just found it fun to perform experiments and/or thought that the new knowledge would be useful in further studies or in a future profession. Others appreciated the new knowledge as such. Only six students thought that they could use the new knowledge in their everyday life.

There was no conformity between the learner types and the forming of transformative entities, therefore there seems to be no strong connection between the deep understanding of a phenomenon and the arousal of transformative experiences. However, participants that have reached a deep understanding are also more unanimous in their thoughts about usefulness. They either find the studies useful because of the applicability of the knowledge or because of the knowledge value in itself.

**Discussion and Conclusions**

When explaining the phenomenon in the pre-instruction examination, the students only used their prior experiences and perceptions, whereas in the exam after the inquiry-based instruction, they also utilized scientific knowledge and concepts which they had learned during the intervention. After the inquiry-based instruction, the students' answers reflected a deeper understanding of the phenomenon. Five types of learners were found, one type reaching the level of meaningful learning. This diversity of learner types reflects the complexity of students' understanding.

The findings in this study are in accordance with previous studies (Hofstein et al., 2004; Kipnis et al., 2008; Sriwattanarothai et al., 2009), when students had better conceptual understanding of the issues due to study in the inquiry-based laboratory. This study shows that meaningful learning was enhanced when students had the opportunity to personally choose the equipments and materials used for constructing their knowledge of the phenomena, as Tobin (1990) and Tang et al. (2009) have suggested.

The teachers in this study valued inquiry, and the learning material prepared for the intervention was based on literature about the inquiry method, and were thus well prepared to guide the students carefully. This also had an influence on the students' abilities to make inquiries (see Apedoe, 2008; Brown et al., 2006). Contrary to the findings of Brown et al. (2006), the intervention presented no remarkable problems concerning time or structuring of the instruction; the students had enough opportunity to plan their inquiries even though they had little previous experience of the inquiry method.

In accordance with Pugh (2004:192-193) we have found that understanding a phenomenon does not imply the arousal of transformative experience. In transformative experience, the student's relationship with the world is transformed as he/she comes to see some aspect of the world in a new way.

Although we can not generalize the findings of this study, we have attained some useful information concerning the teaching of friction. This study is also an example of teachers in the role of researchers, working in accordance with the aims of teacher education. Further research might extend the intervention study to be repeated in several classrooms, and if possible, in the context of a longer intervention.

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