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Smartphones as Scientific Instruments in Inquiry Based Science Education

Henrik Egholm Wessel
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Abstract

Smartphones are becoming more and more popular including among students in Danish high schools. With small programs, also called applications, smartphones can be turned into small scientific instruments for many in the class, so instead of working in groups of four or five, students can work in groups of two or three and they can therefore be more active and engaged.

The thesis is about finding out if it was possible to use smartphones as scientific instruments in inquiry based science education, if the students were willing to use their own smartphone in class, if the smartphones were precise enough to be used to gather worthwhile data and what the advantages and disadvantages are in using smartphones in class.

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FACULTY OF SCIENCE
UNIVERSITY OF COPENHAGEN

Master's thesis

Henrik Egholm Wessel

Smartphones as scientific instruments in Inquiry Based Science Education

Academic advisor: Robert Harry Evans

Submitted: 02/04/13

Abstract

Smartphones are becoming more and more popular including among students in Danish high schools. With small programs, also called applications, smartphones can be turned into small scientific instruments. With smartphones used as scientific instruments, school classes can have enough instruments for many in the class, so instead of working in groups of four or five, students can work in groups of two or three and they can therefore be more active and engaged.

This thesis was about finding out if it was possible to use smartphones as scientific instruments in inquiry based science education, if the students were willing to use their own smartphone in class, if the smartphones were precise enough to be used to gather worthwhile data and what the advantages and disadvantages are in using smartphones in class. The study for this thesis was made from January 2012 until January 2013 in five different high schools in Denmark with four different lessons, all about physics. The lessons were constructed using inquiry based science education (Lawson, 2010) and the 5F and 1E inquiry teaching model, which consists of six parts. The first part is the elicit phase, where the students pre knowledge is determined. The second part is the engagement phase, where the students are motivated to be interested in the lesson. The third part is the exploration phase, where students conduct their own investigations. The fourth part is the explain phase, where students explain their results. The fifth part is the extent phase, where students extend the knowledge they just obtained into a new case. The last part is feedback, where students get feedback from one another and the teacher about their learning.

The four lessons that were constructed were about sound, two different acceleration lessons and a lesson in Tivoli. In the lesson about sound, the students had to measure the dB-level compared to the distance from a loudspeaker. In the acceleration exercise the students measured the acceleration when they did some simple experiments in the class. The Tivoli lesson was a lesson held in Tivoli, during the period Tivoli had “Faglige dage” where a class could come to Tivoli and have a lesson there, so they could use the rides in Tivoli to do physics. The students could use their smartphones to measure the acceleration during the rides. A total of 252 students participated in this study, and 76.9% of them had a smartphone. Of those with a smartphone 96.5% were willing to download applications and use the smartphone in a lesson.

The data to this thesis, was collected by using questionnaires, where the students had to answer different questions for example sex, age, if they have a smartphone and if they wanted to use it in a lesson. Furthermore the students were asked to send their data after the lesson. For the lesson with sound the students had an answering sheet where they could write down what they had been during the lesson, which they had to hand in after the lesson. One class that did a lesson about acceleration, made a report after the class, and the teacher for the class send the students reports to the author of this thesis.

The students were able to use their own smartphones to measure both dB and acceleration and they were willing to use their own smartphone. The students were able to get consistent data,

when they used the smartphone to measure acceleration. The smartphones had some build in limitations, which could cause some problems. Especially with the dB-meter, where some of the devises had some limitations, in that they could not measure high dB levels. By planning lessons to take limitations into account, it is possible to work around the problems. On the positive side, the students think that it is more engaging to use smartphones in class, and that it makes the lesson more interesting. The students are fast to learn how to use an application and they love to use their smartphone. The use of smartphone can also distract the students, because Facebook and text messages are easily accessible. This problem is not unfamiliar in normal lessons, where students are also distracted by computers.

Introduction

Smartphones are becoming more common in our society, and it is also true among gymnasium students. Therefore, there is also a great potential for smartphones, if you can use them as scientific measuring instruments. The reason the phones can be used as scientific measuring instruments is because of the applications (app's) you can install on them. Both Google Play (Android) and Apple's App store (iTunes) have around 700,000 applications (Womack, 2012). Some of these applications are in a category called 'Education' and in a category called 'Tools'. Within these categories it is possible to find some applications that can be used by students in the classroom, for making scientific measurements.

If it is possible to use the phone as a measuring instrument, it is possible that each student or each small group of students have an opportunity to make measurements, which will immediately make it more tangible for the students as they then will have scientific measuring instruments in their own pockets. Likewise, it would be a better way to utilize resources, as most students have smart phones, while any gymnasium rarely has a measuring instrument for everyone. If students find that they can have scientific measuring tools in their pockets, they might be more interested in science; this study may therefore be a goal for a larger question.

Some scientists already use smartphones as scientific instruments. Some use the camera in the smartphone (Sjøgren, 2012), and some use applications (Simonsen, 2013), (Kielstrup, 2013). One of the things that the scientists can use is that there are a lot of people with smartphones. If they can get people to help them with their research, they can have a lot of data from different places.

Background

How people learn

It can be hard for a physicist to accept that there is no finite answer in didactics. In that sense science didactics is more like "humanities disciplines". Of course you can measure the activity in the brain, but those measurements cannot capture the complexity of the learning process. During the last 100 years there has been attempts to develop experimentally grounded theory, one of the big contributors to this theory was Swiss psychologist Jean Piaget (1896-1980) (Winsløw, 2006 and Lawson, 2010). Piaget himself called his field of science for genetic epistemology or the study of cognition genesis. This should be understood as individual's learning, and is about the conditions for learning and knowledge of each individual (Winsløw, 2006). One of the central parts in Piagets theory is the idea of mental structuring or schemata. There are two main schemata, the figurative scheme and the operative scheme (The scheme Theory). The figurative scheme is about phenomenon like things and people. The operative scheme is about actions and their consequences. Figurative schemata are the easiest to understand, since they are about the recognition of certain things and categorize them. An example is our understanding of what a dog is: there are many different dogs but they are all dogs, so every time we see a dog we can recognise it as a dog. These schemata can be of a more abstract nature, like what a quadratic equation is and what radioactivity is. Operative schemata (also called action schemata) are about doing something with phenomenon. A operative scheme normally consists of three elements: 1. Conceptions about a situation that activates the scheme, 2. An action that is normal for that situation, 3. An expectations for the consequence of the conducted action, or as Lawson called it If/then/Therefore reasoning (Lawson, 2010). For example of a person sneezes (first element/If) it will activate someone saying "God bless you"(second element/then) and you will expect some kind of reaction from the person that sneezed like "thanks" (third element/Therefore). People learn through these schemata through actions and experience. When we learn or experience something new, we will automatically try to put it into an existing scheme. But sometimes the schemata have to be changed a little to fit new experiences. Of course these changes can be more or less massive. Piaget distinguishes between two sides of this matter. The two sides are assimilation and accommodation. Assimilation is where a new experience fits into an existing scheme maybe with a small change of the scheme, like if you only have seen big dogs and then see a really small dog, then you have to change your view of what a dog is. Accommodation is when a new experience does not fit into any of your schemata and has to be adapted to give room for the new experience, for example when you learn to do math with non-natural numbers, lapses certain principles that are important for understanding calculation of natural numbers that multiplication is repeated addition (Winsløw, 2006). This idea of schemata is a fundamental part of Piaget's experimental work.

According to Piaget intellectual development occurs in terms of four major stages (the stage theory). The four stages are sensori-motor, preoperational stage, concrete operational stage and formal operational stage. The first two stages are not that relevant to this thesis due to the fact that they mostly include children under the age of 7. The concrete operational stage concerns mostly children of the age from 7-12 and the formal operational stage 12 and above. The four stages are basically characterized by type of operations a child is capable of. In the sensori-motor stage the child's recognition is based on sensation and movement. In the preoperational stage the child can deliberately refer to a person or object even when they cannot see the person or object (this is not possible in the sensori-motor stage) (Winsløw, 2006). The next two stages are more interesting due to the fact that it is the two stages that are most relevant for a teacher and will be elaborated more. The concrete operational stage is the stage where the child can do mental operation in a concrete situation in situations that the child can remember or experience. They also develop their ability to use the operative schemata (Winsløw, 2006). As Lawson writes, what the child can do in the concrete operational stage is:

- “Class Inclusion: The individual Understands simple classifications and generalizations (e.g., all dogs are animals; only some animals are dogs)” (Lawson, 2010, p. 48).
- “Conservation Reasoning: The individual applies conservation reasoning to perceptible objects and properties (e.g., if nothing is added or taken away, the amount, number, length, weight, ect., remains the same – is “conserved” – even through the appearance differs)” (Lawson, 2010, p. 48).
- “serial ordering: The individual arranges a set of objects or data in serial order and establishes a one-to-one correspondence (e.g., the youngest plants have the smallest leaves)” (Lawson, 2010, p. 48).

Formal operational stage is the stage where the child can do particularly logical-deductive reasoning (Winsløw, 2006). Like before Lawson writes what the child can do in the formal operational stage:

- “Combinatorial Reasoning: The individual systematically considers all possible relations of experimental conditions, even though some may not be realized in nature” (Lawson, 2010, p. 49).
- “Identification and the Control of Variables: In testing hypotheses, the individual recognizes the need to consider all the possible causal variables and design a test that controls all but the variable being investigated” (Lawson, 2010, p. 49).
- “Proportional Reasoning: The individual recognizes and interprets relationships between relationships described by observable variables” (Lawson, 2010, p. 49).
- “Probabilistic Reasoning: The individual recognizes that phenomena are probabilistic in character and that conclusions and explanations must involve probabilistic considerations” (Lawson, 2010, p. 49)

- “Correlational Reasoning: In spite of random fluctuations, the individual recognizes causes or relations in the phenomenon under study by comparing the relative number of confirming to disconfirming cases” (Lawson, 2010, p. 49).

In the formal operational stage the child or students is able to make an experiment and vary certain variables. Like in the experiment where the students have to find the connection between a pendulum cycle time, and string length and weight. In that experiment they will know to vary only one variable at the time. The combination of the scheme theory and the stage theory are the bases in the theory of the individuals learning. Winsløw writes that learning consist of at least three things: “The individual's existing schemata (learning is assimilation and accommodation of schemata)” (Winsløw, 2006), “Individual's actions and experience acquired (learning occurs as a result of experience)” (Winsløw, 2006) and “The individual's cognitive development (the types of schemata, and hence experience which the individual can handle)” (Winsløw, 2006). The first term can be described as putting a puzzle. The new piece must be added to the existing puzzle. In the same way, when we learn something new, the new knowledge has to be added to something that we already know. If it is too different from the things already know, we cannot adapt it in to an existing scheme. The second term means that the new knowledge has to be learned by the student itself. As with the example with the puzzle, the student has to lay its own puzzle. This is an important part of Inquiry based science education. The third term means that the learning processes also have a development process. One of the most important things in teaching is to know what the students know about a certain subject before it the subject is taught. If the teacher knows what the students know, then the teacher can teach the student accordingly (Lawson, 2010). The teacher should not overwhelm the student’s developmental capabilities. Instead the teacher should try to improve the student’s capabilities.

Inquiry based science education are built over the idea that the students have to work with a concept to learn it, and is based on the Piagetian theory. In this thesis the students are using the concept from Piagetian theory that they have to work with real word sources like acceleration and level of sound. They made their own investigations and their own observations. When working acceleration and level of sound students developed both their figurative scheme and their operative scheme. When working and make measurements with acceleration and level of sound, the students develop their figurative concept, and when they are analysing their data, they develop their operative concept. Operative concepts are driven by If/then/Therefore reasoning, which is a part of Inquiry based science education. For example in this study, **if** sound diminishes by distance, **then** a graph can be made, and **therefore** the relationship can be observed. Furthermore from the stage theory we know that instruction should not overwhelm students’ developmental capabilities. The instructions should be planned so they improve those capabilities. Therefore the different groups decided for them self, what they wanted to do or how they wanted to make their own measurements.

Inquiry based science education

The lessons in this thesis will be based on Inquiry based science education (IBSE) and consequently an understanding of IBSE is helpful in following this research.

IBSE is a form of problem-based education, where the students are responsible for solving problems using scientific methods where they may design experiments and make their own hypothesis. The students are, to some extent, independent in their experiments. The teacher's job is to guide the students with open questions, without giving them direct answers. IBSE seems to have a positive effect on students based on research (Minner, Levy, & Century, 2009).

During IBSE, students originate their own hypotheses, design their own experiments and explain the results. This form of education can help strengthen the links between teaching and disciplinary research (Spronken-Smith & Walker, 2010)and should help students remember the outcomes of their experiments better over a longer time. In addition, IBSE helps develop student skills in self-reflection, critical thinking and responsibility for their own learning. (Spronken-Smith & Walker, 2010)

There are basically three possible levels of inquiry, two of which will be used in this study's lesson planning. The three levels of inquiry are:

- Structured inquiry – where the teacher provides an issue or a problem and an outline for addressing the problem.
- Guided inquiry – where the teacher provides questions to stimulate inquiry but students are self-directed in terms of exploring these questions.
- Open inquiry – the students formulate their questions themselves and are self-directed in terms of exploring their questions.

The selection of the level of the inquiry will depend on the students' familiarity with inquiry methods. From the author's point of view, the first two types of inquiry can be used for students who haven't tried inquiry before or who are very inexperienced with inquiry. With open inquiry the students need some kind of experience with inquiry to get something out of it. In this thesis the lesson plans used are based on structured and guided inquiry, because the students generally do not have any experience with using inquiry in class and because there is a limited amount of time for this project in the classes.

IBSE consists of the three basic phases, 'exploration', term introduction' and 'concept application' (Lawson, 2010).

The exploration phase helps students learn through their own activity when they explore new fields. Students can decide for themselves which experiments inside the topic, they will make, and this should help them raise new questions that may not be answered in normal ways of teaching.

In the term introduction phase new terms are introduced to label new concepts. All new terms are introduced after the students have worked with the topic in the exploration phase. The new terms can be introduced using a textbook, a video, the teacher or by another student. This helps the students to better describe what they found out in the exploration phase.

In the concept application phase students apply the new terms and ideas they just learned into new contexts. This will extend the students' knowledge for the subject.

Inquiry instructions are is many ways the way people think when they explore their surroundings and learn. For that reason anybody who has reflected on learning and teaching has on their own discovered some sort of inquiry instruction. For the same reason it is not possible to say who invented the inquiry method. Even in ancient Greece they had some sort of inquiry, Socrates had his famous Socratic method (Lawson, 2010)

Johann Friedrich Herbart was a German philosopher and influenced American education thought in the early 1900's. He had the idea that education should develop character, and the process of building character starts with the students' interests. Herbart had two ideas as building blocks for education, interest and conceptual understanding. Herbart suggested two types of interest, the first was direct experiments in the real world, and the second was based on social interaction. The second building block in Herbart's idea was conceptual understanding. Herbart thought that the sensory perceptions of objects and events were important, but not sufficient for the development of the mind. In Herbart's model consistent ideas was very important. Each new idea must be related to existing's ideas. Herbart's model is one of the first models that systemized the approached to teaching and have been used in various forms by teachers for more than 100 years (see Table 1). (Bybee, et al., 2006)

Table 1. **Herbart's Instructional model**

Phase	**Summary**
Preparation	The teacher brings prior experiences to the students' awareness.
Presentation	The teacher introduces new experiences and makes connections to prior experiences.
Generalization	The teacher explains ideas and develops concepts for the students.
Application	The teacher provides experiences where the students demonstrate their understanding by applying concepts in new contexts.

(Table from Bybee, et al., 2006 page 5)

Figure 1 provides an overview of the historical and contemporary models starting with Herbart (see Figure 1).

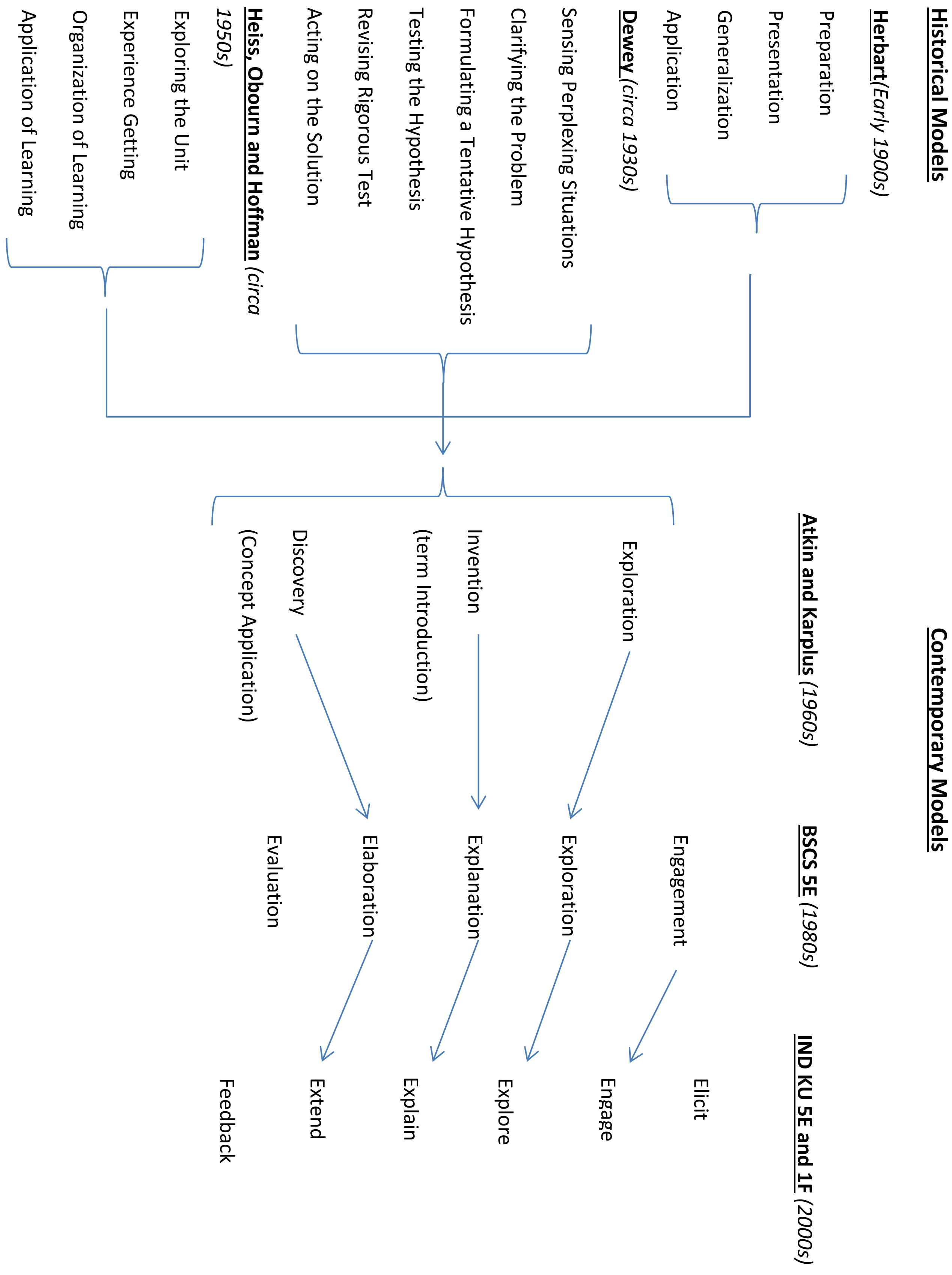


Figure 1. Historical development of IBSE. Modified from (Bybee, et al., 2006)

John Dewey began his career as a science teacher. There was a connection between Dewey's conception of thinking and science inquiry due to his background in science. In his book '*How we think'* Dewey came up with a complete act of thought in which he describes what he means as indispensable traits of reflective thinking. Those traits are: 'defining the problem', 'noting conditions associated with the problem', 'formulating a hypothesis for solving the problem', 'elaborating the value of various solutions' and 'testing the ideas to see which provide the best solution for the problem'(see Table 2) (Bybee, et al., 2006).

Table 2. **Dewey's Instructional Model**

Phase	summary
Sensing Perplexing Situations	The teacher presents an experience where the students feel thwarted and sense a problem.
Clarifying the Problem	The teacher helps the students identify and formulate the problem.
Formulating a Tentative Hypothesis	The teacher provides opportunities for students to form hypotheses and tries to establish a relationship between the perplexing situation and previous experiences.
Testing the Hypothesis	The teacher allows students to try various types of experiments, including imaginary, pencil-and-paper, and concrete experiments, to test the hypothesis.
Revising Rigorous Tests	The teacher suggests tests that result in acceptance or rejection of the hypothesis.
Acting on the Solution	The teacher asks the students to devise a statement that communicates their conclusions and expresses possible actions.

(Table from Bybee, et al., 2006 page 6)

A new variation of John Dewey's instructional model was introduced in 1950 by Heiss, Obourn and Hoffman. They included a method called 'the learning cycle'. It was based on the thoughts of Dewey but had some corresponding steps and was 'exploring the unit', 'experience getting', 'organization of learning' and 'application of learning' (see Table 3) (Lawson, 2010 and Bybee, et al., 2006).

Table 3. **Heiss, Obourn, and Hoffman Learning Cycle**

Phase	Summary
Exploring the Unit	Students observe demonstrations to raise questions, propose a hypothesis to answer questions, and plan for testing.
Experience Getting	Students test the hypothesis, collect and interpret data, and form a conclusion.
Organization of Learning	Students prepare outlines, results, and summaries; they take tests.
Application of Learning	Students apply information, concepts, and skills to new situations.

(Table form Bybee, et al., 2006 page 6)

Robert Karplus was a theoretical physicist at the University of California-Berkely, who became interested in science education in the late 1950s. His interest got him to investigate the way children think and the way they explain natural phenomena. J. Myron Atkin from the University of Illinois (in 1961), shared Karplus ideas about teaching. Together they came up with a new model. The new model or learning cycle consisted of ‘exploration’, ‘invention’ and ‘discovery’ (seeTable 4) (Bybee, et al., 2006).

Table 4. **Atkin-Karplus Learning Cycle**

Phase	Summary
Exploration	Students have an initial experience with phenomena.
Invention	Students are introduced to new terms associated with concepts that are the object of study.
Discovery	Students apply concepts and use terms in related but new situations.

(Tabel from Bybee, et al., 2006 page 8)

The 5E and 1F model

It can be helpful to know something about the 5E and 1F model if you want to construct an inquiry based lesson. The 5E and 1F is an extension of the three phases from Atkin-Karplus (see Table 4) and help structure a lesson plan (see Figure 2)

The 5E and 1F consist of 'Elicit', 'Engage', 'Explore', 'Explain', 'Extend' and 'Feedback'.

Elicit is the phase where you can get an idea of how much the students know about the subject before the lesson starts. It could be some questions about the topic, just for the teacher to see, so the teacher knows what knowledge the students are starting with. Also if students have any misconceptions of the topic they can be clarified before they start.

Engage is the phase where the students get interested in the topic. If IBSE is to work properly the students have to be interested and curious. When they are curious they will want to find out more. There are several ways to get students engaged, it could be with some pictures, a video or some questions like "have you ever …." Or "how many of you …." these questions can start a discussion, which can open up for more questions that the students can try to answer. The choice of how to get the students engaged depends on several things. For example age of the students, or gender or the topic. If for example we had a lesson with acceleration as the topic, a video of a racing car could probably engage many boys but not all the girls. Instead you could use a video from a roller-coaster ride instead which could engage more students of both genders.

Explore is the phase where the students work with the question they asked themselves in the engage phase. The students can make small experiments and collect data. This will help them develop their abilities to observe, measure and predict. If their experiments are in the laboratory with scientific tools, they also get experience with instruments. While the students work with their experiments, they can ask themselves some new questions and maybe more relevant or deeper questions or just new questions they want to work with afterwards. The teachers role in the explore phase is to act as a facilitator. The teacher initiates the activity and gives the students time to investigate their experiments. If needed the teacher can guide students as they work with their explanations, without giving them answers.

In the Explain phase the students have to use their data and their knowledge from the explore phase to come up with an idea or theory. They have to reflect on the data they observed. In the explain phase the teachers job is to ask students about their own explanations. To help them with an explanation the teacher can direct students attention to specific aspects of the engagement and the explore phase.

In the Extend phase the students have to extend their knowledge from the explore and explain phase, so they can answer a new problem or question. If the students can transfer their existing knowledge to a problem, they can get a deeper understanding of the topic they worked with. It is also in this phase the teacher can get an idea if some of the students still have some misconceptions or if they only understand a concept in terms of the experiment they just worked with.

The Feedback is an important part of all the parts in the 5E. If the 5E is going to work optimally, there should be a constant feedback not only to the teacher but also to the students. If the students work in small groups there should be feedback between the groups, so they can get good ideas from each other. The feedback between the teacher and the students/groups helps the teacher constantly know where the students are, and can help them on the way or ask them questions so they can get new ideas.

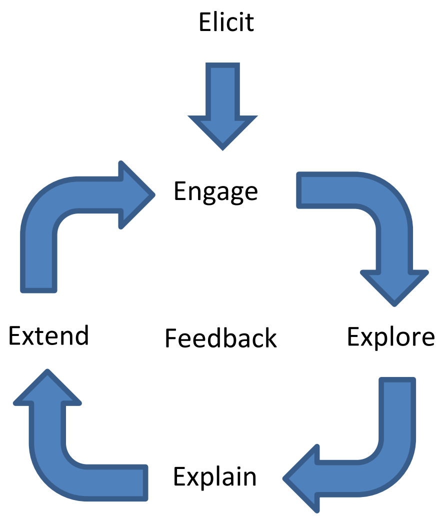


Figure 2. The 5E 1F model from Department of Science Education at Copenhagen University

The 5E and 1F model can be explained with Figure 2. Every lesson plan should start with elicit, so the teacher has an idea of the students' knowledge of the subject and have a chance to catch any misconceptions from the beginning. After the elicit we go down to the engage, and get the students interested in the subject. When the students are engaged, they can come up with an experiment and start the explore phase, where they get a chance to work with the subject themselves. During and after the exploration the students have to explain what happens in their experiment. The teacher can help by asking questions about what happened in the experiment. When the students come up with an explanation they can extend their knowledge by taking what they've just learned and transfer it to a new but similar problem. After the extend phase the circle starts again with the engage phase for a new problem and by that way it is possible to build more on the students existing knowledge. In all phases, feedback is important, feedback between students and teachers, between students and students, students and instruments and so on. Constant feedback helps the students to come up with new ideas and ensure that they do not get stuck. If they do not understand the instruments they cannot come up with an explanation to the problem.

When you look at Figure 2, it may seem very strict, but of course you can even have a mini circle inside one of the phases, for example the students have to learn a new instrument to do the exercise, they can have a mini circle to learn how to use the instrument, or in this thesis case an application. But Figure 2 gives an idea of what has to come first. You cannot have the explain phase before you have done the experiment and you cannot start with the extend phase. But you can mix elicit and the engage phase or the engage phase can be a part of the experiment. An experiment can often be engaging by itself. When the students explain what happens in the experiments they can go back and forth between the experiment and the explaining. It is a natural thing to do because you can test whether the original idea or theory fits with what is observed.

In Figure 1 we can see the historical development of IBSE from the start 1900's until 2000's, where we have the 5E and 1F model for IND KU that are used in this article.

What to do in IBSE

In the beginning it can be difficult to know what to do in IBSE. So what is the teacher's job and what is the student's job in the different phases? From Table 5 and Table 6 it is possible to see what the students and the teacher have to do and what not to do in IBSE.

Table 5. What the students need to do during IBSE. Modified from (Bybee, et al., 2006)

Phases of the model	The 5E and 1F model: What the student does	
	Does	Doesn't
Elicit	Answer questions from the teacher	Withhold any questions or misunderstandings
Engage	Shows interest in the topic Ask questions such as, "what can I find out about this?"	Asks for the right answer Gives the right answer (to other students) Seeks one solution
Explore	Be an active part of group come with explanations and test them Be open-minded within the limit of the activity Asks relevant questions Records observations and ideas	Fails to participate in group work Fools or plays without a goal in mind Stops with one solution
Explain	Comes up with an explanation based on experience and the experiment Discusses their explanation with others and accepts any helpful ideas or errors in their explanation Listens critically to and questions others explanations	Asks for the right answer Accepts an answer without any questions Comes up with explanations pulled out of thin air or without evidence
Extend	Applies new labels, definitions, explanations and skills in new but similar situations Uses previous information to ask questions, propose solutions, make decisions and design experiments Draws reasonable conclusions from evidence	Ignores previous information of evidence
Feedback	Seeks feedback from teachers and peers	Avoid asking for feedback from teachers and peers

Table 6. What the reacher need to do during IBSE. Modified from (Bybee, et al., 2006)

Phases of the model	The 5E and 1F model: What the teacher does	
	Does	Doesn't
Elicit	Elicits responses that uncover what the students know or uncover what misconception the students have about the subject, by asking them questions	Ignore the students background knowledge or their misconceptions
Engage	Creates interest Raises questions	Lecture Explain concepts Provide definitions and answers
Explore	Encourages the students to work together without direct instructions from the teacher. Asks open-ended questions Provides time for the students to work with their experiments Acts as an advisor for the students Observes and listens to the students when they work	Provide answer when students ask Tell or explain how to work through the problem (give them cookbook instructions) Directly tell the students that they are wrong Give information or facts that provide the answer
Explain	Encourage the students to explain concepts and definition in their own words Asks for justification and clarification form students Formally clarifies definition, explanations and new labels when needed Uses the student's previous knowledge as the bases for explaining concepts	Accepts explanations that have no justification Introduces unrelated concepts or skills Ignores or neglects to ask for the student explanations
Extend	Expects the students to use formal labels, definitions and explanations provided previously. Encourage students to extend their knowledge to new situations Reminds the students of alternative explanations	Provide definitive answers Lecture Directly tell the students that they are wrong Lead students step by step to an answer
Feedback	Gives students feedback about their learning	Fails to give students feedback

How to make an Inquiry based lesson

Learning objectives

There are many things to consider before planning a lesson. Some of them are "what is in the curriculum", "what are the learning objectives", "What do students know beforehand", "what equipment do they need" etc.

One way to plan a lesson is by a method called backward design (Wiggins and McTighe 2005 as cited in Lawson, 2010). Instead of starting from scratch, you start by looking at the official curriculum from the government and find some learning objectives, so you know that the students are supposed to know and what they can be tested for. From that you know what you want the students to know or to be able to do. The next step is to make sure that your plans will lead to the desired results. The final step involves the planning of learning experience and instruction.

Even when you've figured out what to teach, it is not enough just to follow the 5E and 1F model. There are a lot of educational and didactic questions you have to ask yourself while designing a lesson.

Questions to work with

Lawson 2010 devised 25 questions you can use to design a lesson plan for Inquiry. The questions help to designs and carry out a lesson. Some of the most important questions for making a lesson can be found here (Lawson, 2010, p. 114-118).

1. "*Does the lesson involve concepts fundamental to understanding the discipline's embedded theories?"* (Lawson, 2010)
2. *"Is the lesson appropriate in terms of the students' developmental stages?"* (Lawson, 2010) It is important for a teacher to know what developmental stages his or her students are at. The instruction must challenge but not overwhelm student reasoning.
3. *"Does the lesson involve materials and activities that interest diverse students?"* (Lawson, 2010) A good engagement phase where all the students get interested is important for inquiry.
4. *"Do lesson materials and/or activities provoke student's thinking, questioning, and discussion of meanings?"* (Lawson, 2010)

5. *“Are there provisions within the lesson for a variety of levels and paths of investigation?”* (Lawson, 2010)
6. *“Does the amount of reading impede the success of students with limited reading ability?”* (Lawson, 2010) Every time a lesson involves some amount of reading, there is a chance that students with limited reading ability are going to have some problems. By having only a small portion to be read, all students have the opportunity to participate equally in lesson.
7. *“Are visual and technical aids such as demonstrations, diagrams, slides, videos, and computers used as effective aids or supplements?”* (Lawson, 2010)

Student behaviors

8. *“Are students making observations that raise questions?”* (Lawson, 2010) It is important that the objective of the lesson allows the students make observations that raise questions, it is by being engaged in the exploration and wanting to come up with an explanation that indicates that inquiry is taking place.
9. *“Are class conclusions based on the evidence rather on teacher authority?”* (Lawson, 2010) To be fully inquiry the classroom conclusion, has to be based on the students observations and not the teachers authority.

Teacher behaviors

10. *“Are new terms introduced only after students have had direct experience with materials, events, or situations that enable students to assimilate the verbal presentation?”* (Lawson, 2010) One of the important things in inquiry is that the students have a chance to learn and get an idea of new things before they get the correct terms for them.
11. *“Does the teacher provide additional materials, experiences, or events that enlarge refine, and reinforce the meaning of the introduced terms?”* (Lawson, 2010)
12. *“Did the students and the teacher enjoy the lesson?”* (Lawson, 2010)

A lot of these questions are not only important to inquiry but also are important to other forms of teaching. Not all of these questions can be weighted equally every time, but it is a good thing to consider them when lessons are made. For example, some times a lesson will contain more reading that at other times.

Components of good lesson plans

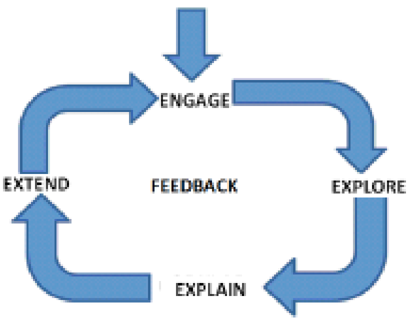
The reason to write a lesson plan is to list how a teacher will help students attain lesson objectives. It should be possible for another teacher to take a lesson plan and make the same lesson. For that reason there are some things that are a good idea to have in a lesson plan, like what the students should learn and what the teacher has to do during the lesson. There should be a short overview of the lesson's objectives and what concepts are going to be introduced. The lesson plan should also have some sort of background information, so it is possible for other teachers to use the lesson and know what they, and the students, have to know beforehand. There should also be a part in the lesson plan with things the teacher has to do before the lesson starts. For example maybe the teacher has to find some instruments or prepare a special setup. In addition the lesson plan has to contain some explanations to the different stages in the 5E and 1F model.

An example of a lesson plan can be seen in Figure 3:

Organisational Title: measurement of dB vs distance	Dates:

Conceptual Plan

Goals: Repetition of sound waves and understanding of volume and distance	The Ministry of Education Goals: http://us.uvm.dk/ physics c: sound and light
Content Learning Objectives: the physical characteristics of sound and light and their connection to our senses	

Process Learning Objectives:		Sources for lesson:
To learn to use a decibel meter	 **Drawing of the learning cycle**	**Vejen til fysik C** **Aktiv fysik**

Activity Plan (outline)

Time	List of activities	Teacher	Student
-3 minutes -2 minutes -15 minutes -30 minutes -10 minutes	-explain what is going to happen during the lesson -divide in to groups -At least one computer and one smartphone in each group -elicit questions and exploration with FourierTouch -engaging, at what level do we hear music -the distance law for dB -does your ears take damage from loud music (-use a balloon to show the distance law)	-explain -help with forming the groups -ask questions, and circle around the groups -ask questions to the program -classroom experiments with music -help the students to start their experiments -help with the calculations -help with finding answers in books or the internet	- listen -get together in groups -answer the questions in the group -use the FourierTouch program to repeat sound waves -discuss of they think the music is loud -measure the dB in difference distance -make calculations -find out when the ear takes damage

(An extended version of the activity plan has to be attached to provide information on this table.)

Evaluation plan

FORMATIVE:	SUMMATIVE:
Gives students feedback on their ability to use the	**A test of their understanding of the physical characteristics of sound and light and their connection to our senses**

Figure 3. Example of an IBSE lesson plan for a sound experiment

A lesson plan like this needs to be followed up by an extended version, but it is possible to use this lesson plan in class as a guide on to what to do.

An example for the extended version of the activity plan:

Measurement of dB vs distance.

Introduction:

Begin the lesson with some music, while the students find their places.

Explain what is going to happen during the lesson, and write the questions they will answer on the board (background knowledge).

Execution of the lesson:

Elicit questions: to be discussed in the groups. The students have worked with sound and light for a long time, so they should be able to answer these questions. What is a transverse wave and what is a longitudinal wave? What does the amplitude means for the wave? How is dB calculated? (The teacher ask the questions to the whole class, and then gives the students time to think about the questions. Maybe walk around the students and listen to what they say and think, without helping them too much.)

Engaging and exploring with FourierTouch: Play with the program, what do we see? Can we see a difference in the program, between a male and a female voice? Why do we see a transverse wave when a sound wave is a longitudinal wave? While exploring the program, there is a chance for the students to answer the elicit questions, if they did not have the chance before. (The teacher gets the students to use the program FourierTouch and gives them time to test the program, and walk around and ask them questions from the elicit phase.)

Engaging: At what level do we listen to music? Get one or several students to use their headphones from their mp3 player, and get them to turn up the volume to what they use to listen music. Turn up the music in the classroom to the same level, and measure the dB and discuss if the music is too loud? (The teacher explains what is going to happen, and controls the music in the classroom. The music is increased gradually until all have a measurement. Discuss in the class, if they think the music is loud).

Explore: The students can use their smartphone to measure the dB-level in the classroom, at different distances to a loudspeaker. (The teacher sets the music at a fixed volume, and helps the students make their measurements if they have problems.)

Explain: by looking at the data the students can see a correlation between the distance and the sound level. It is not important that the students find out that the dB goes down with 6 every time the distance doubled, but that they can see that the dB-level is decreasing over distance (the teacher helps the students by discussing their results with them in their groups.)

Extend: by looking at the Internet, the students can find out at what level sound can be harmful. The student can discuss whether they listen to music at too loud a level.

The end of the lesson.

This thesis will be about smartphones as scientific instruments in Danish gymnasiums, where the students have to use their own smartphones in class.

The research questions for this thesis are:

- Is it possible to use smartphones as a scientific instrument in classrooms?
- Are the smartphones precise enough to be used as a scientific measurement instrument?
- Are students willing to use their smartphones as instrument?
- What are the advantages and disadvantages using smartphones in class?

Method

The study was made in the period from January 2012 to January 2013, starting with a pilot study in January 2012 to see if it was possible to use a smart phone in class and to find out how many students have a Smartphone, and then a larger study from September 2012 to January 2013.

12 classes from five schools participated in the project, with a total of 252 students in all. Some of the students in the different classes did not answer the questionnaire for different reasons. To make sure that as many students as possible responded to the questionnaire, they were asked to fill out the questionnaire at the end of the lesson.

The project consisted of three parts. The first part was to test if it was possible to use smartphones in class and if the students were willing to use their own smartphone in a lesson. The second part was in Tivoli and it was about seeing if it was possible to use smartphones outside the controlled environment that the classroom is. The third part was the part where the lessons were tested in different classes.

Three lesson plans were constructed, based on the curriculum from the Ministry of Children and Education, to make sure that it would be interesting for teachers to try it out. The three lessons were divided into three different levels of physics so as to fit the Danish three levels of physics (C, B and A) educational level. The first level is physics C, typically in the first year in the gymnasium. The second level is physics B, and it is the level the students obtain if they have had physics in two years, so it is on either the first and second year or on the second and third year. The last level is physics A and it is the level the students obtain when they have had physics for three years. Of the three topics, one was about sound and two about acceleration. The two acceleration lessons were: acceleration in one direction and centripetal force.

Before the idea was tested in the classes, a large group of smartphone applications were tested, to have an idea of which applications worked and which did not. One of the problems was finding the best application for the intended lesson outcome. There are hundreds of applications both for Android and for the iPhone. For the lesson about sound, an application that could measure sound level was needed, and for the lessons about acceleration an application that could measure acceleration was sought. It was possible to find some applications that could measure sound and acceleration. All the new smart phones have a built-in accelerometer, so they can determine the orientation of the device, and of course they all have a microphone. The demands for the sound application were that it could measure in decibels and the demand for the acceleration application was that it could save and send the log file to a computer. With these demands a lot of the applications were removed. Another demand was that the selected application had to be available on both Google Play (Android) and at the App Store (iPhone). Because there are not that many applications made for both Android and iPhone, the demands were changed so that the applications did not have to be from the same developer, but they should have the same options. Furthermore the applications had to be free, so the students would be interested in downloading the program. Even with all these restrictions it was easy to find some applications.

App testing

To see how well the dB- meter was working, and to see what the students could expect to get during the experiment, a test was made. At the time of the test, the author did not have access to an iPhone. The test was made with a laboratory quality dB-meter, two different smartphones (a HTC Legend and a Samsung Galaxy SII) and two different applications. The instruments were placed at a fixed distance from the loudspeaker. The loudspeaker was connected to a tone generator that played a constant tone. During the experiment the amplitude was gradually increased and the noise level was noted. The graph from the experiment can be seen in Figure 4. As seen on the graph, the data is shifted compared to the real dB-meter, but it is consistent. This means that the smartphones did not measure the precise value, but the error was the same all the way through the experiment.

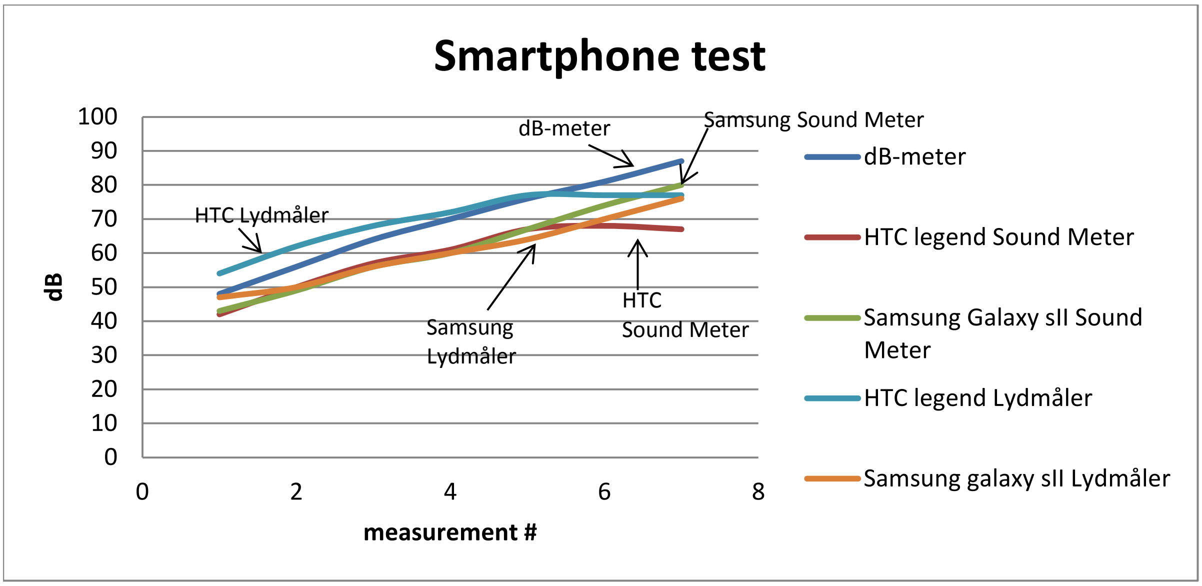


Figure 4. Measurements made with a tone generator, at a fixed distance from the loudspeaker to the smartphones and dB-meter. The sound was gradually increased.

The application Sound Meter (Smart Tools co.) was chosen dueto the fact that it was the more consistent between the two smartphones, compared with Lydmåler (TACOTY CN).

Another experiment was conducted to see what would happen when the smartphones were moved. In this experiment, a loudspeaker was connected to a tone generator that played a constant tone and at a constant noise level, then the instruments were moved further and further away. The results for that experiment can be seen in Figure 5.

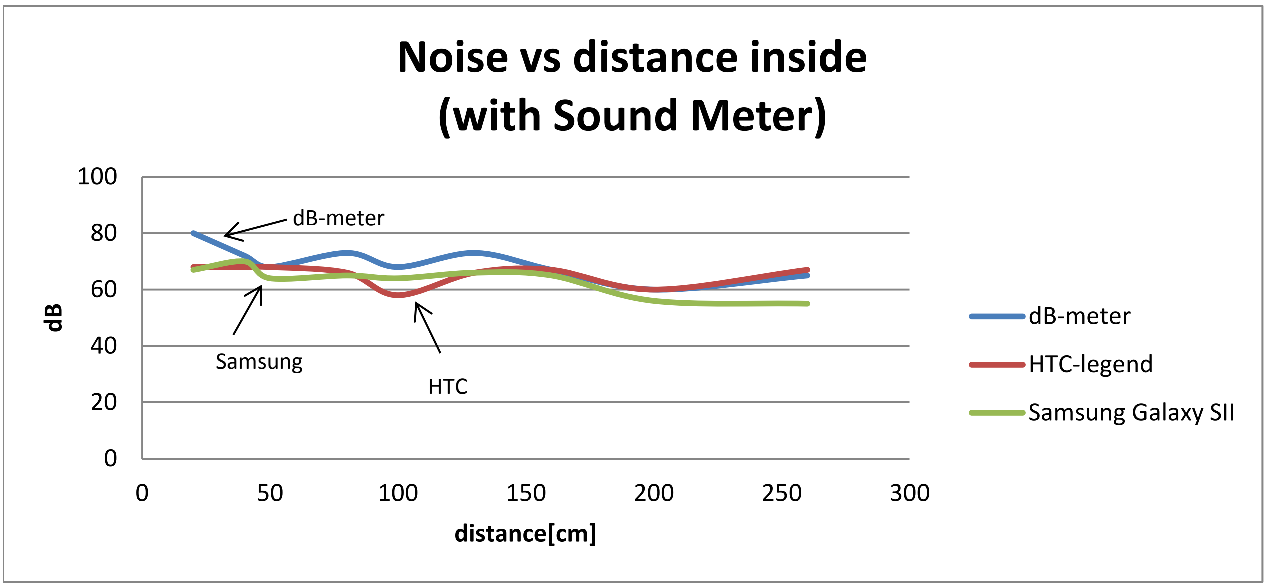


Figure 5. Measurements made with a tone generator, in a small room. The distance between the loudspeaker and the smartphones and dB-meter was gradually increased.

This experiment was made inside in a closed room, a similar experiment was made outside, to see if it was better to do it outside. The results can be seen in Figure 6.

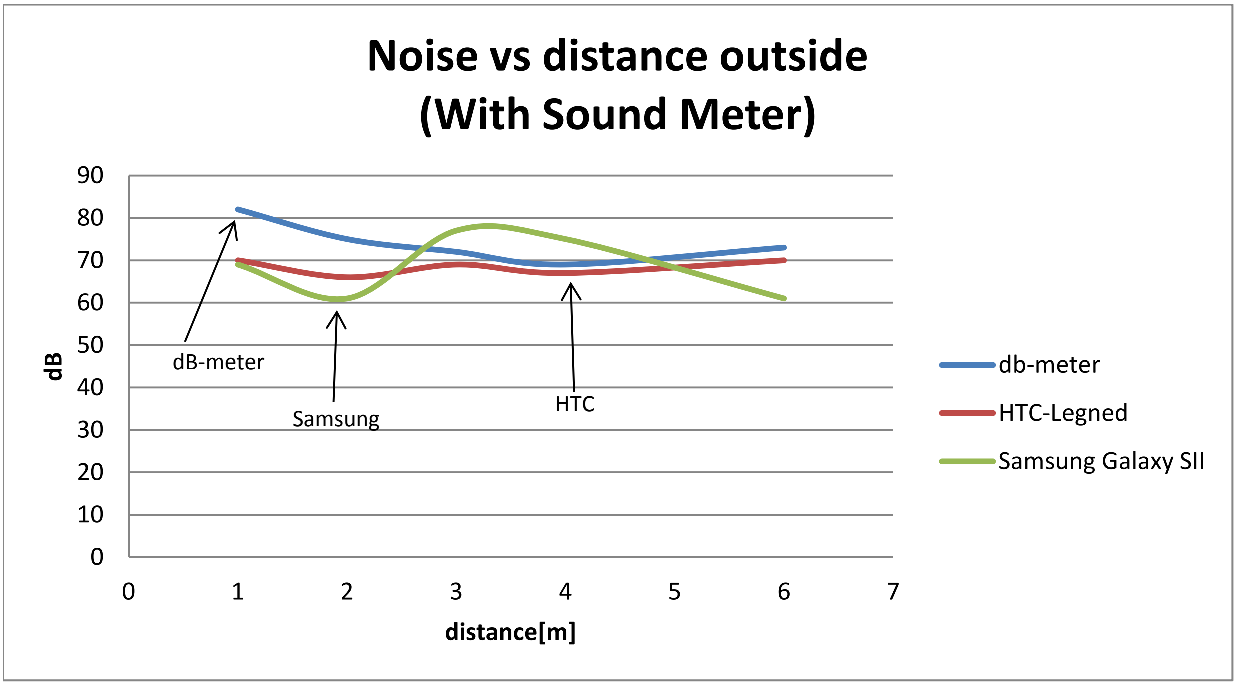


Figure 6. Measurements made with a tone generator, outside. The distance between the loudspeaker and the smartphones and dB-meter was gradually increased.

As mentioned before, the Sound Meter (Smart Tools co.) was chosen as the application for students with an Android smartphone. The students with an iPhone used the application called dB Volume (DSP Mobile UG (haftungsbeschraenkt)) due to the fact that it was suggested by other teachers, and at the time sound applications were tested, the author did not have access to an iOS device.

Test for the acceleration applications were also made, but they were tested as a part of the preparations for "Faglige dage" in Tivoli as described later.

Academic days at Tivoli

During the period where the project was made, Tivoli had what they called "Faglige dage" or academic days (Tivoli is an entertainment park). The concept is that schools can spend a day in Tivoli, and conduct exercises and experiments instead of normal classroom experiments. During the time students are in Tivoli they can try out all the rides that they want for free, except for an entrance admission that their school pay. Tivoli provided some suggestions on what to do during the day, but schools decided for them selves what they wanted to do. One of the things that the students could try, was to take a cup of water with them in "det gyldne tårn" and see what happen with the water when they were in a free fall ("det gyldne tårn" is a high tower where you are fastened to a pod and the pod is dropped from a height of 64m or it is actually pulled down). It was possible to rewrite one of the lesson plans to make it fit this concept, and it gave an excellent opportunity to see if it was possible to use the smartphones outside of the classroom. For the students it is very engaging that they can have a day in Tivoli. Classes for the Tivoli project were found by using three methods. The first one was to send an invitation to a Facebook page called Smartphone teaching, the second way was a newsletter from IND (Institut for Naturfagenes Didaktik), and the third way was via private connections. Four classes from three gymnasiums were interested.

As a preparation for "Faglige dage" some acceleration applications were tested. Two of the problems that occured during the testing were with saving data and sending data. For the iPhone it was fairly easy to find an application that could save, store and send the data and the application SensorLog (Bernd Thomas) was suggested for the students to use. But for Android it was a bit more difficult. One of the applications (Accelero-meter Log (RabiSoft)) tested had a problem that it only could make measurements for less than a minute, but it was easy to send the data to an e-mail, but it could not store the data, and it had to be sent right away. Another application (Accelerometer Values (bearphone)) could save larger data files, and store them, but it was difficult to send the data afterwards. Of the two applications Accelerometer Values was suggested for student use (another application was also suggested but more on that application in the next section).

Questionnaire for the students and data collecting

When the classes had finished their lesson with smartphones, all the students were asked to fill out a questionnaire anonymously. In the questionnaire the students were asked the following questions:

- Date of the lesson, school, class, age, gender
- Do you have a smartphone?
- Which operating system do you have on your smartphone?
- Do you have an Internet connection on your smartphone? (no, yes pay for consumption, yes have free usage)
- Do you have the opportunity to use Wi-Fi on your smartphone/iPod/tablet?
- Would you be willing to download applications (free) to your smartphone/iPod/tablet, and use them in class?
- What did you get out of using a smartphone in class?
- What do you think that you could learn by using a smartphone in class?
- Would you ever think of using your smartphone outside of class, to make different measurements?
- Do you get distracted in class, when you are using a smartphone/iPod/tablet, due to sms or Facebook?

In the studies made from September 2012 to January 2013, the students were asked to send their results and what they measured from the lessons to the author of this thesis. It turned out that it was a problem to get the students to remember to send their results, so an answering sheet was made, which they could hand in after the lesson. On the answering sheet, the students had to write what they did and what their results were. If it was possible, the teacher was asked to send the students' reports, without any names, if they had to make one.

Fysik Værktøjskasse and Smartphone teaching

During the period these thesis were made the idea of getting an application made especially for the project arose. An idea of what should be in an educational application was formed. To get input from other teachers, the Facebook group, Smartphone teaching, was asked what they would like to have in an application (see Figure 7).

With the input from the Facebook group and the idea from the author of this thesis, an application was developed by a programmer who tried to fulfil all the wishes for such an application. The application was called 'Fysik Værktøjskassen' or physics toolbox (Pless, 2012). "Fysik Værktøjskassen" solved the problems of finding a good acceleration application. The application fulfilled the need that an acceleration application could save, store and send data easily. The test version was also promoted on the Facebook group, so there was a possibility to get feedback. Even though "Fysik Værktøjskassen" only was a test version and sometimes crashed the students were given the choice to download the application, since it was easier to send data from that application.

Figure 7 Input form the Facebook group Smartphone teaching

The Facebook group was asked to give inputs on lessons, which could combine the use of a smartphone (see Figure 7). With the ideas from the Facebook group the lesson plan for physics A was made.

Lesson plans/exercise instructions

All the lesson plans were made before the visits to the schools and before the teachers had the chance to see them. For all the lessons exercise instructions were also made which the students could use during the lesson. All participating teachers decided for themselves how much time they would spend on the project, but they had received advice on for how long it would take. The three exercise instructions were as follows:

Exercise one: Space travel to Mars

When astronauts are in space, they do not feel the normal gravity from earth.

Over a longer period it can be a problem for astronauts to be in weightlessness. If astronauts train with, for example elastics, some of the problems can be helped.

If one were to make a manned space flight to Mars, you would have to find a way to create an artificial gravity field.

How does the acceleration sensor in the phone work?

Use the phone to find out what the value earth's gravitational field is?

Design an experiment to show how you could make an artificial gravity field. How would one be able to use it in space?

Find out why it is a problem to stay for a longer time in space without a gravitational field.

Exercise two: Acceleration

Picture from: http://browse.deviantart.com/art/Acceleration-44339435

All daily movements have something to do with acceleration. For example when we drive a car or bicycle. When we start up after stopping at red at the traffic light, or when we jump off the diving board at the swimming pool, we experience acceleration.

But what do we really know about acceleration?

Discuss as a group what acceleration is and how it is calculated (what are the units for acceleration?).

Play around with your application on the phone and find out how it works, do a little experiment at your table.

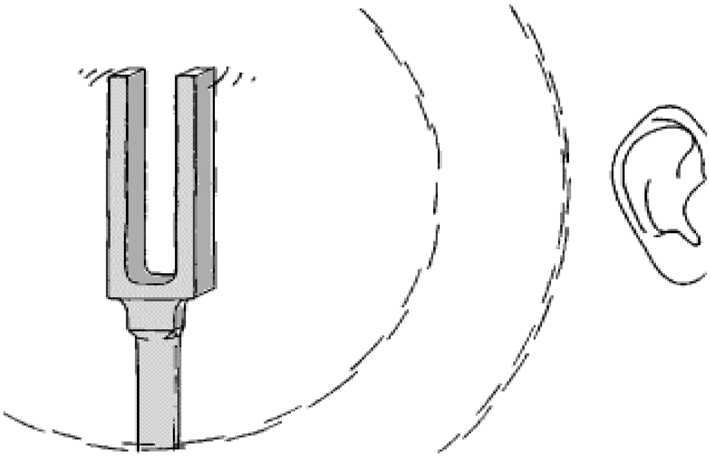
Who in the class can make the greatest acceleration or who can make the longest constant acceleration?

Conduct a few small studies at school where you measure your acceleration with the phone and record a video at the same time.

Look at your data from your phone to a computer, what can you see?

Exercise three: Sound measurement

How loud can you hear music in your headphones and how can we measure it?



Picture from: http://www.ahorn.dk/asu/base/lydhtm/lyd2/lyd2.asp

Virtually everyone has an mp3 player now, and listens to music while they walk or cycle. But can it actually be harmful to listen to music? How loud should the sound to be as loud as in the headphones?

You should find out how the sound level depends on the distance to a loudspeaker.

You should find out how you will make a plan and where you want to measure.

You should come up with a proposal for how to measure how loud you listen to music in your headphones.

You should find out if it can be harmful to your ears to listen to as much music as you do.

None of the three exercise instructions was changed during the research period, but the way the lesson was held was changed for acceleration and sound measurement. For the experiment with acceleration, the students had problems with understanding how to hold the smartphone. If the smartphone is not held in the correct way all the measurements can be very difficult to interpret and the idea of the lesson is not to find the best way to measure, but to measure different forms of accelerations. The students were also made aware that their experiments should be simple due to their level of physics. At physics B level they only have to work with motion in one dimension, and a lot of the students did motions in all three dimensions. Finally it was a problem to import the data from the smartphone to a computer, even with a guide, so there had to be a walkthrough guide at the board the start of the class.

For the experiments with sound measurement a smaller change was made. When they had to come up with an experiment on how to measure how loud they hear music in their earphones all the students came up with the same idea that did not work. So instead the lesson was changed so they had two minutes to come up with an idea, and then talked about their ideas in plenum to found out what the problem was with their first idea, and then they had five minutes to come up with a new idea. Then again once more a class discussion in plenum took place to find a new idea and use that. Nothing in space travel to mars was changed due to the fact that no classes with physics A level had the time to test it.

The Tivoli visit also had an exercise instruction and that exercise instruction was changed during the period. Here are the two versions of the exercise instruction:

Instruction for Tivoli physics (First draft)

During the experiments you must use your phone to measure acceleration on different rides. There are some small practical things that are nice to know

In order to get any data that can be subsequently compared, hold the phone in the same way on all the rides.

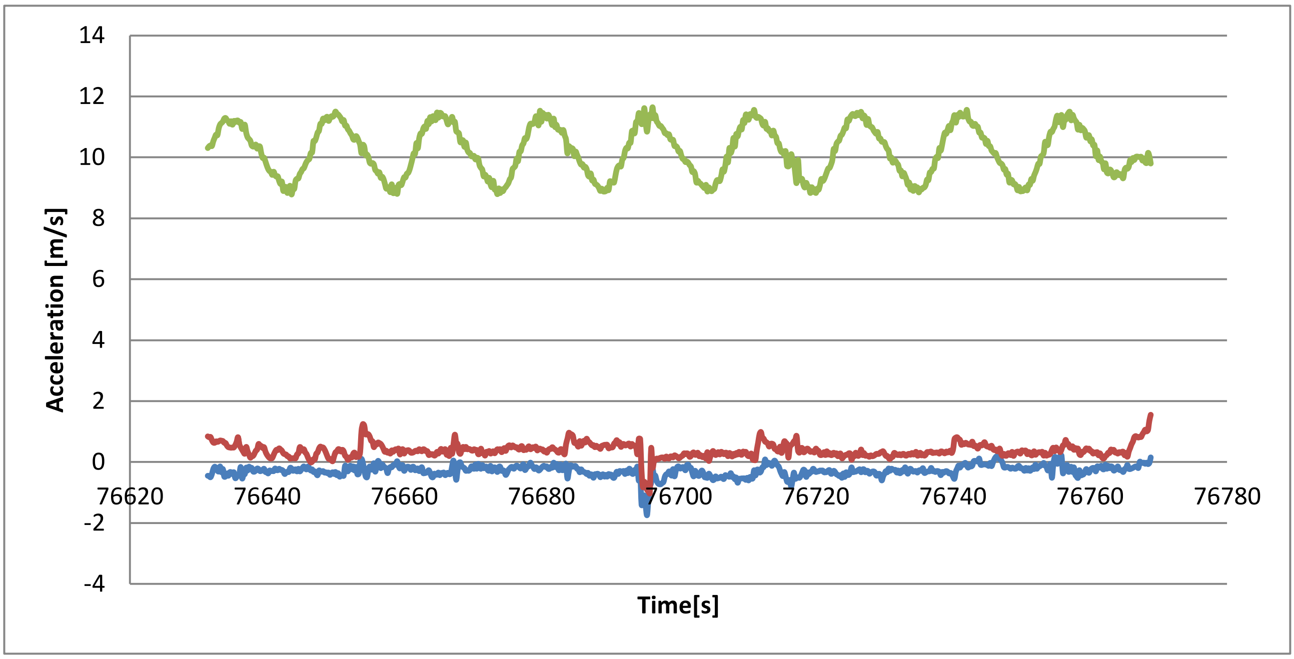
During the experiments, the phone must be in a zipped pocket so they do not fall.

Phones are not allowed in "Himmelskibet" and "Vertigo" even if they are in a zipped pocket.

Remember to note which rides you had been on and when, so you know which measurements were made for each ride.

Task 1

Use the phone's acceleration application to find the ride that made this acceleration graph:



Task 2

Use the phone to find the ride that exposes you to the greatest acceleration. If there are any of the rides you do not want to try, you can use your phone to record a video which can be used in Loggerpro when you get home (Keep in mind that you cannot use the phones on "Vertigo" and "Himmelskibet")

Instruction for Tivoli physics (final version)

During the experiments you must use your phone to measure acceleration on different rides. There are some small practical things that are nice to know.

In order to get any data that can be subsequently compared, hold the phone in the same way on all the rides.

During the experiments, the phone must be in a zipped pocket so they do not fall out.

Phones are not allowed in "Himmelskibet" and "vertigo" even if they are in a zipped pocket.

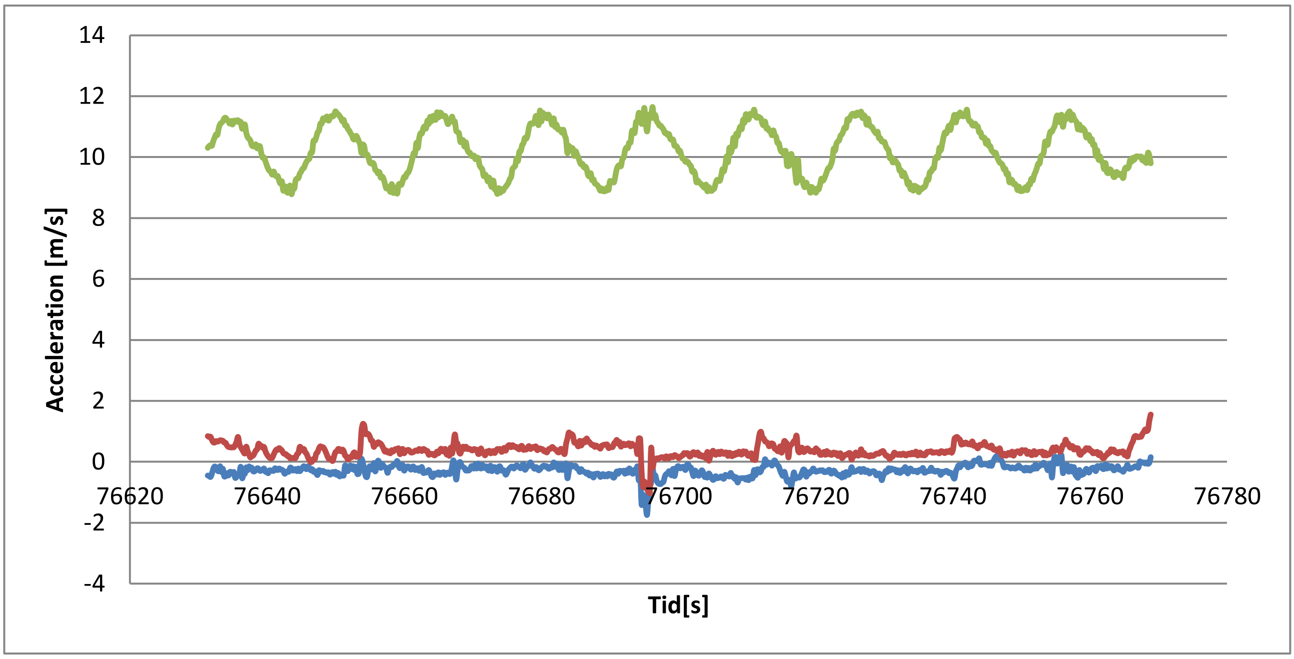
Remember to note which rides you had been on and when, so you know which measurements were made for each ride.

It may be advantageous to increase the standby time, to prevent the phone from go into standby to early.

After the exercises you must send all your data to hewessel@gmail.com

Task 1

To get an understanding of how the application works, you should start in "Ballongyngerne" play with the app and see if you can get a graph as the graph below.



Task 2

After you master how the app works on your phone, you yourself have to pick a ride and make a measurement equivalent to task 1. After you have made the measurements you should take a video of the ride for later use.

Task 3

Use the phone to find the ride that exposes you to the greatest acceleration. If there are any of the rides you do not want to try, you can use your phone to record a video which can use in Loggerpro when you get home (Keep in mind that you cannot use the phones in "Vertigo" and "Himmelskibet")

Class work at home:

Look at the graph you made in Task 2, and look at the video of part of the ride. Take small clip from the video and put it together with the graph.

Show your graph without video clip to another group and see if they can guess what ride you have chosen.

Compare class results from Task 3 and find out the ride with the greatest acceleration

After the first class had been to Tivoli, some problems occurred and the exercise instructions were changed. One of the problems was that the students did not have the chance to look at their data on a computer in Tivoli, so they could not see if their data was any good. So to make sure that they had any good data, they had to test their smartphone in "Ballongyngen" and get a graph on their screen on the smartphone similar to the graph in the exercise instruction. Furthermore none of the students could find the ride that the graph was made from in the first class. Also the part on what the students had to do when they came back to the school was added, so they could see how they could use their data.

As a help to students with importing their data, a guide (see Figure 8) was made with the help from one of the teachers from one of the classes.

Vejledning til import af data fra en csv fil fra Accelerometer Values til Excel (2010)

En csv fil er et primitivt filformat hvor alle data ligger i en kolonne.
I hver celle ligger en række data adskilt af komma.
Det skal du 'fortælle' Excel så programmet kan fordele data fra en celle ud i en række celler sådan at hver enkelt dataserie kommer ud i hver sin kolonne.

Inden du kan komme i gang skal du oprette en mappe på computeren til dine datafiler.
Jeg har lavet en mappe i min DropBox, der hedder Tivolidata.
Så skal du flytte filerne over i mappen og give dem gode navne.
****
Åbn en ny projektmappe og kald den noget med Tivoli og gruppens medlemmer
Gå til menuen *Data -> Hent eksterne data -> fra tekst*
Vælg datafil, begynd med ballongyngen

Nu åbner Guiden *Tekstimport* med 3 vinduer hvori du skal angive nogle indstillinger
1 Vælg oprindelig datatype *Afgrænset* i stedet for *Fast bredde*.
2 Vælg afgrænser *semikolon* i stedet for *tabulator*
3 -> avanceret:
vælg decimalseparator "." i stedet for "," vælg det i dropdown menuen
vælg tusindtalsseparator "," i stedet for "." eller " "vælg det i dropdown menuen
Klik *udfør* og se at data står flot fordelt i kolonner med overskrifter
Dobbeltklik på fanen og giv den et godt navn fx Ballongynge data

Nu er dine data tilgængelige for beregning og diagramtegning
iPhone appen Sensorlog giver en datasværm så overvældende
at jeg har valgt at kopiere udvalgte kolonner over i en ny datafane.

Marker udvalgte kolonner ved at holde ctrl nede mens du klikker på kolonnernes bogstav
ctrl c for kopier, gå til et nyt regneark og aktiver celle A1 , sæt ind.
Dobbeltklik på fanen og giv den et godt navn fx Ballongynge acc.

Gentag alt dette for dine øvrige data så du til sidst har en hel stribe faner med data fra din tur i Tivoli.

Figure 8. Imported guide for data from accelerometer value(and Fysik værktøjskasse). A simular guide exists for Sensor Log. Made by Jonas Olden Kromann

If the students follow this guide, they have been able to import their data without any problems.

In the planning of the different exercises the 5F and 1E model was considered as were the 12 questions to work with (originally 25 questions from Lawson, 2010), that were mentioned earlier. All the lessons for example consisted of a minimum of reading to make sure that students with reading disabilities do not have trouble following the lesson. Also the lessons were evaluated afterwards to make sure that the students and the teacher enjoyed the lesson and to see what should be changed before next time, as in the case with the Tivoli experiment where the students did not find the ride that they should (see “Instruction for Tivoli physics (First draft)”). It is not that the students and the teacher did not enjoy the lesson but it could be better, therefore the lesson was changed.

An example for a lesson that the students and the teacher did not like was exercise: Acceleration. Some big problems occurred with the first class that tried the exercise: acceleration, when there were big problems with the data importing. The flow of the lesson totally stopped and the exploration phase stopped. The students and the teacher got frustrated. After the class the teacher and the author of this thesis, evaluated the lesson, and found the problem. The teacher was willing to test the lesson again in the same class, this time with better results with data importing, and the engaging and exploration phase worked as it should the second time. With the changes the students could enjoy the lesson and the teacher was happy with the results. The problems had to do with some problems with the way that Excel works. A smaller clarification in the import guide was made to prevent the problem again.

Results

As mentioned earlier, there were three parts to the project. The first part was the testing in the beginning to see if it was possible to use a smartphone and to see if the students were willing to use their smartphone in class for physics. The second part was the lessons at Tivoli where four classes participated, and where one of the questions was to see if it was possible to use a smartphone outside of the classroom. The third and final part of the project, as the part where the lessons were tested in different classes.

From Table 7 it is possible to see the schools and classes participated in the various experiments.

Table 7 The distrubution of schools/classes by what experiment they participated in

School/Class	Tivoli	Experiment: Sound	Experiments: Acceleration
Vordingborg Gymnasium			
1C		x	
1X		x	
1M		x	
1Y		x	
2Z	x		
G2			x
Frederiksberg HTX			
2B	x		
2G	x		
Niels Steensens Gymnasium			
3A	x		
Roskilde Gymnasium			
3gfysb			x
Roskilde Katedralskole			
K1		x	
K4		x	

Questionnaire part 1

The first part of the questionnaire consisted of closed questions like age, school, sex, if they have a smartphone, if they have any internet connection on the smartphone and if they are willing to download applications. It is only in the last question where they have an opportunity to write any comments, and it was the question about if they are willing to download free applications for educational use.

The data in this thesis will be presented in two different ways. In the tables the data will be in raw form, whereas in the text and in the bar charts the raw data will be presented as percentages. The raw data comes from the questionnaires and is obtained by counting the answers. If the questions were open-ended, all the answers were categorized into closed categories, so they could be counted in the same way as the close ended questions.

252 students answered the questionnaire. The age range was from 16 to 24 (where 3 students did not answer the question about age). The division between the genders was 141 females and 107 males with 4 students with no answer. (see Table 8).

Table 8 The distribution by age

	15	16	17	18	19	24	No answer	Total
Females	1	53	57	24	5		1	141
Males	1	26	55	18	6	1		107
No answer		2					2	4
total	**2**	**81**	**112**	**42**	**11**	**1**	**3**	**252**

This is the distribution on the ages of the students based on gender.

A total of 194 students have a smartphone or 76.9%, where 104, or 73.7%, females have a smartphone, and 87 or 81.3% of the males have a smartphone. In this study all devices that can install applications are called smartphones, even though some of them was either tablets or iPods (See Table 9).

Table 9 The distribution of smartphones

	Females	Males	No answer	Total
Do not have a smartphone	37	20	1	58
Have a smartphone	104	87	3	194
total	**141**	**107**	**4**	**252**

This is the distribution on who have a smartphone based on gender.

Out of the 194 students who have a smartphone 42.2% have an Android smartphone, 54.6% have an iOS device, 1% have an Android and an iOS device and 1% with a Windows phone and finale 1% did not answer what operating system (OS) they have on their smartphone. If we look at the total number of students 33.3% have an Android device and 42.9% have an iOS device (see Table 10).

Table 10 The distribution of Operating Systems (OS)

	15	16	17	18	19	24	No answer	total
Android	1	22	36	17	5	1		82
iOS		35	51	13	6		1	106
iOS/Android		1		1				2
Windows			2					2
No answer	-	1	1	-			-	2
total	**1**	**59**	**90**	**31**	**11**	**1**	**1**	**194**

This is the distribution of the OS based on the age

Windows smartphones are relatively new compared to all of the iOS and Android devices which can be the reason why there were so few of them.

88.4% of all the students are willing to download free application for educational use. 3.1% of the students do not want to download any applications and 8.3% did not answer the question. This is for all of the students also the students without a smartphone. If we only look at the students instead with a smartphone then there is 96.5 % are willing to download an application for educational use and 3.4% who do not want to download (see Table 11).

Table 11 Distribution of students willing to download free applications

	Number of students
Not willing to download	**8**
Do not have a smartphone	4
Have a smartphone	4
Willing to download	**223**
Do not have a smartphone	33
Have a smartphone	190
No answer	**21**
Do not have a smartphone	21
Total	**252**

The distribution of students willing to download applications based on if they have a smartphone

Some of the students who did not want to download applications for educational use gave these explanations:

S1: 'I feel that I will not be able to learn as well as by theoretical instruction'

S2: 'No, do not want to have all kinds of apps on my phone, which deals with school stuff. Would rather have these things on a computer'

S3: 'I do not trust either third party apps or hardware to provide accurate results'

S4: 'Does not work properly'

From the last two quotes, we can see that those students do not think that the smartphone work properly. The two other quotes are more based on that they want to learn in another way.

Not all of the students who are willing to download applications will do it without reservation, and their reservations can be put into three categories. The problem with space requirements on their smartphone, the problem with distractions and the problem with trust the application developers.

S5: 'yes, but there is very limited space on the older smartphones which can quickly become a problem'

S6: 'Yes very much and at the same time no, because I think, besides it is a brilliant idea, many people too easily get distracted and end up doing something else'

S7: 'It depends on whether it is relevant, and looks reliable. Yes, if it is useful'

There are also some of the students that would rather have these applications on their laptop computers like the student who did not want to download applications, but they are still willing to download some applications.

Questionnaire part 2

The second part of the questionnaire was based on open-ended questions. The four questions were: What did you get out of using a smartphone in the lesson? What do you think that you could learn by using a smartphone in your lessons? Could you consider using your smartphone outside class to measure different things? Do you get distracted when you are using a smartphone in the lesson, to use Facebook or sent text messages?

The students' answers for the four questions, were divided into different categories. In the first three questions it was possible to be in more than one category, but in the last question it was only possible to be in one category.

The first question was: What did you get out of using a smartphone in the lesson? All the students' answers were categorized to begin with into 14 categories. The 14 categories are: No answer, measurements, it was okay, for later use, do not know, for the assignment, for nothing, fun/different, bad measurements, same as without, quick measurements, easier, easier that a computer, better understanding. Due to the small number of answers in some of the categories, some of them were combined, if there was a similar category.

Table 12. Answers to the question 'What did you get out of using a smartphone in the lesson?'

	No answer	Fun/different	Nothing	Measurements	Easier	To make the assignment
#students	50	63	45	35	25	18

	Better understanding	Easier than computer	Bad measurements	Ok	Later use	Same as without
#students	18	9	7	2	2	1

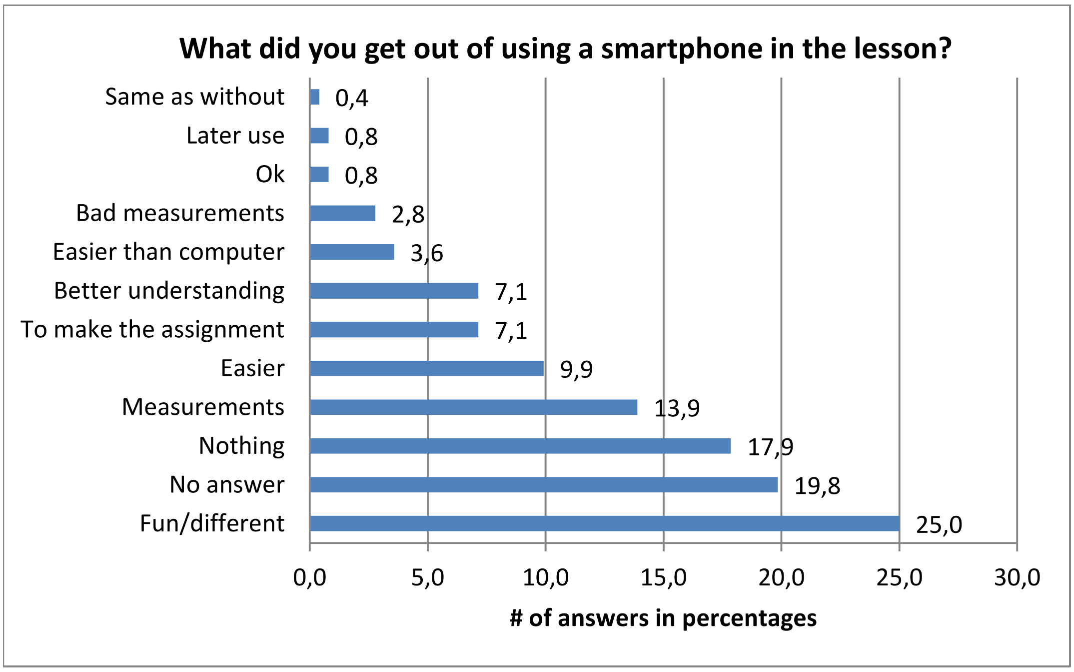


Figure 9. Data from Table 12

In Figure 9 one can see that 19.8% of the students did not answers this question.

7.1% of the students answer that they got a **better understanding**.

S8:'It's a better way, than the traditional methods, and it's a cool way to learn'

S7: 'It provides a good insight on power and acceleration. Good idea and easy to use'

S9: 'Assignments, and a good help in academics'

From this we can see that the students think that they learn better or in another way by using their smartphone, over traditional blackboard teaching.

25% of the students answer that it was **fun or different**. This is the largest group of them all. Here are some of their answers

S10: 'It has been funnier and easier. Because then you can see results on your own, instead of only the teacher'

S11: 'It makes the class more fun, and perhaps a little bit more interesting, because it's our "spare time" which in principle are meddling with the class, which gives you a better understanding of what the teacher explains'

S12: 'It gets more fun and interesting to perform experiments and collect data, which makes you pay more attention'

S13: 'Funnier to perform experiment, because we're measuring data with our own phone. Creates a bigger interest, in performing experiments. And to look at the datas in the end'

S14: 'I provides another interest, by using your own phone. It gets more interactive'

S15: 'The lessons has been more fun than usual blackboard teaching. Funnier by using a smartphone for experiments and the opportunity to enjoy different experiments instead of performing measurements in class or watching videos. Bigger interest'

S16: 'Funnier, more exiting. Connecting something from physics (theories) together with everyday stuff'

S17: 'It motivates me, because I love my phone higher than anything else'

The common thing here is that the students think it is more fun because they have to use their own phone or they have to be active during the lesson. Especially that they have to use their own smartphone motivates them.

9.9% of the students answer that it was **easier**

S18: 'It's easier'

S19: 'You've got everything you need, by your hand'

S20: 'It is easier when we're using our phones for measurements. Because we're using our phones, outside school'

S21: 'I've got rid of the usual "instruments" we usually use'

The common thing here is that the students think it is easier because they do not have to use the school equipment. They know how their smartphone works, because they are using it all the time.

3.6% of the students answer that it was **easier than with a computer**

S22: 'If you just have to do a quick research online, and you don't bother to turn on your computer, it's way easier to go online with your phone'

S23: 'Calculator, formula collection, dictionaries, translation'

Mostly of the students that said that the smartphone was easier than a computer, said that they used it for research or as a calculator of some sort. They did not say anything about that it was easier to make measurements with a smartphone instead of a computer.

2.8% of the students answer that they got **bad measurements**. They answer

S24: 'We used to much time on designing our experiment an to get data. Perhaps it would have been better to start with an experiment, with guidance, where we could be sure of good results'

S25: 'I would have been fine with a normal decibel-measuring instrument'

S26: 'Not much because the program I downloaded wasn't that good'

13.9% of the students used their smartphone to make **measurements** (all of the students hopefully used their smartphone to make measurements, but they also got something else out of the class). Here follows some typical answers.

S27: *'Learned to calculate data with my iPhone. I use for an example Wolfram alpha calculater, so have got much out of it'*

S20: *'It is easier when we're using our phones to measurements. Because we're using our phones, outside school'*

S28: *'We we're able to measure dB, by the help of an app. If we didn't had it, it would be harder/ not possible to measure the strength of sound'*

7.1% of the students answered that they used their smartphone to **make the assignment**. Here are some typical answers

S29: *'That I'm listening to loud music'*

S30: *'I've found that you can use it to find programs, which can help you perfom experiments close at hand'*

S31: *'In Danish I've got language-help that can assist with commas and etc. In physics I've got sensorlog which can be used for acceleration. And then I'm taking photos of the experiments and etc.'*

Here we can see that S31 already use her smartphone in another subject than physics, and she is not the only one. Typically the students that are using their smartphone for other subjects than physics, are using their smartphone as a lexicon or formula collection.

0.8% of the students answers that they could use their smartphone **later**. Here are their answers.

S32: *'You can use the stuff you learn in school, in your free time'*

S33: 'It was okay and I can maybe use it another time'

0.4%(1 student) of the students answer that it was the **same as without**. She said

S34: *'Possibly the same, as without'*

0.8% of the students sad that it was **okay** to use a smartphone in class. One of the students was the student from before s33. The other student answer were.

S35: 'I don't have a smartphone, but it have been okay, but regular measuring instruments are better'

17.9% of the students said that they did **not get anything** out of using a smartphone. Here are some of their answers

S36: 'Not really anything, besides Facebook'

S37: 'Confusion, because I'm an illiterate regarding electronic devices. And calculator'

S38: 'Not much. For information searches I use my laptop and for notes I use paper. The phone is to slow to use'

S16: 'I've been less effective than usual'

Some of the common things for those who had answered that they did not get anything out of using their smartphone, is that they either did not use it or they have some kind of problems with using it.

The second question was; what do you think that you could learn by using a smartphone in your lessons? The categories the answers was categorized in was: No answer, to use different programs, more aware, useful applications, distracted, do not know, examine things, fun/ more desire to learn, technical stuff, imprecise, easy, nothing, easier than a computer, yes, comes at some time, better learning/understanding.

Table 13. Answers to the question 'What do you think that you could learn by using a smartphone in your lessons?'

	No answer	Technical stuff	More aware	Imprecise
#students	47	2	2	5

	Comes at some time,	Yes	Easier than a computer	Nothing
#students	6	7	8	11

	To use different programs	Useful applications	Examine things	Better learning/understanding
#students	12	12	17	24

	Do not know	Fun/ more desire to learn	Easy	Distracted
#students	30	37	41	46

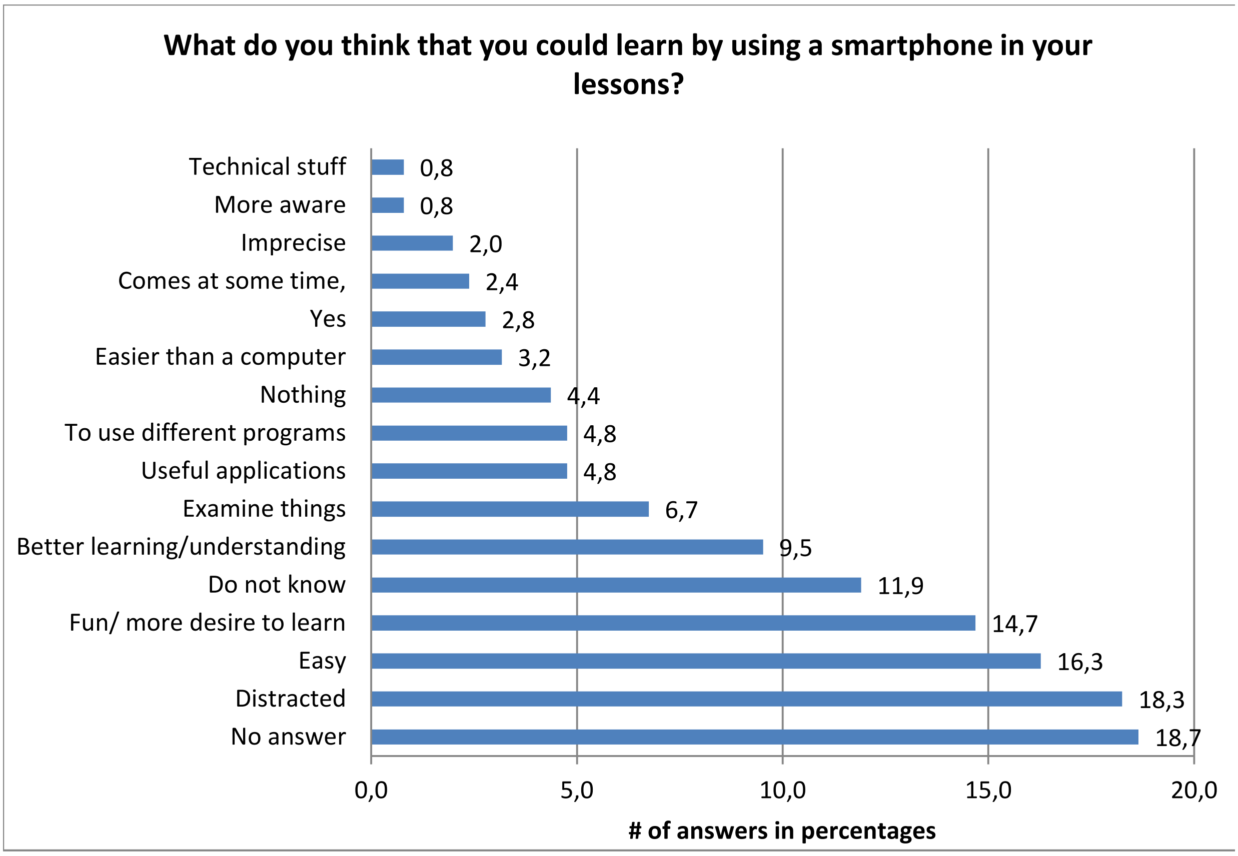


Figure 10. Data from Table 13

From Figure 10 we can see that 18.7% of the students did not answer this question

14.7% of the students answer that it could be **fun/more desire to learn**

S40: 'The thing that it's new and exciting gives a better interest in it = usually you learn more'

S41: 'Funnier, and more knowledge'

S42: 'It would be more motivating, because it's different and it's more directed for our generation'

S43: 'An advantage could be that we learn how to use the apps that are available, learning new systems. It's funny. Disadvantages could be that it's not safe enough yet, and technical errors can occur'

S21: 'It's simply easier. You can take your experiment with you home'

S44: 'It's funnier, usually you're using your phone in secret, and now you don't have to hide it. Disadvantages: Perhaps you will do something you're not supposed to do'

The common thing for these students is that they think the lesson can be more fun when they are using their smartphone, and that it is more motivating.

9.5% of the students answer that the smartphone could give them **better learning/understanding**

S45: 'I'm learning by watching and executing, so it would help me out a lot'

S46: 'If you have a hard time understanding what has been told, it perhaps would be better with variation. In return, it could also be confusing'

S47: 'Would be easier to understand and relate to it'

S48: 'I think I would get a better understanding of what my phone was capable of'

S49: 'I think it would be way cool and funny if we use a smartphone in class. I do believe that the benefits are higher than regular teaching – easier, faster'

S50: 'Different kind of teaching. To learn more about everyday stuff and by that, understand their "physical background". Disadvantage: It could be kind of unserious'

S16: 'How theories can be used in reality'

S51: 'To get a better understanding of data, because you have been involved in the collecting'

S52: 'Something you don't learn from a book, because there's no living pictures in a book'

The students that answered better learning/understanding, said that they wold learn better for different reasons, for example that they learn better when they have hand on experience.

6.7% of the students answer **examining things**

S53: 'I would be able to perform exact/ better measurement. But smartphones could draw attention away from the class'

S54: 'It's practical if you have to exam different stuff'

These students think that the smartphone can be used to examining things.

4.8% of the students answer that they thought they could learn **to use different programs**.

S55: 'What this device also can'

S19: 'Those apps you can download (e.g. physics) could be useful. You also learn how to use your smartphone for a whole other purpose than usual'

S56: 'Could learn how to use it for academic use'

These students think that they could learn, what useful applications there are for smartphones and what their smartphone are able to.

4.8% of the students answer that they would get some **useful applications**

S57: 'Advantages could be different useful apps (calculator, db measurer, guitar tuner etc.). Disadvantages could be distracting elements such as text's or Facebook. The youth are weak, keep smartphones away'

S58: 'Faster information searches. Relevant free downloading apps. You get easily distracted to do something else, but it's the same with the use of a computer in classes

Like the same as the last category with different programs, but are based more on useful applications, like calculator, that applications that can be used for measurements.

0.8% of the students answer that they could learn more **technical stuff**

S59: 'More "technical stuff"'

S60: 'Use technology in everyday life'

These students think that they learn more about technical stuff, and how to use it in everyday life.

0.8% of the students answer that they could be **more aware**

S33: 'By using something, that almost everyone knows, you could be more attentive'

S15: 'Theories in reality, gets more people to get with it. Disadvantages could be that you do something else with your phone, than you're supposed to'

These students think that when smartphones are used in a lesson, more students would be more aware in the lesson. For example because that more student know how to use the smartphone.

16.3% of the students answer that it would be **easy** when using a smartphone. The thing that they find easy is that they know how to use their smartphone and it is right at hand

S61: 'Not as fast as a computer, but small, nifty and extremely useful'

S62: 'There are a lot of smart apps. There are many who's got an iPhone and a smartphone – that means that you don't have to wait around to get to use the instruments'

S63:'I can take notes. I can calculate on my smartphone. Can make measurements'

S64: 'The disadvantage is that you're able to use your phone. The apps are created for us students, so they are "child friendly"'

3.2% of the students answer **easier than a computer**. It is almost the same reason than from before. It is easier to use a smartphone that using a computer

S65: 'Easier than bringing a computer with me'

S66: 'It has obvious advantages if you use your smartphone. E.g. If you need precise calculations, then it's easier to use a phone instead of a computer'

S67: 'The advantage is that if you don't have your computer with you, the phone is a good backup. The disadvantage is that you not always use the phone for relevant stuff'

2% of the students answer that the smartphone would be **imprecise**

S68: 'Disadvantage: The numbers can't be used, because they don't match. Advantage: It's easy. Most students got one'

S69: 'It gives some results that we can work on later. It is not that precise in its measurements'

These students think that the smartphone is not precise enough, and for that reason the data cannot be used.

18.3% of the students answer that it would be a disadvantage that they could get **distracted** while using a smartphone in class. A lot of the answers will be a part of some of the other answers. But some only answered that it would distract.

S70: 'I don't think they should be a part of the class, because some students find it hard to manage such a freedom'

S39: 'I like the regular measuring instruments, you would easy get to do something else on your phone, and the teacher isn't quite confident in the use of the program (yet)'

The concern for these students is that the smartphone is distracting because it is too easy to do something else with the smartphone than participate in the lesson.

2.4% of the students answer that the use of smartphone in class would **come at some time** anyway

S71: 'Yes, I think it will come at some point anyway'

S11: 'Yes, I firmly believe that, it's the future, as well as we, the young ones, are the future. Perhaps someone won't find it that serious, but you have to into notion. I think it's like that in every class'

S72: 'If we continue the teaching like this, you would learn how to design the experiments to get the results you hope for. (Perhaps useful later on)'

As we can see from the students' answers, they think that, in time, the use of smartphones as tools for learning will become a more and more common sight in classes

2.8% of the students answer **yes**

S73: ‘Yes’

S74: ‘Yes, if you can handle it and doesn’t play any games’

S75: ‘Yes, depends on the subject’

These students think that the smartphone can be used in a lesson, but it depend on the subject of if the students can handle the distractions that smartphones can give.

4,4% of the students answer that they think that they can learn **nothing** with a smartphone

S36: ‘I don’t think you can learn anything by the use of a mobile phone’

S76: ‘It’s a little bit hard to see the advantages, because it perhaps would be a limited teaching’

S77: ‘No, I just think the system is fine’

S38: ’Nothing, it’s too difficult to use the most of the functions, e.g. writing notes’

S3: ‘Can’t see obvious advantages by using a smartphone in class’

For different reason these students do not think that they could learn anything if they should use a smartphone. Some of them think that the normal blackboard teaching is fine and that they learn more that way or that they just not see any advantages.

11.9% of the students answer that they **did not know** that they could learn with a smartphone. A typical answer was

S79: ’Don’t know’

But some students also gives some interesting answers

S79: ‘I don’t know, it depends on what the class is about’

S80: ’I would probably be able to. I find it hard to judge, because I’m not quite aware of how you use it’

S81: ‘Don’t really know what you could learn from it. But it makes the class a lot funnier’

The third question was; would you consider using your smartphone outside class to measure different things? Their answers could be in the following categories: No answer, no, to measure different things, for sports, for school/helpful applications and maybe.

Table 14 Answers to the question 'Would you consider using your smartphone outside class to measure different things?'

	No answer	No	To measure	For sports	School/help applications	maybe
#students	28	121	73	7	8	21

Students that is willing to use their smartphone outside of school

From Table 14 we see that 11.1% of the students did not answer the question and that 48% of the students do not think that they will use their smartphone for measuring outside of school. 28.9% of the students could imagine using or have used their smartphone to make measurements. 2.7% of the students thinking of using their smartphone or are using their smartphone for sports. 3.1% are using their smartphone for school relevant or helpful applications. 8.3% do not know if they want to use their smartphone outside of school.

28.9% of the students answered that they could imagine themselves using the smartphone to measure.

Most of the 28.9% of the students that answer that they would make measurements outside of school mostly said that they would make some measurements for fun, or just because they had an application on their phone.

S82: *'Maybe a concert or a party with loud music'*

S83: *'Yes, but just for fun once in a while'*

S84: *'If I had one (a smartphone)'*

S85: *'Yes, because after you have installed it, I believe that you will use it as a tool'*

And then some of the 28.9% that would make measurements outside of school could imagine themselves, using their smartphone to get a better understanding of what they did in class, at home.

S86: 'To measure some of the things we have gone through in class to get at beater hold of it'

Some of the students already use different applications, to help them I school or with homework

S34: 'For example, I have the Periodic Table'

S87: 'Yes formularies I often use when I need to calculate something outside of school hours'

3.1% of the students that already use their smartphone for measurements, are using it for sport (like Endomondo, an application that can measure your running trail and speed) or they have an idea that it could be fun to try to make some measurements at the gym.

S88: *'If, for instance, would measure some things in his sport. I'm going instance to the gym and that it would be useful to measure some things'*

S89: *'I use it to measure average speed and see elevation lines of cycling'*

48% of the students that said no to the idea to make measurements outside of school, did not give any explanations, but some wrote more than just no.

S64: 'No, but it could probably be fun to try it'

S7: 'Most likely not'

The two students above do not entirely exclude the idea of use their smartphone at home, but they still say no. If some of the other 48% of the students that also said no, do not exclude the idea entirely, then there is a chance that some of them with the right or interesting application would consider using their smartphone in their free time for measurements.

The last question was; do you get distracted when you are using a smartphone in the lesson, do to Facebook or text messages? Their answers could be in the following categories: No answer, no, yes, some times and by others in class.

Table 15. Answers to the question 'Do you get distracted when you are using a smartphone in the lesson, do to Facebook og text messages?'

	No answer	No	Yes	Sometimes	By others
# students	27	150	42	32	1

The number of students that are getting disturbed in class

As we can see in Table 15 10.7% of the students did not answer the question. 59.5% of the students do not think that they get disturbed by Facebook or text messages, 29.7% of the students think that they get disturbed in some sort of way (16.6% yes, 12.6% sometimes, 0.4% by others)

Here are some of the students' answers on why they get disturbed.

S90: 'I never have a computer with me and no smartphone either, but it disturbed me that other do'

S30: ’Using it on rare occasions, but may well get distracted some time, and then it is very annoying to work in a group where others are using their phone’

These two students above are getting distracted by others but it is a very small part of all students that have a problem with others using their smartphone or computer (according to what they have replied).

The next two students are examples on students that are, or would get, distracted by Facebook or text messages.

S91: ‘I think that I would be distracted if I had a smartphone’

S87: ‘Yes, it's hard not to use Facebook and texting because it is so easily accessible’

The next tree students are examples on students that are getting distracted sometimes but common for them is that it depends on what kind of lesson it is, and how interesting it is.

S35: ‘In one way or another I do. But you got to learn how to handle it, and teaching is many times more fun when there are electronics involved’

S85: ‘Would say that there is a possibility, but if it's interesting enough, it would not happen’

S72: ‘At times. It really depends on whether we are using the phone in class (then no) or we just have blackboard teaching (then sometimes)’

The student Tivoli results

Figure 11. Students from Niels Steensens gymnasium looking at their smartphones to make sure that they understand how they are working. Picture: Jonas Salomonsen

From the students that sent their results from Tivoli, one can see their measurements from the different rides. To begin with there are some examples of graphs from two different rides that were made by the author (see Figure 12and Figure 13). They can be used as a comparison for some of the group's graphs. A comparison graph for all the rides was not made, so some of the student's results will not be compared to the author's results, but they will be discussed and compared against other group's results. The smartphones work in the way that they measure acceleration in the x, y and z-axes. If the smartphone is laid down on a table, with the screen upwards, the z-axis then normally is up through the screen, the y-axis is along the length of the smartphone and the x-axis is across the width of the smartphone. That means that in the following graphs, that the label with x-axis, y-axis and z-axis, represents the smartphone's acceleration in the x, y and z direction. If the explanation to the right of the graph says accelerationX, accelerationY and accelerationZ the meaurements are made with an iPhone. If it on the other hand it only says X, Y and Z the measurements are made with an Android smartphone. In Figure 11 we can see that the students look at their smartphone after they have tried the ride “Ballongyngen” to see if they have had held their smartphone correctly and to see if they were getting the expected result.

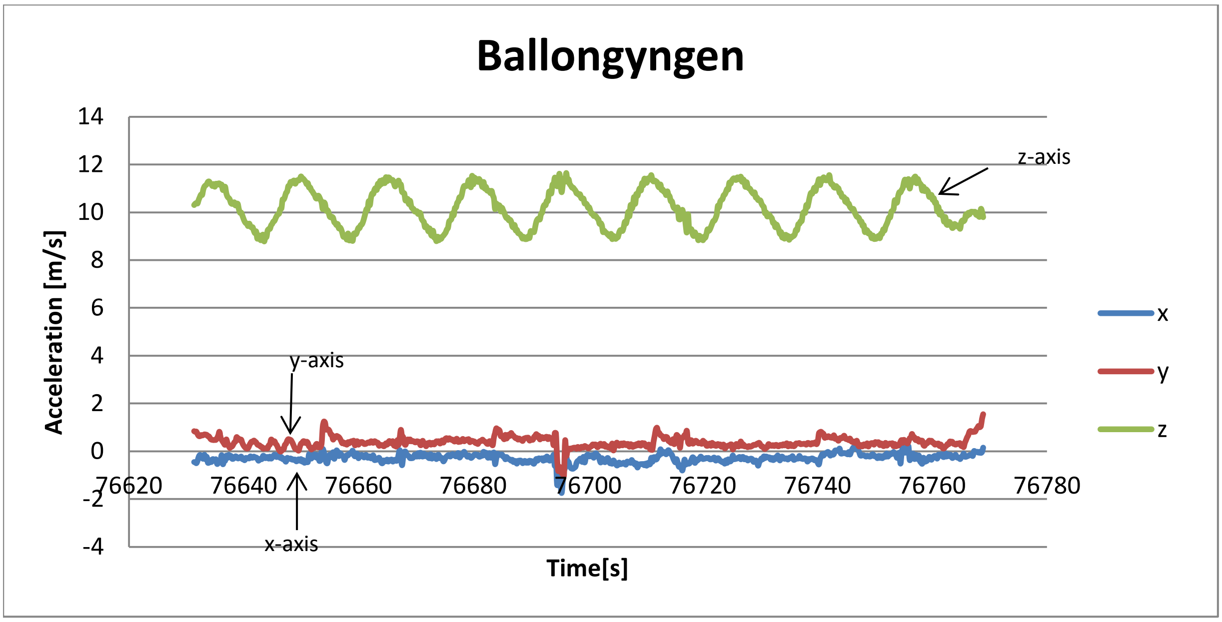


Figure 12 graph from the data form the ride ”Ballongygnen”

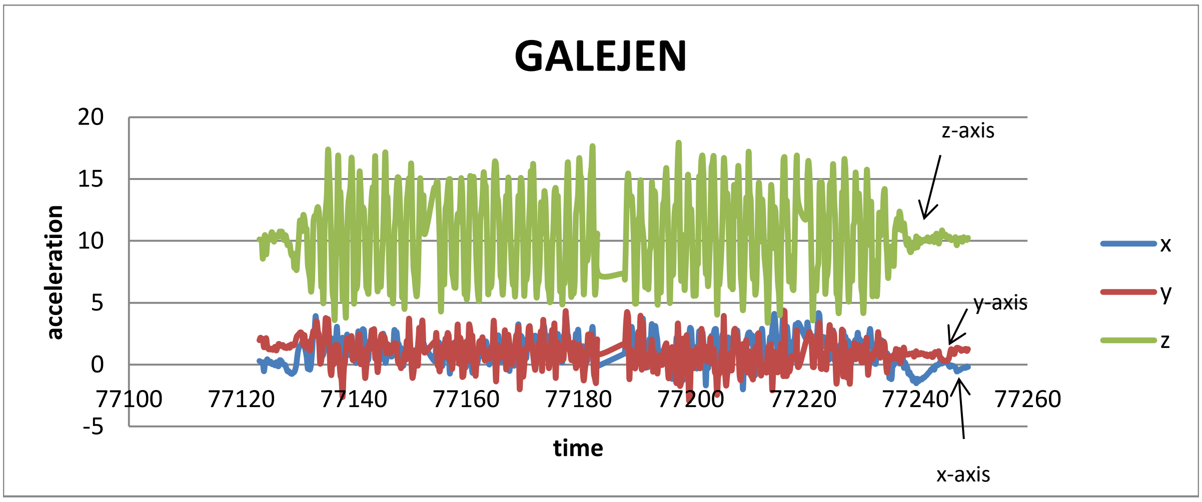


Figure 13 graph from the data form the ride ”Galejen”

Here are the graphs from 3 different students groups.

Group 1

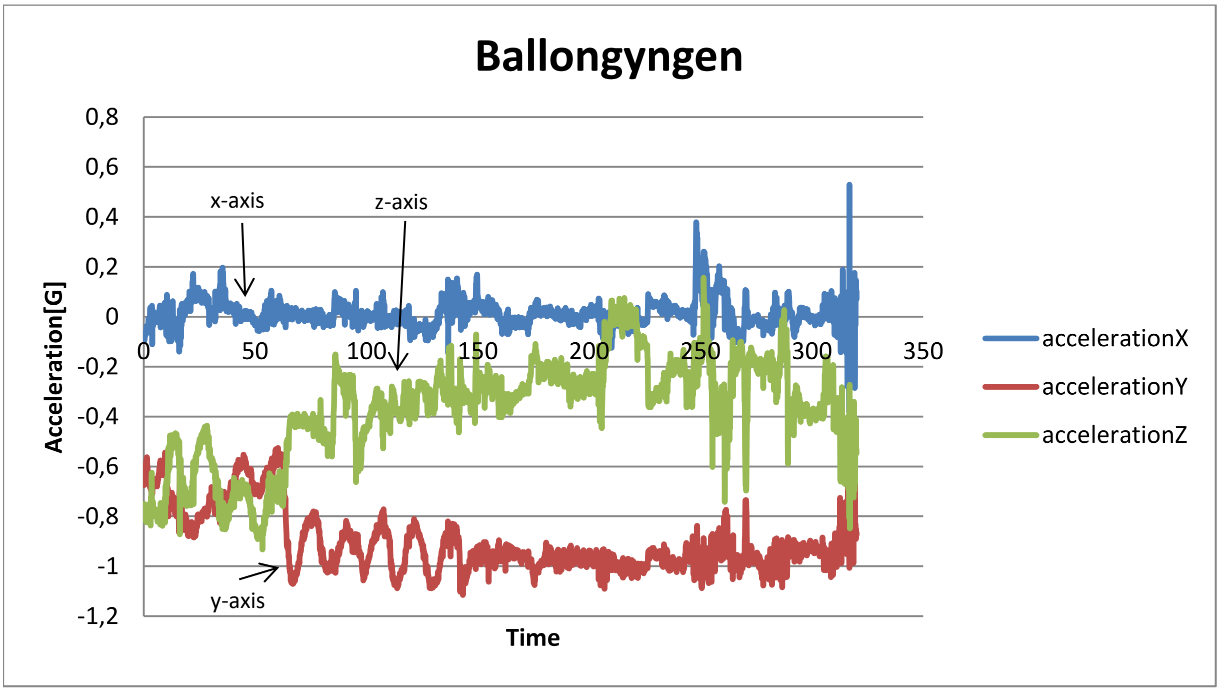


Figure 14 Group 1 graph from the data form the ride ”Ballongygnen”

As one can see from Figure 14 for different reasons, the students do not get the expected results (compare with Figure 12). One of the reasons can be that they have held their smartphone slightly crooked. This will be discussed later on.

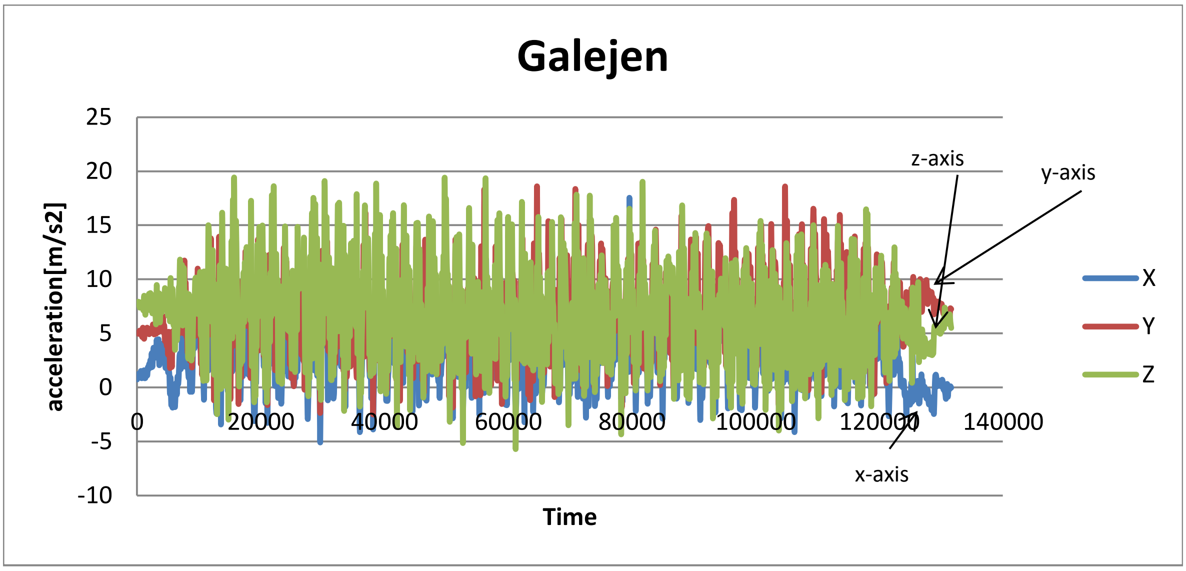


Figure 15 Group 1 graph from the data form the ride ”Galejen”

Likewise we can see that the group does not get the same in Figure 15 as the comparison in Figure 13. One of the problems or challenges with the ride “Galejen” is that there is movement in all three directions. The ride goes around in a circle and at the same time up and down. When there is movement in all directions, then it can be difficult to hold the phone stable and the measurements are together.

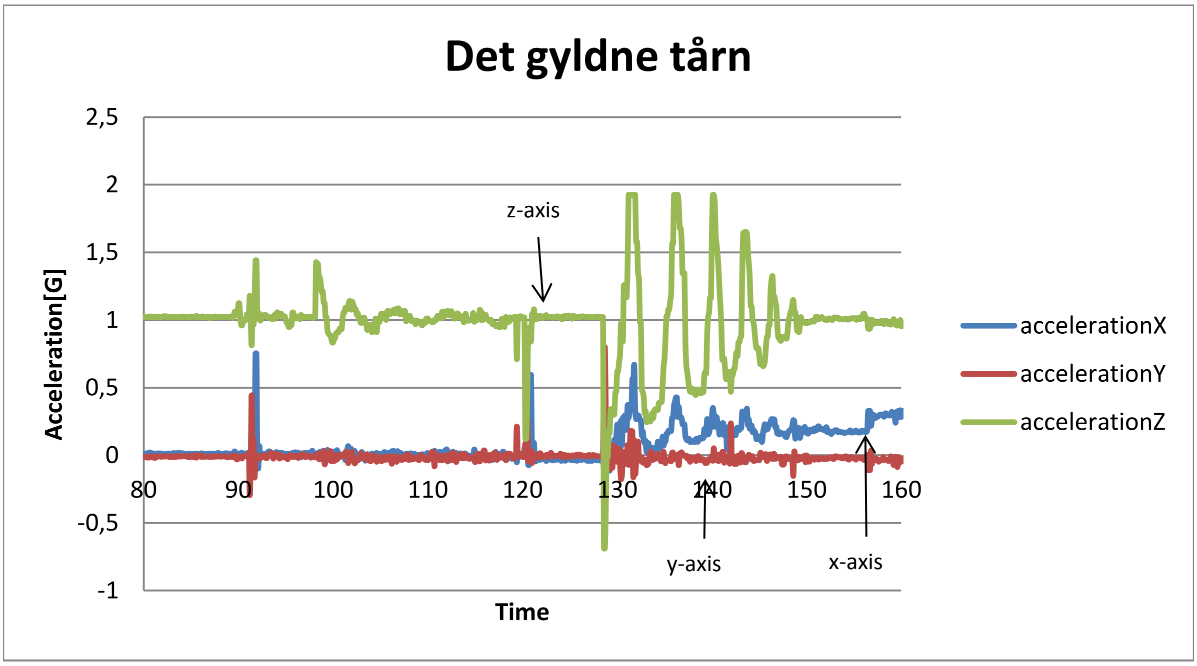


Figure 16 Group 1 graph from the data form the ride ”Det gyldne tårn”

One of the really good rides to get good measurements is “Det gyldne tårn” as we can see group 1 data in Figure 16. It gives good measurements in the sense that “Det gyldne tårn” data is easy to analyse, because the ride only moves in one direction (up and down), the more simple the movement is the easier the analyse of the graph is. It is also one of the rides that show the phones limits, as will be discussed later.

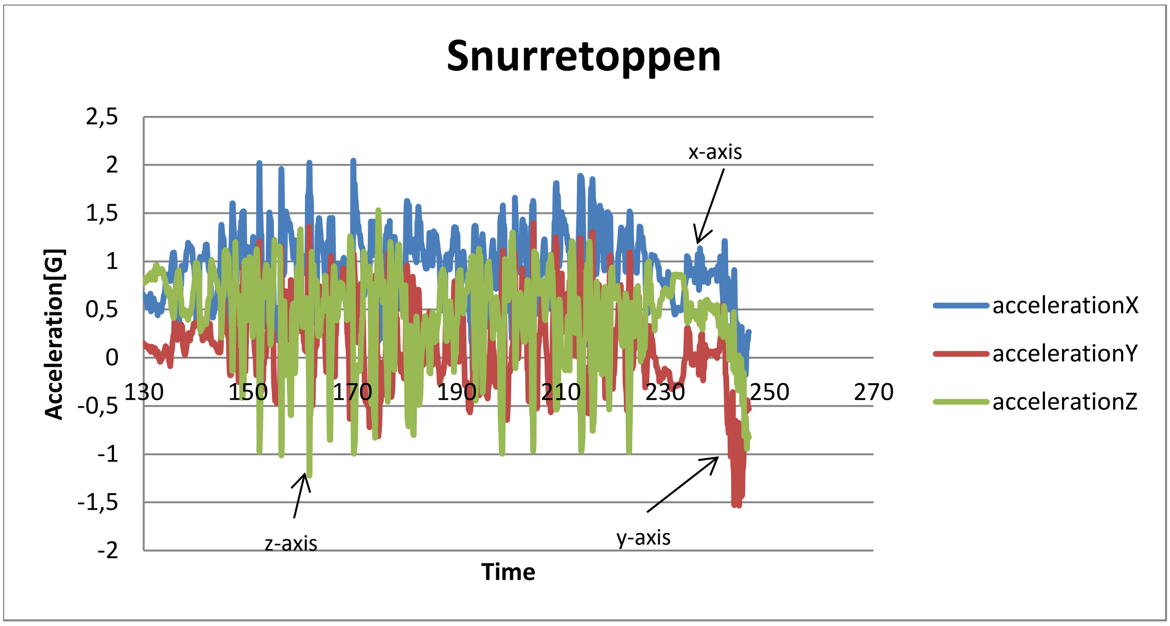


Figure 17 Group 1 graph from the data form the ride "Snurretoppen"

As we can see in Figure 17 there is movement in all directions, and by that reason it can be difficult to see anything on the graph. Like in the example from Figure 15

Group 2

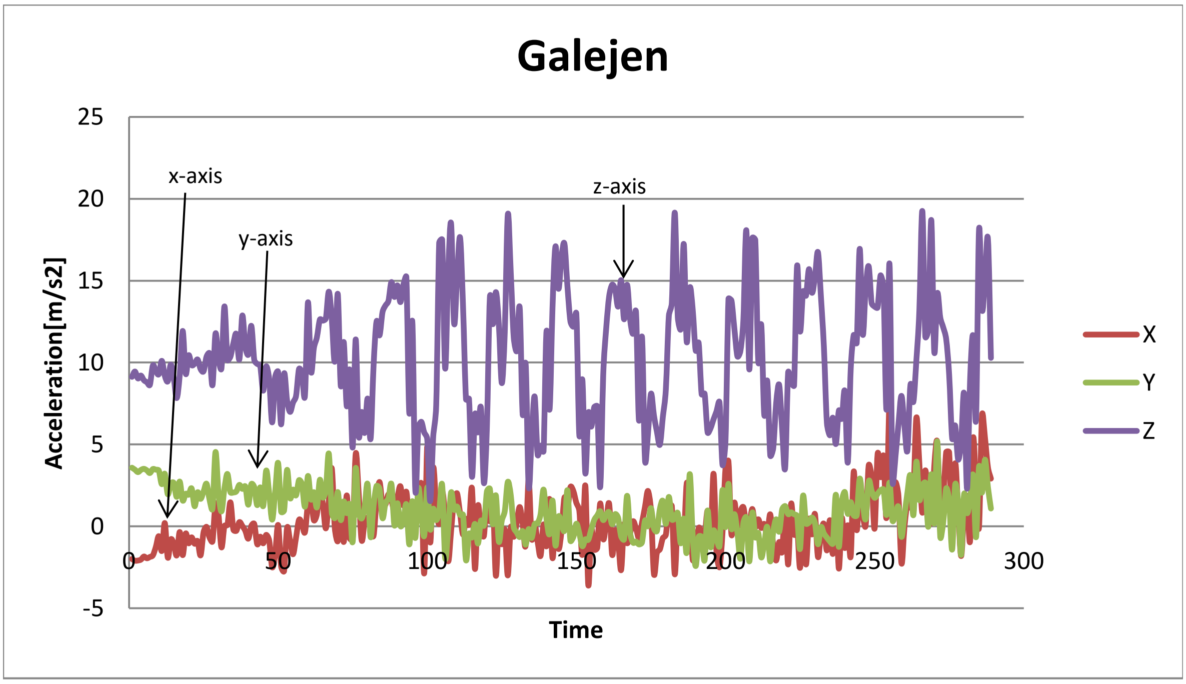


Figure 18 group 2 graph from the data form the ride "Galejen"

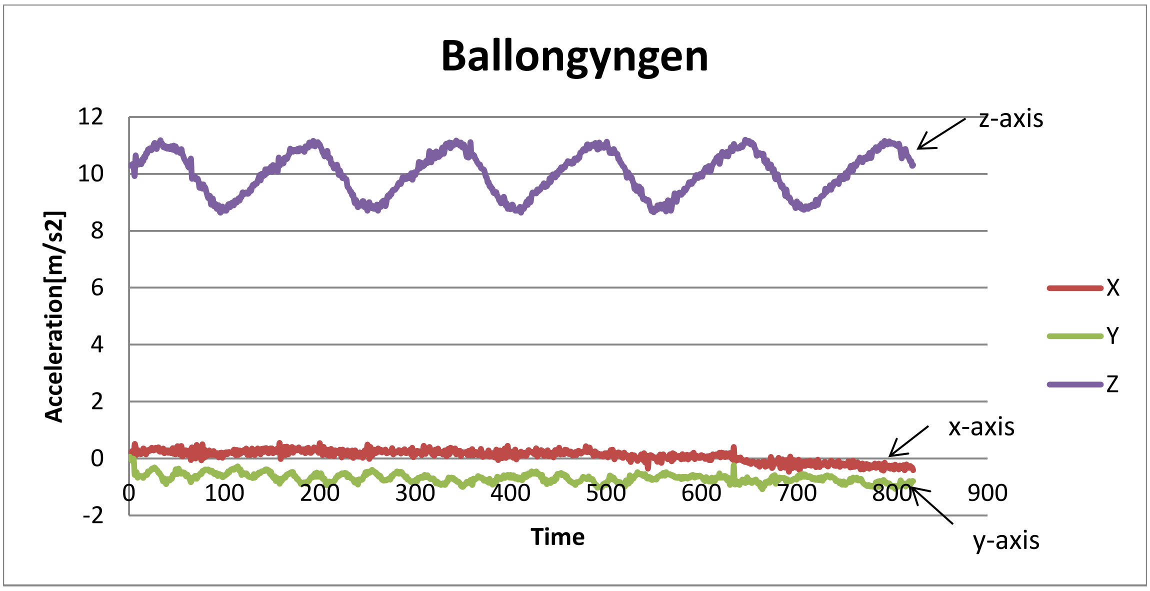


Figure 19 Group 2 graph from the data form the ride "Ballongygnen"

As we can see from this group they got some results that look more like the comparison. Especially Figure 19 looks like Figure 12. From that we can see that the data can be replicated. The fact that the data can be reproduced is going to be used in the results from Group 3. Their graph from the ride "galejen" looks a little different (see Figure 18 and Figure 13). It is hard to say what the reason is, but it could be that the measurements are over a shorter time of the ride. Sometimes it can be difficult to see if the units of the time are in mille seconds or in seconds.

Group 3

Group 3 did not write down which rides they tried. But some of their graphs are still represented here to show that it is possible to determine the names of some of the rides based on their data.

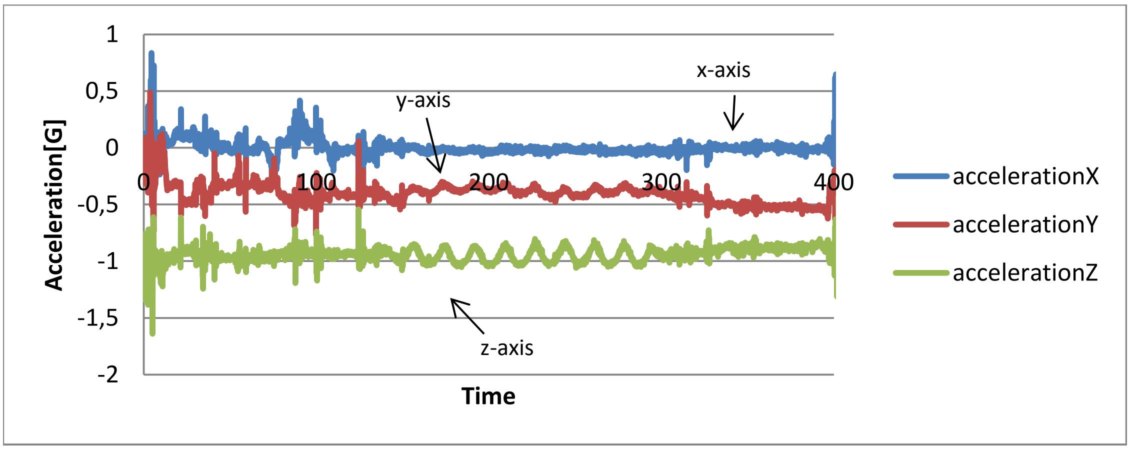


Figure 20. An unknown ride from group 3

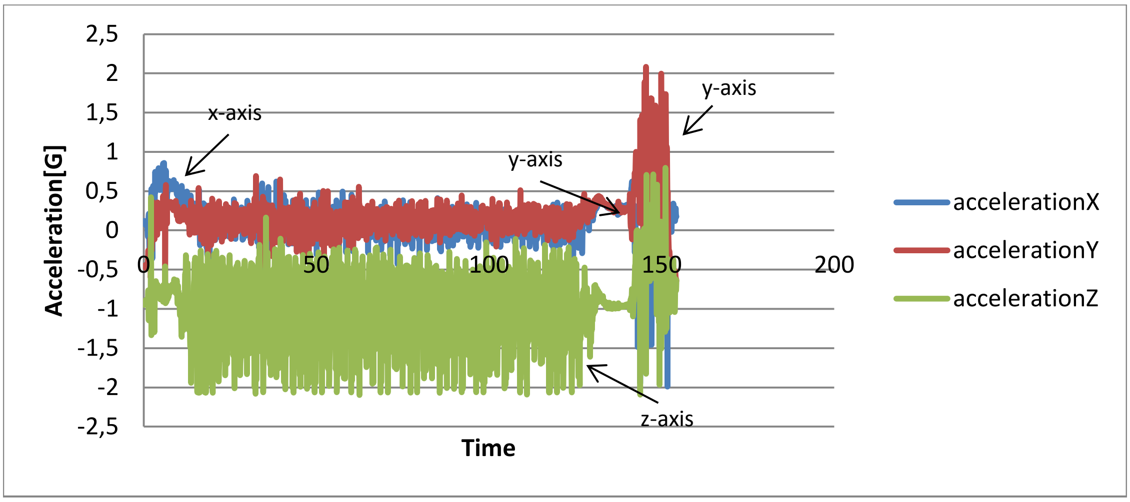


Figure 21. An unknown ride from group 3

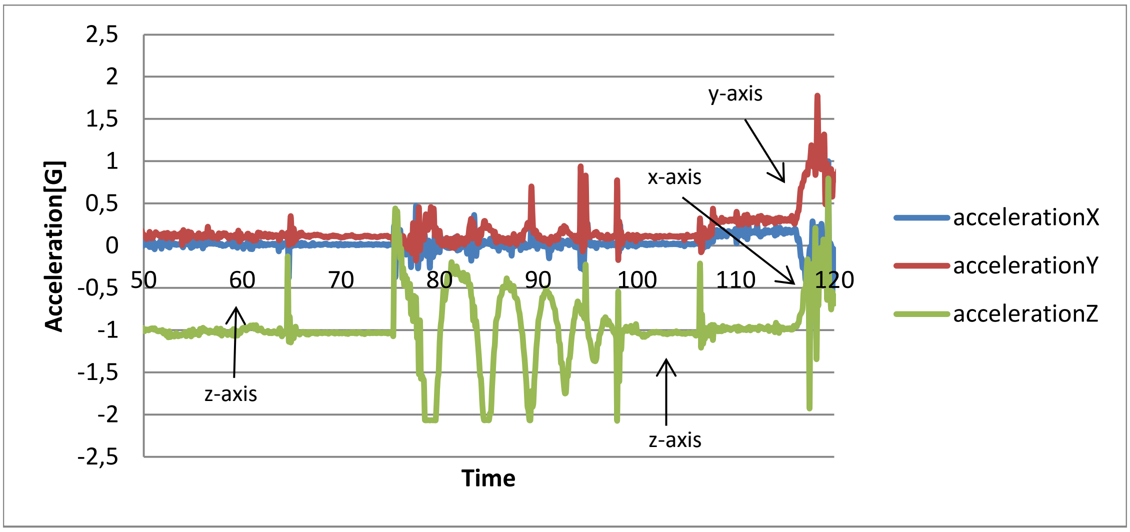


Figure 22. An unknown ride from group 3

Out of the three graphs that group 3 has made, it is possible to determine two of the rides. It is Figure 20 and Figure 22. By the best assumptions the two rides is “ballongyngen” Figure 20 and “Det gyldne tårn” Figure 22. It is not possible to see what ride Figure 21 is from, the best thing we can say is that most of the movement is in the z-axis, if they have held their smartphone with the screen facing upwards. Then the ride moves up and down. Due to the movement in the x and y-axis there are also some movement in these directions. It could maybe also be the ride “galejen” but it is not that easy to see. The important thing here is that it was possible to recognise some of the rides even though we did not know which they were. This gives some indication that the measurements are consistent, even though the measurements are made with different smartphones

As we can see in Figure 23 it can be pretty wild when the students test some rides. Here they are in the ride called “Dæmonon” and they have to have the smartphone in a zipped pocket, and for that reason the orientation of the smartphone (or the smartphone) can shift during the ride, and make the data hard to interpret.

Figure 23. Students from Niels Steensens gymnasium getting data from ’Dæmonen’. Picture: Jonas Salomonsen

Students results In-class lessons

Exercise: Sound:

Two classes tested the lesson in its finished stage. Since none of the classes made a report on the subject, their results are based on the author’s observations and on the student’s class notes.

Here are some examples of what they found. Since not all of the groups made a graph of their observations, the graphs for groups 1-3 are made by the author with the group’s results.

Group 1:

At the loudspeaker 99-103 dB, 1 meter from the loudspeaker 76-81 dB, 2 meter from the loudspeaker 72-76 dB, 3 meter from the loudspeaker 69-72 dB, 5 meter from the loudspeaker 70-72 (To make their graph the average for each measuring points were taken, and used as the value for that distance. see Figure 24).

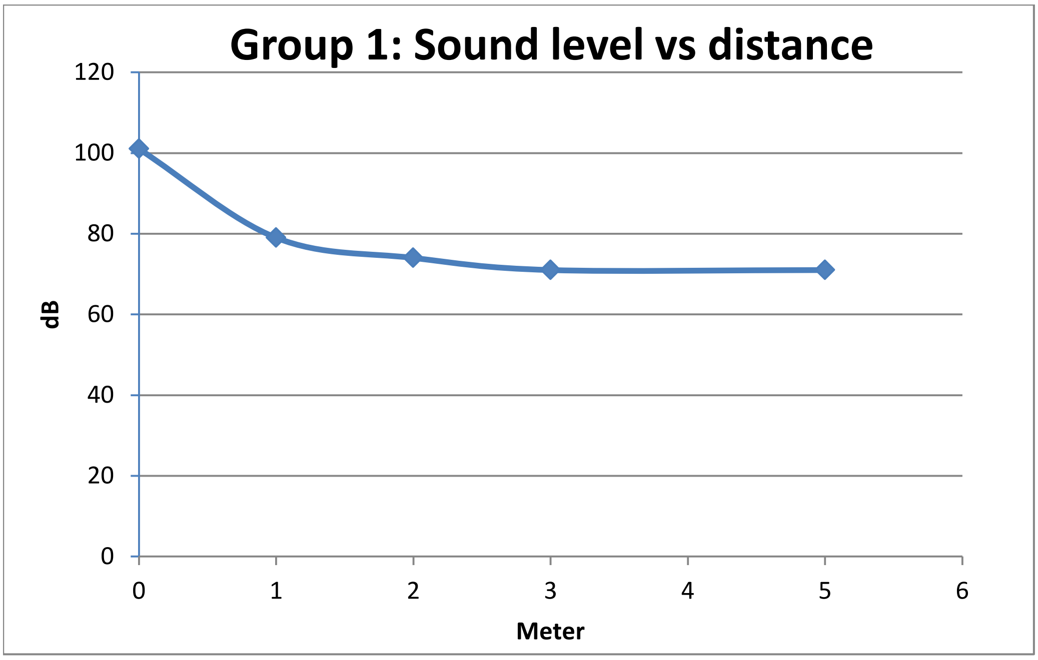


Figure 24. Graph made from Group 1's results

This group listens to music at 80-82 dB and found out that it is a bit harmful.

Group 2:

At the loudspeaker 105 dB, 0.5 meter from the loudspeaker 83 dB, 1 meter from the loudspeaker 80 dB, 2 meter from the loudspeaker 75 dB, 4 meter from the loudspeaker 72 (see Figure 25).

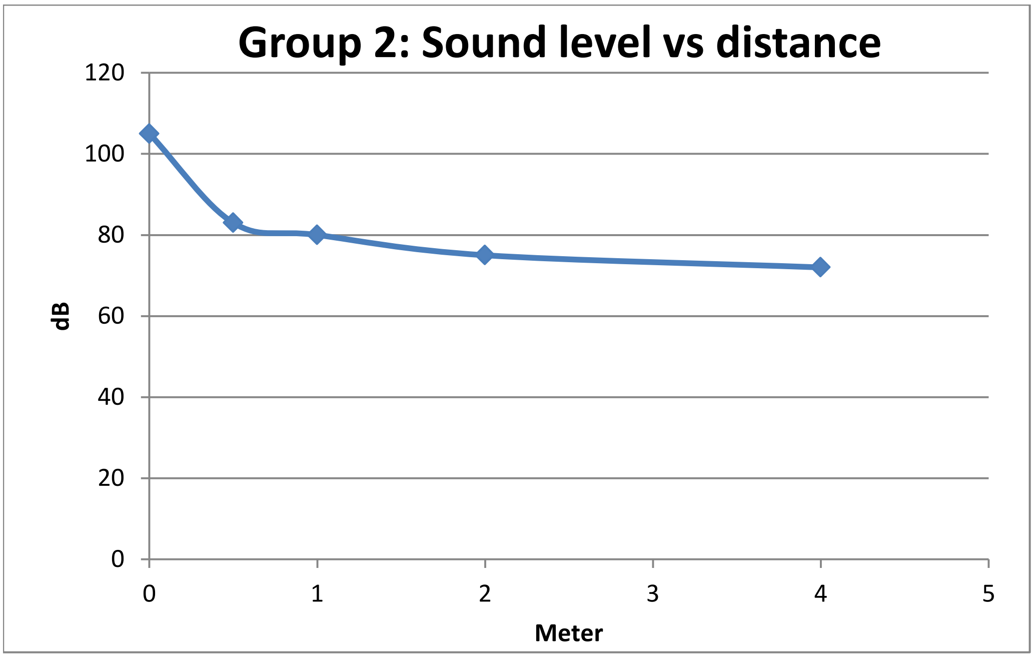


Figure 25. Graph made from group 2's results

This group listens to music at 72 dB, and answered yes to it could be harmful.

Group 3:

At the loudspeaker 98 dB, 1 meter from the loudspeaker 85 dB, 2 meter from the loudspeaker 75 dB (see Figure 26).

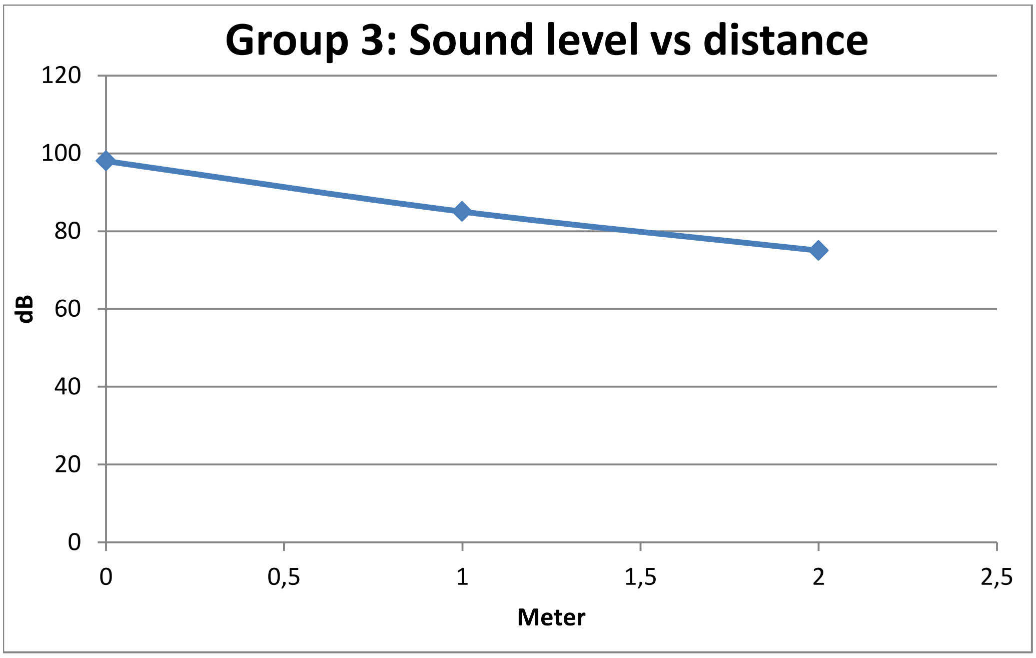


Figure 26. Graph made from group 2's results

The group answered that it can cause permanent hearing damage if Long-Term loud sound.

Group 4:

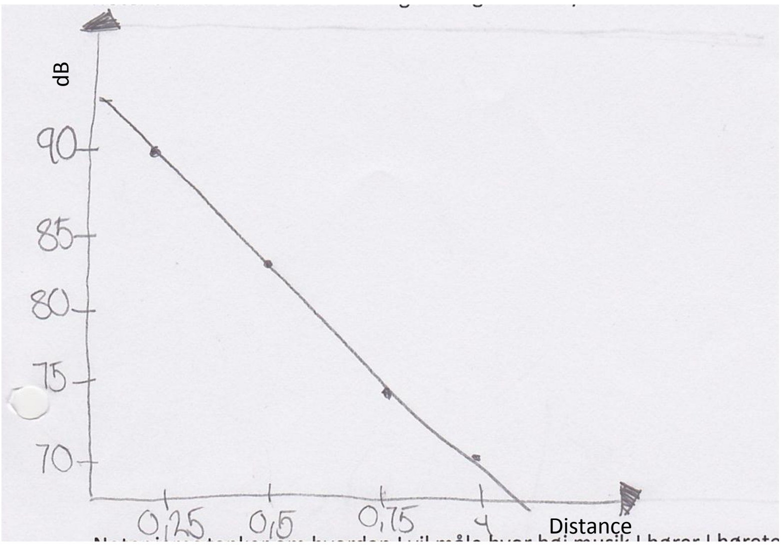


Figure 27. Graph made by a group of students. (Distance on x-axis, dB on y-axis)

This group made this graph in Figure 27. They did not answer the question on how loud music they listen to.

All of the groups (not only the four groups from above) found a correlation between distance from a loudspeaker and the sound level. And that the sound level drops when they walked away from the loudspeaker. From Group 1 (see Figure 24) and Group 2 (see Figure 25) we can see that they have measured that the sound level drops more when closer to the loud speaker, than when farther from the loud speaker, as we would expect (in an optimal case the dB would decrease by 6 every time the distance doubles). An example of how the students made their measurements can be seen in Figure 28.

It was very different how loud the music was which students said they listened to, and varied greatly from class to class. It varied between 60dB to around 100 dB. However the groups that answered that they listen to music around 70 dB and above, said that it was harmful in varying degrees. And the groups that listen to music at the highest noise level said that it was more harmful than the groups with lower noise level. The students were able to find the necessary information on the Internet, so they could answer the question. Hopefully the students would be more aware of how loud music they are listening to during the lesson.

Figure 28. Students from Vordingborg gymnasium measuring the dB-volume. Picture: Henrik Egholm Wessel

Exercise: Acceleration:

Two classes tested the lesson in its finished stage. One of the classes made a report from their experiments. Here are some of their results.

Group 1

This group decided to make an experiment where they measured their acceleration during a run.

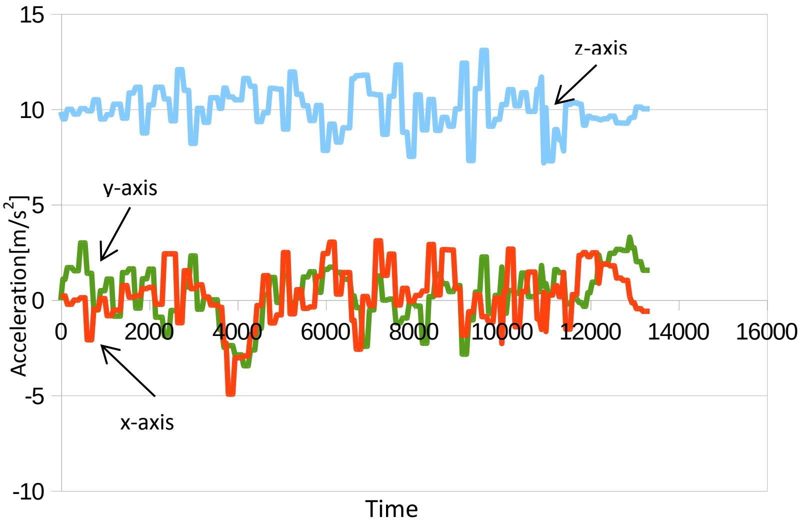


Figure 29. Graph and picture from Group 1 from Vordingborg gymnasium, measuring their acceleration while running.

When they looked at their data, they saw that they had a lot of noise on their z-axis as we can see Figure 29 the z-axis is jumping up and down a lot. Furthermore they saw that the x and y-axis also fluctuated due to the fact that they maybe shook the smartphone a little bit from side to side while running. They got the idea to push a person on a chair instead, where the person on the chair holds the smartphone (see Figure 30). When they pushed the chair instead of running, the z-axis was much more stable.

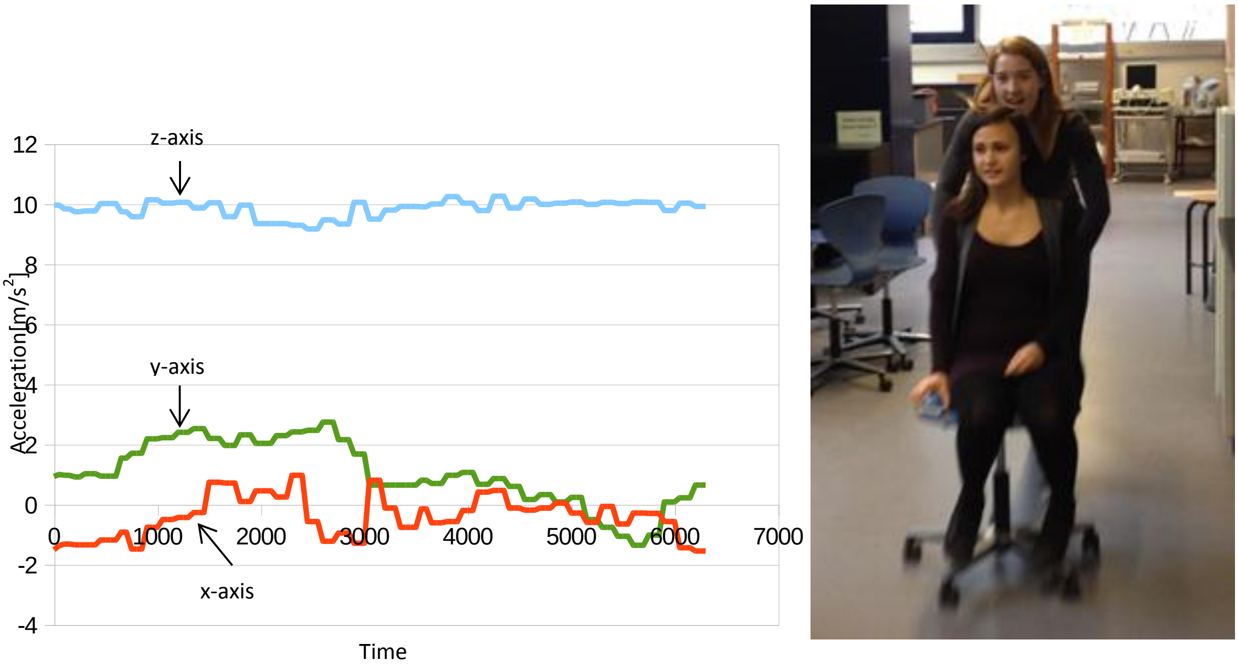


Figure 30. Graph and picture from group 1 from Vordingborg gymnasium. Measuring their acceleration when pushing a chair.

Here are their discussions of their results (They are holding their smartphone so the movement/running are in the y direction.)

***Running with the phone lying down (see Figure 29)**:*

Here it's also the y-axis we had to look at.

We see that the y-axis goes up and down a lot, which is due to the phone jumping up and down and to the sides. Therefore, there are reflections on the z- and x-axis as well.

Driving on chair, phone lying down (see Figure 30):

Here it's the y-axis we had to look at.

Here we see that the y-axis clearly is rising, when we're driving forward on the chair. We also see that it drops again, when we're stopping the chair. The z-axis is situated around 10, due to the gravitational acceleration.

As we can see Group 1 found a way to make their measurements so that they could decrease the amount noise in their data. They can see that when they are running, the smartphone bumps up and down, and also from side to side. It is difficult for them to hold the smartphone still while running. By using the idea with the chair, it is possible for the group to hold the smartphone still.

After they have made some new data with less noise, they can see that the y-axis rises when they start running and that it decreases when they decelerate.

Group 2

This group decided to do an experiment where they measured their acceleration during a jump

Figure 31. Group 2 from Vordingborg gymnasium measuring their acceleration in a jump

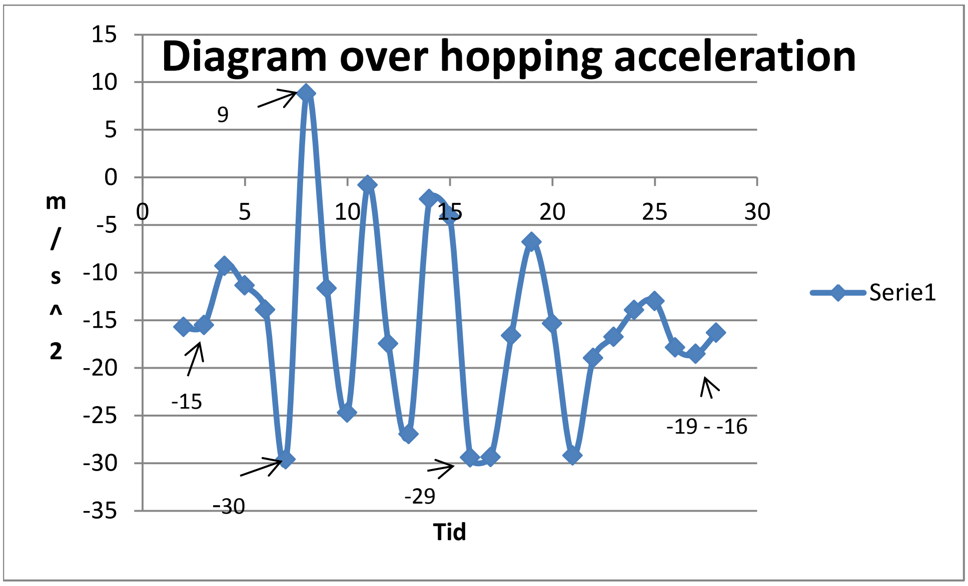


Figure 32. Data from group 2 from their jump in Figure 31

Here are their discussions of their results they got from Figure 31and Figure 32 (as a help the points that they are talking about is marked in the graph by the author):

In the first picture, the person is standing still, turning on the app, and this corresponds to – 15 on our chart, showing the acceleration of the jump.

In the second picture, we see that the person is bending her knees and prepare for her jump, while she tries to keep the iPhone as horizontal and still, as possible. And that shows at our chart by the point of – 30.

In the third picture, the person is hanging in the air, since she just accelerated from the step and therefore is hanging in the air, still focusing on keep the iPhone horizontal. It shows at our chart by the point of 9.

In the fourth picture, the person has just hit the floor and automatically bends her knee, to prevent the overload and prevent the impact that often follows, when you make a jump. This point is shown at our chart as – 29.

At the fifth and last picture, the person has just prevented the impact and is now standing straight again. When the person had to go from bended knees to straight legs, the end of the chart will appear different of the rest, point -19 to -16.

The reason why the jump is changing is because the jump starts at a step and finishes at the floor, therefore the points will be different, because you're going from a higher level to a lower level.

They have also pointed out some sources of errors

When we had made a graph from our data we could see that there were two high points instead of one, as we expected. This is due to the hand that holds iphone during the jump, automatically will make a minor fluctuations and thus provide more high points.

If there were only to be a single high point, make sure to keep the iphone close to your body throughout the test, the jump in our case.

The graph starts at -15 where the person starts the app and get ready to jump, but most likely there is a delay on the iphone which therefore causes that we start at -15 and not 0. When the person bends his knees, as shown in picture 2. Therefore, we cannot start at 0

The group themself pointed out that some of the peaks in the graph could be due to the fact that they did not hold the smartphone still, then they made the jump. As we can see, the group analyses their jump from the graph. The overall analysis looks correct, where they can see that they bend in their knees and jumps, and that they also bend their knees when landing. They can see that in their graph over the acceleration and point them out. One of the peaks that they think is the jump (their point 9) looks more like that they did not hold their smartphone still, otherwise the acceleration should not be positive. A positive acceleration means, in the way they have held it, that the smartphone should have been pulled down. Furthermore if we look at the last sentence in their analysis, it looks like that they only mean that the acceleration changes because they are jumping from a platform and down to the floor. This is of course not correct. If they have made a normal jump on the ground, the acceleration would also change. It is not clear for the author that the group thinks that or if it is a bad description from their part.

The students that did the exercise: Acceleration were able to do simple experiments with their smartphone where they measured their acceleration. Often they tried with experiments that were much too complicated, to begin with, but they changed their experiments so they were simpler, as we could see with Group 1. After the students did their experiments they were able analyse their data on a computer. Still they did have some problem when they had to do the analysis.

Discussion

Is it possible to use smartphones as scientific instruments?

Is it okay just to find applications for iOS and Android? Yes, from the students' answers, we saw that of all of the students with a smartphone, only 1% had another operating system than iOS and Android as we can see in Table 9. Of course the smartphone market should be watched so the distribution is known. If the distribution of operating systems changes drastically, then the question has to be considered again, and then maybe applications for other operating systems have to be found. Depending on how many smartphones are required in the lesson, it could be possible to only find applications for one operating system. With a distribution of 33.3% Android smartphones and 42.9% iPhones it would still be safe to say that a third of the class could use a smartphone. If the lesson is designed so there have to be at least three in each group, it would be possible. There are different advantages for both operating systems. At this moment, more students have an iPhone than an Android smartphone (see Table 10), and it seems as if the iPhone sometimes is a little more precise, based on cautious observations during the testing period without actual data to prove it. If it is the coding in the applications or the hardware, is difficult to say. One of the advantages of Android smartphones is that it is easier to find free applications, and if teachers want to develop their own application, it is easier and cheaper to get it on the Internet. If you want an application with a specific purpose then it can be difficult to find that on the Internet. For example, it was difficult to find an application, for Android that could easily send the logged data to an e-mail address. It was one of the reasons why "Fysik Værktøjskassen" was made.

Are the smartphones precise enough to be used as scientific measurement instruments?

Some of the problems with using smartphones are their precision and built-in limitations. As we can see in some of the graphs from "Det Gyldne Tårn", the smartphones have a problem with measuring much more than 2G (20m/s^2). As we can see on Figure 16 the acceleration in the z axes suddenly become very flat around 2G. In normal classes (not in Tivoli) it has not been a problem.

There is also a problem with some built-in limitations in the decibel meters. The microphones inside a smartphone are usually designed to capture the human voice (Smart Tools co.), this is the reason for the limitation. For example a Samsung Galaxy s3 has a limit of 81 dB and a Samsung Galaxy s2 has a limit of 98 dB according to the developer of the application "Sound meter" for Android (Smart Tools co.). If the teacher is aware of the limitations, then the lesson can be planned to work around the limitations, or it can be a part of the student exercise to find out what the limitations for the smartphone is.

But as we can see from Figure 12 and Figure 19 if the smartphones are held in the same way, they will give consistent data, even though the measurements were made with two different smartphones. This is a very important, because if they were not consistent, it would not be possible to use them as scientific instruments, since a key thing is that scientific instruments always have to give the same results if the same experiment is to be made twice.

What are the advantages and disadvantages using smartphones in class?

Another problem that came up during the experiment was that, suddenly an application did not work on some iPhones. The problem was that there had been an update for the iPhone's operating system (from iOS 5 to iOS 6), between the time when the application was found and the time when the class had to download it. The application that was found had been updated so it only worked with the new operation system. So all the students with the old operating system, had to find another application that did work. Fortunately it was the db meter application that did not work, and it is one of the applications where it is easy to find a new one. It would have been a bigger problem if it had been one of the accelerometer applications, where it can be a bigger problem to find a new one that meets the requirements of what the application should be able to do. For example it should be able to log and send data in a csv-file to a computer. Without the possibility of sending the file as a csv-file, the student do not have the change to open their data on a computer.

Despite the built-in limitations, the smartphones did work better than expected. It all depends on what you expect of the class, and taking those limitations into account. One of the things to consider for the sound experiment is how loud the music is playing during the experiment and how small the classroom is. Instead of finding out that the sound level goes down 6 dB every time the distance is doubled, the students can see that the sound level depends on the distance between the smartphone and the loudspeaker. Even with a real dB-meter it can be very difficult to measure that correlation, as we can see in Figure 6. One of the big advantages with the smartphone is that the students know how to use it right away. This is only the case with the dB-meter. With the accelerometer the students generally know how to use the application. The big problem with the accelerometer is that if the smartphone is held tilted then the data can be very difficult to interpret. If we compare Figure 19 with Figure 14, we can see that they do not look similar, even though they are from the same ride. If we look at Figure 20 instead we can see that the group that made these measurements probably have held their smartphone a little tilted, because the y-axis is shifted a part from 0 and it has some of the same movement as the z-axis. It should be possible to see a movement in the y-axis due to movement in that direction, but it should be around 0. A way to make sure that students know how to make good data is to let them test the application and look at their data. By starting with some simple experiments they would learn how the x, y and z axes work inside the smartphone. If the students from the example before have had the chance to test the application, before they came to Tivoli, they would have a better understanding on how the smartphone worked. When they were in Tivoli they did not have the time and chance to import their data to a computer. Even if they had the chance to test the application beforehand, it could still be a good idea to have a computer in Tivoli so they had the opportunity to look at their data immediately. This would of course mean that they have to have a computer with them in Tivoli, and the clever idea with a small measuring device would go away. It would be optimal if it were possible to look at the graphs on the smartphones. In that way the students would be sure to get good data to take home with them. Some of the students detected these problems themselves. By looking at Groups 1 and 2 from the acceleration experiment, we can see that they had some problems themselves. Group 1 saw that there was a lot of bumping up and down when they were running, and came up with the idea of putting the smartphone on a chair (see Figure 29 and Figure 30).They worked around the problem and came up with a new experiment to take it into account, this is a good example of a cycle between the explore and explain phase in 5E 1F model. Group 2 did an experiment where they were jumping. Their problem was that they could not hold the smartphone still in the jump and so they got more peaks in their graph than they had expected. They mention this in their sources of errors. They mention that it could have been prevented by instead keeping the smartphone closer into the body.

One of the things that are possible with a smartphone is the possibility to go on Facebook and get text messages all the time. This can distract the students so they do not pay any attention. As we can see in Table 13 18.3% of the students said that the use of a smartphone in class could be distracting. At the same time when the students were asked if they actually did get distracted 29.7% of the students think that they get disturbed in some sort of way (16.6% yes, 12.6% sometimes, 0.4% by others) (see Table 15) These two groups do not necessarily overlap each other. Some of the students that answered that a smartphone could be distracting in class, answered 'no' to the question if they get distracted. Compared with another Danish report about IT in education, 30-41% of students believe that they were significantly disturbed / very high degree (Bech, Dalsgaard, Degn, Gregersen, & Mathiasen, 2012). During the experiments a large number of students were observed using Facebook, and at the same time the Danish report also said that Facebook is used as a sharing tool (Bech, Dalsgaard, Degn, Gregersen, & Mathiasen, 2012), which was also observed during the experiment. Facebook can be a help for the students, if they are using it as a sharing tool. But as some students said, the use of smartphones makes the class more fun and they have to learn to deal with the presence of distracting elements in the classroom (computer or smartphone), see S11 and S35.

If it is correct that the students do not get distracted if the lesson is interesting enough or they are active during the lesson, then there is a chance that up to 12% of the students (the students that were getting distracted sometimes) find the lesson so interesting that they do not use Facebook and texting during the lesson (unless they have to). But we still have to consider the students that do get distracted by using their smartphone:

It could be an idea to try to design a lesson so as few students as possible would be distracted. If the lesson were designed so it was interesting enough, and in a way so students that are easily distracted do not have to use their own smartphone, but can share with a groupmember with one.

One of the questions that occurred during the experiment was, 'Is it even possible to do an IBSE lesson for students who have not tried it before?' This question can be difficult to give a concrete answer to, and is going to depend on the questionnaire and observations. One of the things to look for in IBSE is, 'Did the students get engaged in the lesson and were they active?' The answer for this question can be yes and no. What worked for one class did not always work for another class. One of the challenges has been that the students were not known beforehand. This could have changed the way the engaging part was designed. For one class it was enough that they had to listen to music and for another class it did not affect them that much. If the lesson were designed by the students' own teacher, the teacher would have a better idea of what engaged the students. Furthermore a lot of the students had some difficulty with the loose structure that is in IBSE. They had difficulty finding out what to do during the lesson. Some of them also took it as an opportunity to relax a little more in class. It was only one class who had to make a report over their experiments. Of course the relaxed attitude could also be a sign that the students did not have a clue about what to do. This would not be the case for all the students, because for the sound experiment, the first question should be fairly easy for them to start and still some of the students were sitting in their seats. They only started when they were asked what they had been doing. This can be due to the lack of experience with IBSE. As one student said:

S24: 'We used too much time on designing our experiment than getting data. Perhaps it would have been better to start with an experiment, with guidance, where we could be sure of good results'

Especially the students that tested the lessons with acceleration had some problems finding out what to do. Because it was a much more open question. With a little help all the groups did find out what to do. Another problem in the acceleration experiment was the data transfer, since none of the students had ever worked with csv-files in excel, which resulted in a certain amount of frustration for the students. So it is certainly one of the things you should be aware of when making a lesson with smartphones. If it takes too long time to see the results, the students lose interest and the important engaging part of IBSE will disappear.

During the period this report was written, the author was in two courses / workshops about using iPads in teaching. None of them were about using the iPad to make measurements. If a smartphone should be used as a scientific instrument it could be a good idea to have workshops where teachers can try it out. There are places where teachers can find help finding applications for teaching. For example the Facebook page "Smartphone teaching" or a homepage called http://skole-apps.dk/. The teachers' knowledge of these two pages is unknown. The Facebook page has 66 members and not all of them are teachers. A way to make the teachers more interested in, or willing to use smartphones as scientific instruments would probably be, if they did not have to find applications themselves. Furthermore it would be a help for the teachers if they knew that the same application existed for both Android and iOS. Especially if they don't have access to both an iOS device and an Android device. Then they can test the application on one operating system, and know how it works on both systems. Another way would be having some teaching materials that they could use to begin with, maybe from the Ministry of Children and Education, or one of the universities. If this teaching material could have its own application, then the teacher and the students know that the application is from a reliable developer. Some of the students want to know that the application is reliable before they download it, see S7.

Another thing to consider is how much space the application requires on the smartphone. Some of the older smartphones do not have as much space as some of the new ones, like this student say:

S5:'yes, but there is very limited space on the older smartphones which can quickly become a problem'

If the application is too large, then the students with old smartphones can have problems downloading it.

Something to think about if you want to develop an application is that the application should be easy to use and as mentioned before, that the application does not take up too much space on the smartphone. One of the things that the students like about the smartphone, is that they does not have to use the normal instruments, as the students said.

S21: 'I've got rid of the usual "instruments" we usually use'

One of the things that make it easier is probably that the applications can be very user friendly, and the students are using their smartphone all the time for other applications and sport applications. Another thing to consider is the transparency of the application. The more transparent the application is, the easier it is to understand what the smartphone measures or how long time it takes before the students can see past the application and see the physics behind. The transparency of applications were not a part of this thesis, but it could be interesting to carry out further research within this topic, if educational applications are going to be used more.

Are the students willing to use their smartphone as an instrument?

Two of the teachers from the classes which were visited, already had some experience with using smartphones as scientific instruments. In both cases they used the smartphone to determine the frequency of sound. So it is not unlikely that the idea of using smartphones as instruments could get implemented, as long the students would be willing to use their own smartphone in class. Based on the results from the questionnaire most of them are willing (see Table 11). Even a large number of students think it would be more fun or that they would learn better (see Table 12 and Table 13).

Smartphones get more and more widespread, it opens up for the possibility that the students can do their own experiments at home as homework assignments. From Table 9 we see that 76.9% of the students have a smartphone. It is very unlikely that all students are going to have a smartphone, so the assignments could be a group assignment. With the Tivoli visit we know that it is possible to let the students make their measurements outside the classroom. An example for an assignment, could be to measure the noise level five times during the day, maybe on their way to school or at a concert, this would of course bring up the problem with precision again. This might also be useful for other subjects than physics, for instance in geography where the GPS function might be helpful. The possibility of making measurements at home also opens up for the possibility that the students have the chance to make the experiment at home, if they have been sick or if they want to understand the experiment better. The possibility of making measurements at home also opens up for students making experiments at home, if they have been sick of if they want to understand the experiment better like S86 means.

In the same way as home assignments, the students have the possibility to make measurements themselves, outside of school work. As we see in Table 14 a large group of the students said that they would not use their smartphone outside school for measurements, but there is a small group (28.9%) that could imagine that they would use their smartphone outside school for measurements, as we can see from for example S83:

Even though it is only for fun once in a while it might increase their interest in science. Even though a large group (48%) said that they would not use their smartphone outside school for measurements there is a small possibility that some of them would do it anyway. As one of the students (who said that she would use her smartphone for making measurements) said

S85: *'Yes, because after you have installed it, I believe that you will use it as a tool'*

When the application is installed on their smartphone, there is a possibility that they are going to use it, just because it is on their smartphone.

Realistically there is a good chance that most of the students are not going to use their smartphone to make measurements for fun, but it could be interesting to do a study about that.

Conclusion

With more than three-quarters of students having a smartphone, the potential of using it as an instrument is great, especially when 96% of the students are willing to use their smartphone for educational purposes. It is possible to use smartphones in lessons, but the main thing to consider when using a smartphone is what the goal is for the lesson. If the goal is 100% correct data, then the built in limitations in the smartphone can be a problem. But if the goal is to show a tendency in a physical experiment, then the smartphones have great potential. One of the most important thing is that the smartphones are consistence, so if a experiment are made more than once with different smartphones, the smartphones will give the same results. One of the big problems with using a smartphone as a scientific instrument is that the students do not have the same smartphone, and that different smartphones can react differently, and can have different built in limits, this is mostly a problem with the dB-meter, and not with the accelerometer, where most of the smartphones have the same limitations. Another with smartphones is the easy access to Facebook and other distractions like text messaging. This problems may not be bigger that the problems with the distractions of laptops. The students find the use of smartphones interesting and engaging. They are happy that they can use their own instruments, and they are fast to learn how to use the applications. Of the two things (the db-meter and the acceletometer), the most potential is in the accelerometer part, because the smartphones have the same build-in limitaions, and are more consistence across the different smartphones. It will take some time and sometimes before the students and the teachers know how to use the smartphone properly. But hopefully after some time it will properly be a natural part of the physics lesson.

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