Smartphone physics – a smart approach to practical work in science education?

Experiences from a Swedish upper secondary school

Tomas Svensson
Smartphone physics – a smart approach to practical work in science education?

Experiences from a Swedish upper secondary school

Tomas Svensson

Abstract

In the form of teacher didactical design research, this work addresses a didactical issue encountered during physics teaching in a Swedish upper secondary school. A need for renewed practical laboratory work related to Newtonian mechanics is met by proposing and designing an activity based on high-speed photography using the nowadays omnipresent smartphone, thus bringing new technology into the classroom. The activity – video analysis of the collision physics of football kicks – is designed and evaluated by following a didactical design cycle. The work elaborates on how the proposed laboratory activity relates to the potential and complications of experimental activities in science education, as described in the vast literature on the topic. It is argued that the use of smartphones constitutes an interesting use of new technology for addressing known problems of practical work. Of particular interest is that smartphones offer a way to bridge the gap between the everyday life of students and the world of physics experiments (smartphones are powerful pocket laboratories). The use of smartphones also avoids using unfamiliar laboratory equipment that is known to hinder focus on intended content, while at the same time exploring a powerful tool for data acquisition and analysis. Overall, the use of smartphones (and computers) in this manner can be seen as the result of applying Occam’s razor to didactics: only familiar and readily available instrumentation is used, and skills learned (movie handling and image analysis) are all educationally worthwhile. Although the activity was judged successful, a systematic investigation of learning outcome was out of scope. This means that no strong conclusions can be drawn based on this limited work. Nonetheless, the smartphone activity was well received by the students and should constitute a useful addition to the set of instructional approaches, especially since variation is known to benefit learning. The main failure of the design was an overestimation of student prior knowledge on motion physics (and its application to image data). As a consequence, the activity took required more time and effort than originally anticipated. No severe pitfalls of smartphone usage were identified, but it should be noted that the proposed activity – with its lack of well-defined results due to variations in kick strength – requires that the teacher is capable of efficiently analysing multiple student films (avoiding the feedback process to become overwhelmingly time consuming). If not all student films are evaluated, the feedback to the students may become of low quality, and misconceptions may pass under the radar. On the other hand, given that programming from 2018 will become compulsory, an interesting development of the activity would be to include handling of images and videos using a high-level programming language like Python.

Keywords
Science education, practical work, laboratory work, ICT, didactical design research, teacher research, smartphones, video analysis, programming, Python, MatLab
Contents

1 Foreword .............................................................................................................. 1
2 Introduction ......................................................................................................... 2
3 Purpose ............................................................................................................... 4
  3.1 Research questions ............................................................................................ 5
4 Theoretical framework ....................................................................................... 5
  4.1 On the purpose and goals of practical work ....................................................... 5
  4.2 On the effectiveness of practical work ............................................................... 6
  4.3 On new technologies in practical work .............................................................. 8
5 Method ................................................................................................................ 9
  5.1 Didactical design process .................................................................................. 10
  5.2 Empirical data collection .................................................................................. 12
  5.3 Ethical considerations ..................................................................................... 12
6 Results ................................................................................................................ 12
  6.1 Didactical design work ..................................................................................... 12
    6.1.1 Context analysis .......................................................................................... 12
    6.1.2 Activity design: following the process ....................................................... 15
    6.1.3 Activity design: risk factors ....................................................................... 18
    6.1.4 Activity design: design ready ..................................................................... 20
    6.1.5 Activity execution ...................................................................................... 21
  6.2 Evaluation of didactical design ........................................................................ 21
    6.2.1 Effectiveness in view of the two-level Millar model .................................. 21
    6.2.2 Failures and surprises ................................................................................ 23
    6.2.3 Smartphone pitfalls .................................................................................... 24
    6.2.4 Brief remarks on questionnaire outcome .................................................. 24
7 Conclusion .......................................................................................................... 25
8 Discussion .......................................................................................................... 26
9 Bibliography ....................................................................................................... 28
10 Appendix A – Video analysis lesson ................................................................. 32
11 Appendix B – Lab instruction ............................................................................ 35
12 Appendix C – Questionnaire ............................................................................. 37
1 Foreword

It is often emphasised that research frequently is driven by the personal experiences or interests of the researcher (Bryman, 2011; Lofland & Lofland, 2006), and this is the case also here. In 2016, aiming at mitigating the shortage of science teachers, the Swedish Parliament approved the proposal to set up a special complementary teacher education (komplettterande pedagogisk utbildning, KPU in Swedish) for already accomplished researchers (Utbildningsutskottet, 2016b). Being fond of teaching, and with my PhD in Physics at hand, this seemed like a golden opportunity to get a teacher certification for the Swedish upper secondary education (I have been teaching quite a lot at the university, but there you do not need a formal certification). After acceptance and enrolment in late 2016, I started attending the first round of this salaried alternative teacher certification program in January 2017. In my case, I followed the program offered by a collaboration between Stockholm University (SU) and the KTH Royal Institute of Technology1. The program involves a 15 ECTS thesis work in the area of didactics. Rather quickly, I decided I wanted to work on something related to the hot topic of digitalisation and Information and Communications Technology (ICT) for educational purposes. In the Swedish upper secondary school, there is now a one-to-one relation between students and computers but much is yet to be done to use ICT efficiently (Fleischer, 2013; Skolverket, 2016; Utbildningsutskottet, 2016a). Despite having been in the centre of attention for many years, the topic is actually of particular interest at this very moment since programming will enter the curriculum (compulsory in many courses starting from the fall of 2018), and even stronger emphasis will be put on digitalisation. It therefore seemed like a good idea to do some action research in which I would investigate the use of a high-level programming language such as MatLab or Python in physics or mathematics teaching during my final practical training period (Verksamhetsförlagd utbildning, VFU in Swedish). However, after consultation with my practical training supervisor, this was judged to be a somewhat unrealistic project. The students I would teach in physics and math would already have a tight schedule, and time to spend on getting into the world of computation could not be envisioned. After that, partly due to my personal course workload, I did not identify an appropriate and appealing thesis topic until a few weeks into my practical training. I was teaching energy physics and was about to start covering collisions and momentum when it became apparent that the available equipment would make it difficult to engage students in productive practical work on the topic. After some thought, I came up with the idea of using the impressive frame rate of modern smartphones to study collisions experimentally, and in the same time bridging the gap between the traditional school physics laboratory setting and the students’ everyday life. In this way, I would work both within the constantly debated topic of practical work in science education, and the contemporary hot topic digitalisation and ICT. With a background in experimental optics and applied spectroscopy, practical work is also close to my heart. So, we set up a teacher research project, and I went kicking footballs with my students, and here we are… I want to thank my thesis supervisor and my VFU supervisor for encouragement in pursuing this kind of project. My impression is that linking thesis work firmly to personal teaching practice in such a manner is a good way to learn how systematically evaluate didactical designs, and to distribute experiences and ideas to the community.

Tomas Svensson
PhD Physics, MSc Applied Physics and Electrical Engineering
Malmö, January 2018

1 Official webpage: https://www.kth.se/utbildning/komplettterande-utbildning/komplettterande-pedagogisk-utbildning-for-personer-med-forskarexamen-90-hp-1.671111
2 Introduction

Practical work in science education – also referred to as laboratory work, experimental work or simply labs – seems to be under constant debate. As described by Hodson (1993), controversies have even concerned whether expensive laboratory activities are cost-efficient at all, or perhaps a direct waste of time. There are also less drastic sides of the debate dealing with how to best design practical activities (demonstration versus individual practical work, recipe-labs versus open inquiry etcetera), and where the most commonly practiced forms often are deemed ineffective. The literature on the topic is truly vast, and it is interesting to note that the debate is not only a recent trend. Overall, it is not difficult to find eager advocates of practical work, and the history is full of passionate pitches in favour of it. Henry Rowland, the brilliant American physicist, wrote already in 1886 that the failure of modern education is that “memory alone is trained” while “to produce men of action, they must be trained in action” and that people that study sciences “must enter the laboratory and stand face to face with nature” (Rowland, 1886). Similarly, the famous educational scientist John Dewey, father of “learning by doing”, summarised it in the following manner together with his daughter Evelyn (Dewey & Dewey, 1915):

No book or map is a substitute for personal experience; they cannot take the place of the actual journey. The mathematical formula for a falling body does not take the place of throwing stones or shaking apples from a tree.

Duit and Tesch (2010), in a more contemporary text, establishes that “science instruction without any experiment is hardly conceivable” and quotes Joan Solomons catchy rhetoric (Solomon, 1994) to illustrate the mainstream view on science:

Science teaching must take place in a laboratory; about that at least there is no controversy. Science simply belong there as naturally as cooking belongs in a kitchen and gardening in a garden.

Although the latter quote may appear a bit drastic, or even narrow-minded (science teaching can also take place outside a laboratory), there seems to be an overwhelming agreement on the importance and value of practical work. However, educational research on the topic in terms of learning outcome, leaves us with a more complex picture. Study after study has shown that there is little evidence of that typical practical activities are effective in terms of enhancement of conceptual understanding, student motivation and interest (see e.g. the recent reviews by Hofstein and Kind (2012) and Duit, Schecker, Hörtecke, and Niedderer (2014), or the influential case study “Does practical work really work?” by Abrahams and Millar (2008)). There is even convincing evidence that practical work can be counterproductive to real learning. Some of these contributions concern the rather obvious risks that ill-planned activities confuse rather than clarify and improve understanding (Anderhag, Thorell Danielsson, Andersson, Holst, & Nordling, 2014; Bergqvist, 1999; Bergqvist & Säljö, 1994), but there is also a widespread more fundamental criticism of overconfidence in the value of laboratory work. The substantial reviews by Kirschner and Meester (1988) and Hodson (1993) constitute excellent starting points to get familiar with this critical line of thought. Kirschner and Meester refers to the issue of laboratory work as somewhat of a paradox. At the same as they agree that there seems to be an indisputable consensus regarding the great importance of practical work, they also report that

There appears to be an overall agreement that laboratory work at present provides a poor return of knowledge in proportion to the amount of time and effort invested by staff and students.

and concludes that

Despite the fact that the results achieved in the laboratory setting are not always in proportion to the time, energy and money spent, and that they are seldom in accordance with the expectations of those who designed
them, it is very rare that one asks fundamental questions as to the use of the laboratory as an educational tool.

Similarly, Hodson describes the situation as follows

There is a notion common among teachers — and often expressed by students, too — that ’what you do for yourself, you understand’. Indeed, the early Nuffield schemes used what they claimed to be an old Chinese proverb ‘I am told and I forget; I see and I remember; I do and I understand’ to support their case for the widespread use of practical work. However, there is abundant evidence that even directly after completing a conventional practical exercise, many children cannot say what they did, why they did it or what they found (Moreira, 1980; Hofstein, 1988; Friedler and Tamir, 1990; Gunstone, 1991). So much for understanding! As Driver (1983) has remarked, it is more likely a case of ’I do and I am even more confused’.

The value of practical work in general is thus far from evident. The details of the research on, and critique of, the effectiveness of practical work will be elaborated later in this thesis, but let us already here mention some main reasons behind the apparent inefficiency of practical work:

- Reliance on cookbook-style experiments that does not stimulate higher-level cognitive skills and also fail to reflect scientific procedures.
- Many experiments are either trivial or simply verifies something already known by the student
- Practicalities (manipulating objects and equipment) stands in the way of linking activity to conceptual ideas and understanding
- Focus on “what to do” rather than on ideas and models (conflict between doing and learning)
- Lack of active linking of observations and ideas during the practical work
- Experiments as isolated events, and not well connected to the course as a whole (limited time spent before and after activity)
- Students not well informed on the purpose of the activity (significant discrepancy in perceived purpose between teacher and student)
- Students do not see the relevance of it neither in their everyday life, nor in their long-term education (gap between the laboratory world and the world outside)
- Lack of metacognition (reflection on the learning process)
- Lack of open inquiry
- Lack of adequate assessment of laboratory skills and knowledge, leading to that laboratory experiences are perceived less central in learning

Hofstein and Kind (2012) summaries this in the following, more minimalistic, way:

The biggest challenge for practical work, historically and today, is to change the practice of ‘manipulating equipment not ideas’. The typical laboratory experience in school science is a hands-on but not a minds-on activity. This problem is related to teachers’ fear of loosing control in the classroom and giving students more responsibility for their learning.

In short, one could conclude as Roth (1994), later also quoted by Hofstein and Lunetta (2004) in their influential review on laboratory work in science education:

although laboratories have long been recognized for their potential to facilitate the learning of science concepts and skills, this potential has yet to be realized.
The contemporary focus within teacher education on curriculum emphases (Roberts, 1982), open inquiry (National Research Council, 2000), the nature of science (NOS) Swedish (Lederman, 2007) and emphasis of metacognition (Zohar & Barzilai, 2013) are examples of trends aimed at turning the ship around. Along this development, there is also a hope that adequate use of information and communication technology (ICT) will enhance effectiveness of practical work (Hofstein & Kind, 2012). But still, despite the nowadays rather long history and strong progress of evidence-oriented education research – both regarding practical and non-practical work – the ship has not turned much (Fraser et al., 2014; Hofstein & Kind, 2012). Part of the solution is perhaps to realise that the main issue is to activate the learners, and that traditional experimental activities not per se activate the learners.

In the present work, I will look into how practical work centred around the nowadays omnipresent smartphone relates to the potential and complications of experimental activities in science education, as briefly touched upon above. The investigation was born out of a didactic problem faced during teaching physics in a Swedish upper secondary school, and has the form of teacher action research, as advocated for example by Cochran-Smith and Lytle (1999) and Wallace and Loughran (2012). Briefly, the available equipment (low friction air tracks and a single force sensor) and traditional approach for instruction related to the physics of impulse and momentum mainly allows verification-style demonstration (classes taught are around 25 students in size). In addition, the equipment was worn and did not always produce sensible data. Aiming at a more productive practical activity, I set out to develop, execute and evaluate new didactical design, ending up with basing it on the impressive frame rate of modern smartphones. While the literature already provides many examples of what can be done with modern smartphones (see section 4.3 below), evaluation of the didactical potential of smartphones activities remains largely unexplored. Although the use of smartphone high-speed photography to study collision dynamics may be a useful addition to the example library, the main purpose of the work is to develop a well-founded didactical design and to present a systematic evaluation of this didactical choice.

3 Purpose

As touched upon above, the overall purpose of this work was to develop, execute and evaluate a didactical design that solved a particular didactical problem encountered in my teaching practice (VFU). The problem in question has two sides: one being practical issues related to the equipment available at the school, the second being a desire to create an even more productive activity. The context was teaching in Physics 1a for upper secondary school, at the time when physics of collisions and momentum were to be covered. Teaching had largely been theoretical for a while, and it was time for some practical work. The practical issues were related to (i) that the available lab equipment made it difficult to engage the students in practical work in small groups (only four air track set-ups available, and only one force sensor), and (ii) that the equipment was worn and not always gave sensible results. The interest in a more productive activity was related to that the standard activity on collisions and momentum would mainly be a demonstration-type verification of theory. In addition, the air tracks had already been used for practical work on Newton’s second law ($F = ma$), and some instructional variation was considered advisable.

Choosing instructional activities is a creative process where often many somewhat arbitrary choices are/have to be made (there is no single activity that can be identified as the best option). As described in section 6, the use of smartphones for high-speed photography of collision processed was rather quickly identified as a promising practical activity, and was thus almost a starting point for most of the

---

2 “Undersökanede arbetssätt” in Swedish

3 “Naturvetenskapens karaktär” in Swedish
work within this thesis. Therefore, a second way of formulating the main purpose of this work can be that it aims to develop, execute and evaluate a practical activity on collision physics based on the high-speed photography capabilities of smartphones.

### 3.1 Research questions

The following research questions were set up to steer the work towards results that can be of use for others:

1. Which will be the main failures and surprises during execution and evaluation, and why were these aspects not identified during the didactical design process?
2. Which pitfalls related to using smartphones for practical work can be identified? Are these possible to avoid by design, or are there fundamental shortcomings that are difficult to circumvent?

### 4 Theoretical framework

#### 4.1 On the purpose and goals of practical work

The purpose of activities is of central importance in didactics. If the purpose is unclear, it is not easy to evaluate a didactical design. Before engaging in didactical design of practical work in science education, it is therefore important to be familiar with the taxonomy of purposes, or goals, of practical work. It is also extremely important to always explicitly discuss the intended purpose or teacher activities, as discussions may become very confusing if participants have different purposes in mind. Purpose taxonomy and research on opinions about purposes has been a central in education science for many years. Kerr (1963), in seminal work on practical work, set up the following taxonomy of purposes for practical work in secondary school science:

1. To encourage accurate observation and careful recording
2. To promote simple, common-sense scientific methods of thought
3. To develop manipulative skills
4. To give training in problem-solving
5. To fit the requirements of practical examination regulations
6. To elucidate the theoretical work so as to aid comprehension
7. To verify facts and principles already taught
8. To be an integral part of the process of finding facts by investigation and arriving at principles
9. To arouse and maintain interest in the subject
10. To make biological, chemical and physical phenomena more real through actual experience

Teacher rankings of these purposes has varied in the course of history, and it has been found that teacher and student have very different views on the purpose of practical work (Hodson, 1993). Hodson (1993) has proposed to merge these purposes into the following five broader purpose categories P1-P5:

A1. To motivate, by stimulating interest and enjoyment.
A2. To teach laboratory skills.
A3. To enhance the learning of scientific knowledge.
A4. To give insight into scientific method and to develop expertise in using it.
A5. To develop certain 'scientific attitudes', such as open-mindedness

A very similar five-item taxonomy is also given in the influential review by Hofstein and Lunetta (2004). However, I would like to add a sixth purpose category, P6,

A6. Connect science to everyday life

This aspect of science education has received quite some attention in recent years, and is now explicitly emphasized in curriculums both in Sweden and internationally (Hofstein & Lunetta, 2004; Högström, Ottander, & Benckert, 2006).

4.2 On the effectiveness of practical work

The literature on this topic is vast, and this section mainly aims at summarising knowledge on factors that render practical work inefficient in terms of goal attainment. For elaboration on, and references to, the individual body of research studies that underlies these factors, I refer to the well written reviews by Hodson (1993) and Kirschner and Meester (1988).

Hodson (1993) argues that the first step in planning teaching is “to be clear about the purpose of a particular lesson” and that the second step is to "choose a learning activity that suits it”. In order to avoid choosing practical work without a good reason, a teacher should always ask himself the following questions, each corresponding to one of the five purpose categories discussed in the previous section:

Q1. Does practical work motivate children? Are there alternative or better ways of motivating them?
Q2. Do children acquire laboratory skills from school practical work? Is the acquisition of these skills educationally worthwhile?
Q3. Does practical work assist children to develop an understanding of scientific concepts? Are there better ways of assisting this development?
Q4. What view/image of science and scientific activity do children acquire from engaging in practical work? Is that image a faithful representation of actual scientific practice?
Q5. Are the so-called 'scientific attitudes' likely to be fostered by the kinds of practical work children engage in? Are they necessary for the successful practice of science?

In the case that practical work still is considered, the education research indicates that a teacher should consider the following known risk factors (RF) that may hinder efficient learning:

RF1. Student lack prerequisite knowledge assumed by the teacher
RF2. Reliance on cookbook-style experiments that does not stimulate higher-level cognitive skills and also fail to reflect scientific procedures.
RF3. Many experiments are either trivial or simply verifies something already known by the student
RF4. Practicalities (manipulating objects and equipment) stands in the way of linking activity to conceptual ideas and understanding. This could be due inadequate skills that poses a major obstacle during the activity, or simply that the instrumental complexity is overwhelming.
RF5. Focus on “what to do” rather than on ideas and models (conflict between doing and learning)
RF6. Lack of active linking of observations and ideas during the practical work

RF7. Experiments as isolated events, and not well connected to the course as a whole (limited time spent before and after activity)

RF8. Students not well informed on the purpose of the activity (significant discrepancy in perceived purpose between teacher and student)

RF9. Students do not see the relevance of it neither in their everyday life, nor in their long-term education (alienation / gap between the laboratory world and the world outside)

RF10. Lack of metacognition (reflection on the learning process)

RF11. Lack of open inquiry

RF12. Lack of adequate assessment of laboratory skills and knowledge, leading to that laboratory experiences are perceived less central in learning. This can include that reports are not marked and returned with a reasonable time (no learning impact), that assessment in arbitrary and has little teaching value, or that constructive feedback is missing.

RF13. Students lack a role model (they have not had the possibility to learn how an experienced experimenter works)

In summary, my interpretation of this long list of known issues – all of them confirmed to be common teacher practice – it is important to avoid over-confidence in laboratory activities. As Kirschner and Meester (1988) put it

It is not at all uncommon to find a student who shows absolutely no understanding of the processes and techniques which he or she applied even a day earlier in the laboratory. It is actually quite easy to perform practical work which does not involve any (sic) thinking at all.

Personally, when reading and contemplating over all this research on the problems of the conventional notion and implementation of practical work, I end up thinking about what can be called a didactical interpretation of Occam’s razor. One of the Latin forms of Occam’s razor reads as follows:

Frustra fit per plura quod potest fieri per pauciora

An English translation is would be something like

It is futile to do with more things that which can be done with fewer

This captures the essence of Occam’s razor well, and based on the above discussed shortcomings of practical work, I believe that this also can serve as a golden principle in didactical design. It this context, it is, for example, interesting to note that Hodson (1993) has pointed out that

In many cases, experiments can be made simpler by cutting out some of the less crucial steps and by using simpler apparatus and simpler techniques. There is much to be said for pre-assembly of apparatus. Many children struggle to set up complex apparatus and have 'done enough' before the conceptually significant part of the activity has got underway.

Not only is this relevant to complexity of setups, but also to laboratory skills. Hodson (1990) argues that laboratory skills “has little, if any, value in itself” and that

it is not that practical work is necessary in order to provide children with particular skills, rather it is that particular skills are necessary if they are to engage successfully in practical work.

Moreover, I strongly agree with the view (Hodson, 1993) that
when successful engagement in an experiment requires a skill that children will not need again, or levels of competence that they cannot quickly attain, alternative procedures should be found — pre-assembly of apparatus, teacher demonstration, computer simulation, etc. […] This is not intended to be an argument against teaching any laboratory skills. Rather, it is an argument in favour of being more critical about which skills to teach, and an argument in favour of making it clear to students that laboratory skills constitute a means of engaging in other worthwhile activities. Those who recognize and accept that there are good reasons for acquiring certain skills may be more motivated to acquire them.

I would summarize this wisdom in the following way: primarily teach skills that the students can use again and again, not what they are unlikely to use again. This has implications for the long-term and subject-to-subject coordination of activities (software skills, lab writing procedures, instrumentation utilisation etc).

4.3 On new technologies in practical work

Chalkboards, books and whiteboards were once new technologies introduced for educational purposes. Today, other technologies are finding their roles in everyday education, and yet others are on the verge of being introduced as educational tools. It is often argued that, out of content, pedagogy and technology, it is content that should be the major drive in decision making. In their influential work on integration of technology in education, Mishra and Koehler (2006) challenges this view:

The traditional view of the relationship between the three aspects [content, pedagogy and technology] argues that content drives most decisions; the pedagogical goals and technologies to be used follow from a choice of what to teach. However, things are rarely that clear cut, particularly when newer technologies are considered. The introduction of the Internet can be seen as an example of a technology whose arrival forced educators to think about core pedagogical issues (Peruski & Mishra, 2004; Wallace, 2004). So, in this context, it is the technology that drives the kinds of decisions that we make about content and pedagogy.

The aim here is mainly to emphasise that content, pedagogy and technology are entangled, and that “viewing any of these components in isolation from the others represents a real disservice to good teaching” (Mishra & Koehler, 2006). They introduce the concept of technological pedagogical content knowledge, arguing that this is a form of knowledge that

…expert teachers bring to play anytime they teach. Sometimes this may not be obvious, particularly in cases in which standard (transparent) technologies are being used. But newer technologies often disrupt the status quo, requiring teachers to reconfigure not just their understanding of technology but of all three components.

My personal view is that the omnipresence of smartphones represents an important disruption of educational perspectives. A typical smartphone has more processing power than all of NASA when it put the first men on the moon in 1969 (Khoso & Khan, 2016), and has several interesting and accessible sensors integrated (camera, accelerometer, microphone, magnetic field sensor, GPS receiver, and ambient light sensor). This offers a multitude of new possibilities for experimental work in schools, including bridging of the gap between traditional physics equipment and technology familiar to students, and could even stimulate and educate students in how to do experimental work even outside of the educational setting (they always carry around science lab). In fact, smartphones are starting to attract some attention in the educational area. There is a stream of reports on how smartphones-based experiments can complement and/or replace traditional laboratory exercises in physics (Aiken et al., 2014; Forinash & Wisman, 2012; González et al., 2017; Klein, Hirth, Gröber, Kuhn, & Müller, 2014; Vieyra, Vieyra, Jeanjacquot, Marti, & Monteiro, 2015; Vogt & Kuhn, 2012), and they are already used for remote labs in massive open online courses (Waldrop, 2013). Although the use of high speed photography for educational, and thus not only scientific, purposes is not a new idea (Heck & Uylings, 2010; Vollmer & Möllmann, 2011), the possibility to do such experiment with recent generation smartphone cameras is, in my opinion, somewhat of a game changer. As an example, Bonato, Gratton, Onorato, and Oss (2017) has used this possibility to address student misconceptions about wave
propagation. Since the possibility is rather new, there are not that many cases studies yet, but I expect that the use of slow motion video analysis in physics education will grow steadily.

The impact that smartphone experimentation has on learning is, however, largely unknown, but there are indications that smartphones can enhance learning. In recent educational research (on tenth graders in the German Realschule), Kuhn and Vogt (2015) compared the learning outcome and motivation between a control group following traditional education on acoustics, and a group where practical work was based on smartphones instead of conventional equipment. They report that learning was enhanced, but that no difference could be seen in motivation in general (although some enhancement in student’s self-concept). As with modern ICT in general (Hofstein & Kind, 2012), the research on the impact of smartphones for educational purposes is, naturally, immature, and additional research is clearly needed before any conclusions can be made. Nonetheless, since variation in instruction is known to be an important part of effective teaching (Hofstein & Rosenfeld, 1996), smartphone laboratory activities is an interesting addition to any teacher’s didactical toolbox. In my view, a particularly interesting question concern to what extent smartphones can be assist in brining physics teaching closer to the real world context, i.e. being a part of the contemporary effort to make learning of science more meaningful to students via context-based teaching (King & Ritchie, 2012). Another, but in my opinion also interesting question, is whether smartphone activities may also open for a more cost-efficient management of laboratory equipment in schools.

5 Method

The general method in this work is didactical design research in the form of teacher research (Cochran-Smith & Lytle, 1999; Wallace & Loughran, 2012). This means that the didactical design research was initiated by an encounter of a dilemma or problem in the practice of a particular teacher, in this case me personally. It can be argued that this is close to the ideal of the reflective practitioner, and thus only part of ordinary best practice. However, due to time constraints, formal systematic design is seldom realistic in the teacher’s everyday life, and it is therefore argued that formalised teacher research is an important part of teacher learning. In addition, it is only through public dissemination that experiences become useful to the teacher and education community in general. For example, Wallace and Loughran (2012) argues as follows:

Advocates such as Marilyn Cochran-Smith and Susan Lytle (Cochran-Smith and Lytle 1999, 2004; Lytle and Cochran-Smith 1991) have long argued that teacher research is an important cornerstone of educational reform. Although in many ways teaching might be described as involving ongoing inquiry into practice, it is through the more formalised approach of teacher research that teacher learning is able to move beyond the individual practitioner and be accessible and useful for others.

They also put special emphases of the notion a dilemma, writing that

The notion of dilemmas is important because, as dilemmas are managed rather than resolved, teacher research based on dilemmas inevitably opens to scrutiny the myriad of decisions that teachers face in constructing meaningful learning experiences for their students. This work, like that of others working in the field of case writing (e.g. Lundeberg 1999; Shulman 1992) offers insights into one form of teacher research that begins to ‘unpack’ the complexity of teaching and learning.

A drawback of teacher research, in my opinion, concerns subjectivity. For example, classroom observation has revealed that there often is a mismatch between actual and self-perceived practice (Hodson, 1993):
Nor can researchers rely on teacher rhetoric as indicative of classroom activity. Classroom observation, scrutiny of laboratory materials and discussion with teachers often reveal a significant mismatch between espoused and actual practice — a feature of practical work noted some twenty years ago by West (1972). Although teachers may profess a belief in, and a commitment to, the value of open-ended or student-driven practical work, for example, they may fail to translate their rhetoric into practice. Teachers’ actual classroom practice is often much more teacher-directed than they claim (and believe) or their curriculum plans would imply.

Even if this work will rely on having audio recordings of teacher-student interaction, these may be subjectively interpreted with unconscious bias. Clearly, it would be more ideal that this kind of didactical design research is also followed by an independent educational researcher.

This remain of this chapter is divided in two parts. The first treats the methodology of didactical design, and the second gives some details on the empirical data collection for the purpose of evaluating the developed didactical design.

### 5.1 Didactical design process

The essence of didactical research is to focus on what, how and why something is to be taught (Wickman & Persson, 2009). When it comes to practical work it is, as discussed above, clearly not enough to stop at saying that for example laboratory work is central in science education. Practical work can differ in purpose, form and contextual fit, and even if the activity itself is the same, its effectiveness will depend on the organization of teaching before and after the actual activity occasion. To support wise didactical design, researchers have proposed various ways of describing an appropriate process. In developing my activity, I have based my work on the didactical design cycle proposed by Gómez Guzmán (2007), for use in mathematics (see also Skott, Jess, and Hansen (2010) for a good introduction to this cycle), in combination with the process for design and evaluation of practical work outlined by Millar and co-workers (Abrahams & Millar, 2008; Millar, Le Maréchal, & Tiberghien, 1999). These two process models are illustrated in the two graphs below.

*Didactical design cycle, reformulated but adopted from Gómez Guzmán (2007).*
When it comes to the two levels of effectiveness, an elaboration has been given by Abrahams and Millar (2008). One should distinguish between the domain of observables, and the domain of ideas, and effectiveness on the two levels can then be described as follows:

<table>
<thead>
<tr>
<th>Effectiveness</th>
<th>Domain of observables</th>
<th>Domain of ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>A practical task is effective at Level 1 (the ‘doing’ level) if...</td>
<td>... the students do with the objects and materials provided what the teacher intended them to do, and generate the kind of data the teacher intended.</td>
<td>... whilst carrying out the task, the students think about their actions and observations using the ideas that the teacher intended them to use.</td>
</tr>
<tr>
<td>A practical task is effective at Level 2 (the ‘learning’ level) if...</td>
<td>... the students can later recall things they did with objects or materials, or observed when carrying out the task, and key features of the data they collected.</td>
<td>... the students can later show understanding of the ideas the task was designed to help them learn.</td>
</tr>
</tbody>
</table>

*Table 1. Elaboration on effectiveness on the two levels: domain of observables and domain of ideas. From Abrahams and Millar (2008), without any modification.*
5.2 Empirical data collection

Audio recordings of discussions between teacher and students was made during the analysis sessions that followed movie recording. All groups were approached. In many cases, discussions were initiated by student questions, but groups were also approached under a “how is it going?” flag. Field notes was taken and elaborated on directly in connection to all activities related to the lab. Compulsory lab reports constitute an additional source of information, having the potential of disclosing the actual work done, misconceptions and learning. To get qualitative information on student opinions, a questionnaire with open questions was also distributed to the student (after completion of lab reports, but prior to concluding session).

5.3 Ethical considerations

This work largely falls within normal teacher activities (planning of teaching, execution and evaluation), although the purpose concerns the formalisation of this process by following a didactical design cycle. In this sense, the purpose of the research is only to design and evaluate teaching more systematically and more carefully than what, most likely, normally is the case. Since the focus is on didactical design, not on human subjects, the work is, to my understanding, outside the scope of the law of ethical review (SFS 2003:460, see §3–4 in particular). Even if this is be the case, good research practice still involves ethical consideration (Swedish Research Council, 2017):

Research that does not use personally sensitive data (3 §) and does not entail physical encroachment, aim to affect subjects physically or psychologically, or entail an obvious risk of harming subjects (4 §) is not to be reviewed, according to the Act. But this does not mean that this research can be conducted without considering ethical aspects.

In the present study, the main aspect of ethical dimensions is the audio recordings made to assist in post-teaching evaluation of the didactical design. This method was approved by the school, and also – via informed consent – by the students and their parents. Before consenting, students and their parents was given written information on the study as a whole, and the audio recordings in particular, following the guidelines for research in humanities and social sciences as given by the Swedish Research Council (Vetenskapsrådet, 2002).

6 Results

6.1 Didactical design work

6.1.1 Context analysis

The educational setting in question here is teaching in the first physics course (Physics 1a, see Skolverket (2017)) for students following the Natural Science Programme and The Technology Programme in the of Swedish upper secondary school, two programmes which are preparatory for higher education.

---

4 Regarding “observational studies conducted through participating, observing and recording”, the Swedish Research Council write in particular that covert participant observation should be an exception rather than a rule (Swedish Research Council, 2017, section 2.3.3). To me, it unclear whether other regulations actually forbids teachers to “secretly” use audio recordings for the purpose of evaluating teaching.
In the particular case here, the course is given to students in their second year of these three-year programmes, with a typical student age of 17 years.

The school in Sweden has an explicit double mission. Apart from its knowledge mission, schools are to convey democratic values and norms, and foster active and responsible citizens (a form of civic education). The mission related to values and norms is out of scope here and will not be considered explicitly in this thesis. There are, however, several general obligations put on teachers (Skolverket, 2013) that should not be forgotten at this stage. Those judged particularly central to design of a single particular physics course activity here are quoted in the list below:

Teachers should:

- take as the starting point each individual student’s needs, circumstances, experiences and thinking
- in the education create a balance between theoretical and practical knowledge that supports the learning of students
- in their teaching take account of the results of developments within the subject area, and also relevant pedagogical and other research
- organise and carry out work so that students
  - experience that knowledge is meaningful and that their own learning is progressing
  - receive opportunities to study subjects in greater depth, develop a frame of reference and context
  - gradually receive more and increasingly independent tasks to perform, as well as take greater personal responsibility

When it comes to physics in particular, the full aim of the subject is described in the physics subject description by Skolverket (2017). This text mentions the following general subject aims (SA):

SA1. Students are to develop knowledge about different applications of physics in areas such as technology, medicine and sustainable development, thereby enhancing understanding of the importance of physics in society.
SA2. Teaching should give students the opportunity to develop a scientific approach to the surrounding world.
SA3. Teaching should take advantage of current research and students' experiences, curiosity and creativity.
SA4. Teaching should also help students participate in public debates and discuss ethical issues and views from a scientific perspective.
SA5. Teaching should thus cover the development, limitations and areas of applicability of theories and models.
SA6. Teaching should also help students develop the ability to critically assess and distinguish between statements based on scientific and non-scientific foundations.
SA7. Teaching should cover scientific working methods such as formulating and searching for answers, planning and carrying out observations and experiments, and processing, interpreting and critically assessing results and information.
SA8. Students should be given the opportunity to analyse and solve problems through reasoning based on concepts and models, both with and without the use of mathematics.
SA9. Teaching should give students the opportunity to discuss and present analyses and conclusions.
SA10. They should also be given the opportunity to use computerised equipment for collecting, simulating, calculating, processing and presenting data.

After mentioning the above aims, it is emphasised that students should be given opportunities to develop the following abilities:

1. Knowledge of the concepts, models, theories and working methods of physics, and also understanding their development.
2. The ability to analyse and find answers to subject-related questions, and to identify, formulate and solve problems. The ability to reflect on and assess chosen strategies, methods and results.

3. The ability to plan, carry out, interpret and report experiments and observations, and also the ability to handle materials and equipment.

4. Knowledge of the importance of physics for the individual and society.

5. The ability to use a knowledge of physics to communicate, and also to examine and use information.

The core content of the course Physics 1a, content that the course should cover, is quoted below:

Motion and force
- Speed, momentum and acceleration to describe motion.
- Force as a cause of change in velocity and momentum.
- Equilibrium and linear motion in homogenous gravitational fields and electrical fields.
- Pressure, pressure variations and Archimedes' principle.
- Orientation to Einstein's description of motion at high speeds: Einstein's postulates, time dilation and relative energy.
- Orientation to current models for describing the smallest components of matter, and fundamental forces, and also how the models have been developed.

Energy and energy resources
- Work, force, potential energy and kinetic energy to describe different forms of energy: mechanical, thermal, electrical and chemical energy, and also radiation and nuclear energy.
- The energy principles, entropy and efficiency to describe energy transformation, energy quality and energy storage.
- Thermal energy: internal energy, heat capacity, heat transfer, temperature and phase transformation.
- Electrical energy: Electrical charging, field strength, potential, voltage, current and resistance.
- Nuclear energy: the structure of an atom and nuclear binding energy, strong forces, mass energy equivalence, nuclear reactions, fission and fusion.
- Energy resources and use of energy for a sustainable society.

Radiation in medicine and technology
- Radioactive disintegration, ionising radiation, particle radiation, half-life and activity.
- Orientation to electromagnetic radiation and the particle properties of light.
- The interaction between different types of radiation and biological systems, absorbed and equivalent doses. Radiation safety.
- Applications in medicine and technology.

Climate and weather forecasts
- The ideal gas law as a model for describing the physics of the atmosphere.
- Orientation to how physical models and methods of measurement are used to forecast climate and weather.
- Reliability and limitations of forecasts.

The nature, working methods, and mathematical methods of physics.
- The characteristics of a scientific problem.
- How models and theories provide simplifications of reality, and can be changed over time.
- The importance of experimental work in testing, re-assessing and revising hypotheses, theories and models.
- Identifying and studying problems using reasoning from physics and mathematical modelling covering linear equations, power and exponential equations, functions and graphs, and trigonometry and vectors.
- Planning and implementation of experimental investigations and observations, and formulating and testing hypotheses in connection with this.
- Processing and assessing data on results using graphs, unit analysis, and estimates of size.

5 “Centralt innehåll” in Swedish.
• Assessing results and conclusions by analysing choice of methods, work processes and sources of error.
• Views on societal questions based on explanatory models of physics, e.g. questions about sustainable development.

Given that the course covers 150 credits, corresponding to not more than around 131 hours of scheduled teaching (Skolverket, 2015), the course curriculum appears massive. Personally, it makes me wonder if not the curriculum design would benefit from trimming along the “less is more”-slogan of the science literacy-project from the American Association for the Advancement of Science (1994).

At the time of this didactical design research, much of the areas of motion, forces and energy has been covered. So far, practical work has been limited, and has involved measurement of friction forces and measurement of the gravitational acceleration constant (9.82 m/s²). Collisions, impulse and momentum remains to be treated (cf. the curriculum item “Force as a cause of change in velocity and momentum.”). Lately, much of the teaching has been rather theoretical (work, energy, energy forms, mechanical energy), and at this time of the course students typically engage in practical work on momentum and collisions using low-friction air tracks. It must be considered that although motion and Newton’s laws are fairly well grasped by the students, the understand of the equations of motion and relations between force and acceleration still needs to mature. This part of the course is typically handled by studying collisions using cart on low-friction air tracks. As described in the purpose above, the equipment is not functioning perfectly and the number of setups would not make it possible to engage all students in productive practical work. Instead, a design of a new activity was initiated, and the subsequent sections elaborate on this process.

6.1.2 Activity design: following the process

The activity design is an iterative process of cyclic content analysis, cognitive analysis (hypothesis on how can student progress their understanding of the content) and instruction analysis (design of an activity that suits this learning process) (Gómez Guzmán, 2007). During this process, didactical knowledge is a driving force, and the work will thus involve careful consideration of the knowledge on practical work discussed in the Theoretical framework chapter above.

From the context analysis above, the conceptual content to be dealt with in the activity is rather clear: the students are about to learn about momentum, its conservation and relation to collisions (forces acting during a certain time). Clearly, this content must be covered theoretically (definition of momentum, \( p = mv \), definition of impulse, \( I = F \cdot \Delta t \), and relation to Newton’s laws, arguments of conservation and so on).

After this brief content analysis, it is time for the main question of the cognitive analysis: how can students’ progress in the construction of knowledge of this content (Gómez Guzmán, 2007). Here, my hypothesis is that an important step in building understanding is to give the students a chance of a concrete experienced the underlying phenomena of collision and momentum transfer, namely deformation, and transfer of kinetic energy via elastic potential energy. This can then be linked to previous teaching in motion, forces and energy forms, and be treated also theoretically (and part of the theory needs to be presented before the practical activity).

Moving on to the instruction analysis (trying to find a task that will constitute the learning activity that suits the above hypothesis of cognitive development, cf. (Gómez Guzmán, 2007)), the practical activity of investigation of colliding carts on air tracks, as typically exercised at the school, would indeed be an option. However, the limited number of tracks available and their imperfect status was the reason why the development of a new activity was initiated. When thinking about a concrete experience of collisions and momentum, slow-motion movies of collisions quickly comes in mind. Work based on a slow-motion film camera would be an interesting option, being powerful for analysis, visually striking and a link to the outside world. However, the school did not have such a film camera, and even if it would have one it would only suit demonstration (which of course could be an option), not individual practical work.
Then, it came to my mind that modern smartphones have a special “slow motion” mode on their cameras. A quick check reveals that many smartphones now can record movies of 240 frames per second (fps), which is not far from the 1000 fps rate of film cameras that are used to generate extraordinary footage of fast processes. It does not take long to verify that 240 fps is enough to resolve, for example, the kicking of ball, including the deformation during the collision time (see figures below).

Three individual frames from a 240 fps movie captured with an iPhone 7 (a hard kick, final velocity being around 14 m/s). Note that the deformation of the ball is beautifully captured. It should, however, be noted that depending on the camera exposure settings, the ball may appear blurry if the exposure time is long. If the individual frames are exposed during the whole time between subsequent frames, i.e. an 1/240 s exposure time, the ball would in this case travel around 6 cm during an individual frame capture, making the 18 cm ball appear quite blurry (here the exposure time is much shorter, since the ball appear sharp). Many of the student movies actually became rather blurry. This does not prevent proper analysis, but makes the analysis less elegant and does not fully show how powerful the slow-motion mode is. In order to get sharp, aesthetically appealing frames to work with, it may thus be worthwhile instructing the students how to control the exposure time. A video, including video analysis data, can be found here on Flickr.

Motion analysis of the kick shown in the previous figure (obtained using a custom-made MatLab program). The velocity after the kick was around 14 m/s. Four frames showed ongoing collision, so an estimate of the collision time is 4/240 s. A well-pumped ball may give a too short collision time and little deformation, so it may be advisable to use a less well-pumped ball. Note also that if the exposure time for each frame instead would have been 1/240 s (blurry ball), a five-frame collision duration would lead to a collision time estimate of (4-1)/240 s (collision time estimate depends on exposure time setting).
A survey in the classes revealed that almost all students would be able to record in 240 fps, meaning that practical activity in student pairs is viable. The activity of recording ball kicks and analysing the dynamics from via individual frames seems like an interesting activity option. At this stage, a literature search revealed that smartphones are being used in practical work in science education, and that there are indications that the approach can enhance learning (see section 4.3 and references given there).

Looking at the five questions Q1-Q5 that Hodson’s recommends any teacher to contemplate over before choosing a practical activity (cf. On the effectiveness of practical work), my impression is that the proposed smartphone activity will answer these questions in a very interesting way.

Q1. Does practical work motivate children? Are there alternative or better ways of motivating them?
   Yes, I am rather convinced students will find the use of slow motion video analysis stimulating, joyful and interesting. This is also one way of bridging the gap between everyday life and experience and the peculiar world of physics (and leads to variation in teaching).

Q2. Do children acquire laboratory skills from school practical work? Is the acquisition of these skills educationally worthwhile?
   Yes. Movie recording and image analysis are common and powerful tools in science and technology. In addition, the skills required will not be far from the student’s current skills in handling smartphones. If image analysis will be new to them, it is definitely worthwhile teaching them. Only standard software like Paint and Photos included in windows are needed. In my opinion, the equipment and skills in question here will survive a didactical version of Occam’s razor. In addition, these skills in questions here seems to be an appropriate way of living up to the subject aim SA10 mentioned above.

Q3. Does practical work assist children to develop an understanding of scientific concepts? Are there better ways of assisting this development?
   Yes, this is my hypothesis (but depends on how the activity is linked to the concepts of the course). The video tests showed ball deformation nicely, and motion analysis based on the smartphone videos was found to produce very good data on speed and acceleration. I believe this is an important part of developing understanding of collision processes and momentum transfer. It can also serve as a foundation for discussions on microscopic deformation, elastic energy and the view of the world as a system ball and springs. To ensure conceptual understanding is in focus, the lab will feature discussions questions, not only “measure/calculate quantities X, Y and Z”

Q4. What view/image of science and scientific activity do children acquire from engaging in practical work? Is that image a faithful representation of actual scientific practice?
   Being an experienced researcher and engineer, my firm answer is yes. The task is similar to many measurement challenges that I have encountered during work in academia and industry. The students will enter the area without any idea of the correct answer. It was the same for me when I started to test the activity. Is the collision time 1 ms, 10 ms or 100 ms? Will the deformation show? What is the force on the ball? It seems like a very good complement to the common drill based on problem solving in text books, with correct answers given in the end of the book. All students will kick the ball differently, so they will all experience reach different answers (and the teacher will not know the answer either).

Q5. Are the so-called 'scientific attitudes' likely to be fostered by the kinds of practical work children engage in? Are they necessary for the successful practice of science?
   Reading what Hodson has to say about this aspect, I would say that this activity has a chance of fostering scientific attitudes. Hodson, for example, criticise the striving for correct answers, typical also in practical work. Here there would be no correct answer to check against. In this
context, Hodson also emphasis that “Youngsters need to see that scientists can be warm, sensitive, humorous and passionate”. Kicking ball and doing physics at the same time seems like a good fit: a social event, linked to everyday life, but using the impressive power of smartphones to do real physics. Not all physics experiments need to be strict exercises in a physics laboratory.

In addition, this activity will differ significantly from other activities in the course. Since instructional variation alone is an important factor in efficient teaching (Hofstein & Rosenfeld, 1996), the activity can be motivated also in this way. Moreover, there is also indications from modern cognition science that involvement of more senses benefit learning, and that it is alarming that schools is an important factor in turning homo sapiens into homo sedens, the seated man (Gärdenfors, 2010). Even if the time spent outdoors kicking football is very limited, it may be a valuable per se.

Continuing to the purpose categories (cf. the section On the purpose and goals of practical work), we may need to lift our eyes above the sole purpose of learning about momentum and collisions, which would be aim A3 “To enhance the learning of scientific knowledge”. Although all purposes can be addressed with the activity, the purposes that could be lifted to become main purposes of the activity are the following:

A1. To motivate, by stimulating interest and enjoyment.
A2. To teach laboratory skills. (video recording, image analysis)
A3. To enhance the learning of scientific knowledge (impulse, collision, momentum, elastic energy)
A6. Connect science to everyday life (smartphone, movies, football kicks)

Aims A4 and A5 concerns nature of science and open inquiry, and to work on these aspects, more dedicated activities can be designed (but they are also partly covered here, since working without access to expected answer is an important part of science and open inquiry). In contrast, aims A1, A2 and A6 appears to be spot on in this exercise. In particular, the activity seems to offer a good chance to focus on the following ability that are to be developed in the physics subject (cf. section on Context analysis above):

The ability to plan, carry out, interpret and report experiments and observations, and also the ability to handle materials and equipment.

This ability also connects to several items in the course curriculum, most notably that students “should also be given the opportunity to use computerised equipment for collecting, simulating, calculating, processing and presenting data” and that the teacher should “create a balance between theoretical and practical knowledge that supports the learning of students”.

In terms of being clear with the purpose, as stressed by Hodson (1993), the activity now seems to have multiple purposes, something which is sometimes discouraged. I stress that the main purpose is still that of enhancing learning of scientific knowledge (motion, collisions, forces, momentum), and learning of basic handling of equipment, data collection and image analysis skills. The others are somewhat secondary. On the other, hand I am not convinced that it is not possible to pursue multiple goals at a time, as long as it is a carefully designed activity well aligned with the course as a whole, while still not overwhelming students with information and laboratory procedures.

6.1.3 Activity design: risk factors

Let us have a look at the risk factors discussed in section 4.2 On the effectiveness of practical work. Below the risk factors are repeated and accompanied by a comment on how this risk is to be accounted for in the activity design.

RF1. Student lack prerequisite knowledge assumed by the teacher
The student’s current understanding of motion and forces should be sufficient (these topics was treated earlier in the course), but the activity is also a way ensuring that this knowledge mature. Practical computer analysis skills could be a problem (extracting frames and positions from frames), motivating the development of a pre-activity training session on video analysis of collisions (see Appendix B).

**RF2. Reliance on cookbook-style experiments that does not stimulate higher-level cognitive skills and also fail to reflect scientific procedures.**

Can be avoided by not providing a too detailed instruction (the pre-activity training session described in Appendix B was not made in a form that the students could copy, and the lab instruction, found in Appendix A, does not explicitly list necessary manoeuvres). Since there is no known answer, students need to rely on their cognitive skills (values for ball acceleration is also surprisingly high, so students are expected to start questioning their results). On the other hand, the laboratory instruction will guide the student quite a bit (see the laboratory instruction in Appendix B), so the activity is still far away from open inquiry.

**RF3. Many experiments are either trivial or simply verifies something already known by the student**

Not the case here. Students will not have an idea about if the collision time is 0.1 s or 0.001 s, and how large the force acting on the ball is.

**RF4. Practicalities (manipulating objects and equipment) stands in the way of linking activity to conceptual ideas and understanding. This could be due inadequate skills that poses a major obstacle during the activity, or simply that the instrumental complexity is overwhelming.**

Using phones and computers. Should not be a major issue, although digital competence is somewhat unclear. In any case, the practicalities are certainly not overwhelming.

**RF5. Focus on “what to do” rather than on ideas and models (conflict between doing and learning)**

Relevant risk. By introducing discussion questions along with questions on collision time, force, speed and acceleration, it should be possible to ensure that ideas and concept are central also during the activity.

**RF6. Lack of active linking of observations and ideas during the practical work**

The main task will be video analysis, and if instructions are not too explicit, students should discuss the physical ideas during this work. The video recording is mainly a short, fun social thing, and it is expected that the analysis phase will lead to productive physics discussion.

**RF7. Experiments as isolated events, and not well connected to the course as a whole (limited time spent before and after activity)**

This activity will be well linked to both previous and upcoming topics. This risk is eliminated by design. For example, it is directly coupled to the topics of motion, forces and Newton’s laws. In addition, it couples well to the recently covered energy topic, since the momentum transfer involves elastic potential energy. It will also be the follow-up activity of the first introduction to impulse and the impulse law \( I = F \cdot \Delta t = m v_2 - m v_1 = \Delta p \).

**RF8. Students not well informed on the purpose of the activity (significant discrepancy in perceived purpose between teacher and student)**

This needs to be ensured. Time needs to be spent introducing the work, and why it is relevant to student learning etc.

**RF9. Students do not see the relevance of it neither in their everyday life, nor in their long-term education (alienation / gap between the laboratory world and the world outside)**
The relevance to everyday life physics and dynamics is evident. The extent of which the students find it relevant to their long-term education depends on how well the teacher can pitch the video analysis value. Personally, I think that the students will not have any problem in seeing the value of image analysis.

**RF10. Lack of metacognition (reflection on the learning process)**

This requires care during the activity (i.e. avoiding IRE-type communication during the activity in favour of open questions that stimulate reasoning and metaprocesses (Hackling, Smith, & Murcia, 2010; Skott et al., 2010). The discussion question will also serve this purpose. To even more emphasise metacognition, the activity can be followed by some smaller metacognition activity (e.g. a mindmap activity in which students are to recollect what the activity was about).

**RF11. Lack of open inquiry**

The proposed activity is intended to replace a typical closed laboratory experiment. In order not to take to many steps at a time, turning it into full open inquiry is not considered. In terms of typical taxonomy of instructional approaches (Gyllenpalm, Wickman, & Holmgren, 2010), this activity is most likely best described as guided inquiry (the question and method is not free, but the answer is largely open and cannot readily be found in a textbook or on the internet).

**RF12. Lack of adequate assessment of laboratory skills and knowledge, leading to that laboratory experiences are perceived less central in learning. This can include that reports are not marked and returned with a reasonable time (no learning impact), that assessment in arbitrary and has little teaching value, or that constructive feedback is missing.**

Students will be informed that a lab report must be written, and that it will be assessed. Feedback will be given in due time. For long-term fostering, image analysis will be part of an upcoming summative test.

**RF13. Students lack a role model (they have not had the possibility to learn how an experienced experimenter works)**

The activity will be preceded with a session where the teacher describes the use of video analysis to study the dynamics of a bouncing ball. This preparatory activity is described further in Appendix B.

### 6.1.4 Activity design: design ready

Based on the elaborations in the above subsections related to activity design, the following activity design is proposed:

1. Initial lecture on video analysis based on smartphone high-speed photograph. Details on this material can be found in Appendix A. Discussion of the purpose of the activity.
2. Distribution of laboratory instruction. The laboratory instruction can be found in Appendix B.
3. Organisation of students in pairs
4. 20 minutes outside activity: recording of slow motion movies of football kicks (at least one video per group).
5. 2 hours, or slightly more if needed, of in-class video analysis and work on discussion questions (as described in laboratory instruction).
6. When lab reports have been handed in, a mindmap activity will be conducted (metacognition on what was learned, and relation to course content).

Note that an important part of the activity is the time spent before and after the actual video analysis activity, and also how the activity fits with both preceding and subsequent topics in the course.
6.1.5 Activity execution

The activity was tested in two classes, one group of 26 students in the second year of the Natural Science Programme and one group of 23 students in the second year of the Technology Programme. Students were instructed to work in pairs (one group was allowed to work three). Movies were recorded outside, a procedure that required not more than around 20 minutes per class, and around 2 in-class hours was devoted to video analysis (per class). Remaining work was done outside schedule (homework, mainly writing of lab reports).

Most of the students had smartphones capable of recording movies at 240 frames per second. The transfer of movies from phones to laptops went smooth.

Due to various practical complications, students did not finish lab reports before my VFU ended. I therefore replaced the planned metacognitive mind map exercise with a shorter, more teacher-centred, feedback summary that I conducted after the end of my VFU period (in combination with questionnaire based on open questions).

6.2 Evaluation of didactical design

The students enthusiastically engaged in the activity, and seemed to enjoy both video recordings and subsequent data analysis. During analysis sessions, there was a lot of physics discussions going on in the classroom, and as a teacher I was very pleased with the flow. The students were not as skilled in computer work as I had assumed, but since image analysis procedures are considered educationally worthwhile (see sections on Design work above), this was not seen as a problem (the matter just required some extra attention and time). The section below analyses, and problematizes, the activity execution in more detail.

6.2.1 Effectiveness in view of the two-level Millar model

The students, no doubt, became was highly engaged in the work. During analysis, all groups was discussing image interpretation and motion analysis, and there was a stream of questions for me as a teacher to handle.

In terms of the two-level Millar model, level one effectiveness (the “doing level”) in the domain of observables was evident. The students did with objects and materials as intended, and generated the kind of data that was intended. As the classroom was filled of discussions of ball contact time, length scales, velocities and acceleration, level one effectiveness in the domain of ideas may also seem evident, but this deserves a more careful analysis.

Based on the audio recordings of teacher-student discussions, it is obvious that there were many questions regarding contact time and estimation of velocities and acceleration. Questions and discussions on contact time estimation reflects that the students are new to movie and image analysis, which is perfectly understandable.

Perhaps more unexpected, the transcripts reveal that putting the knowledge in motion physics into practice was a major challenge to the students. For example, many groups had difficulties in, on their own, making the distinction between final ball velocity, and average ball velocity from the resting position to an arbitrary selected frame during the free flight phase:

[Students] We have reached an answer, but it is not reasonable.
[Teacher] Is it not?
[Students] Not when comparing it to others. The distance has gone from …
[Teacher] Are we talking about estimation of final velocity?
[Students] Yes. The distance is from … there [showing a frame where the ball is resting, before the kick] … to there [stepping forward and showing a second frame where the ball is now in free flight] … That seems to be around 12 cm.

[Teacher] Wait, let us see… Yes, but what are you looking at here? You are looking at the average velocity between these two positions, from rest (zero meters per second) to …

[Students] Oh … yeah …

[Teacher] … but you want the final velocity, so you need to consider the change from, for example, there [selecting the first frame of free flight] … to there [stepping to a second frame with free flight]. If not, you will get the average velocity including a period where it had zero velocity.

[Students] Yeah… so we should take from this image instead?

[Teacher] Yes, for example… And then you will not get such a low velocity…

[Students] Yeah, right…

From the audio analysis, knowing that there were many groups that wanted attention from the teacher, it is interesting to note that it is not very uncommon that I started using funnelling⁶ as a way to speed up progress:

[Students] So, this is our first frame and … there we have a frame where the ball left the foot.

[Teacher] Mmm…

[Students] Should we measure the distance?

[Teacher] Well, what are you after?

[Students] Well. The distance. No, the force… Eh… The ball… [clearly confused, stepping between frames where the ball and foot are in contact]

[Teacher] Are you after the distance during the acceleration of the ball?

[Students] Yes

[Teacher] And what will you do with that distance?

[Students] To get the acceleration in some way

[Teacher] Mmm. Well … let us see this as if there are two different states. The starting condition

[Students] This is the start. Nothing is happening to the ball.

[Teacher] It is resting. And the final state is when it is flying with some velocity.

[Students] Yeah

[Teacher] To get the acceleration, from zero up to that velocity, what should we do? [waiting about eleven seconds for a response] It may be appropriate to get the final velocity by looking at two different frames where the ball is flying freely in the air. If not, you will get an average velocity over the distance you choose, including time when it is resting. But if you take two frames where the ball is flying, and comparing these, you will get the final velocity. The acceleration is just from zero to that, in the collision time.


Discussions related to collision physics occur mainly during the work with the discussion questions. The transformation of estimated velocity and collision time into a force – using the impulse law or Newton’s second law— was, on the other hand, made in the blink of an eye. This means that it cannot be said that the actual ball kick analysis work stimulated so much exploratory talk on collision physics. This does not, however, mean that the ball kick is not an important part of the puzzle to build up knowledge on this area. It may still serve as a good starting point for the upcoming theoretical efforts on impulse and momentum, and it must not be forgotten that the discussion questions ended the activity by shifting the focus towards collision physics and energy. As an example, the below transcript is from a group who completed the video analysis and switched to working with the discussion questions (clearly in need of thinking through the energy transformations involved in the kick):

---

⁶ Lotsning, in Swedish
[Student] We started to think a little, but we do not know …
[Teacher] So, what have you been thinking
[Student] That… the ball goes from being at rest to being in motion… that is, from potential energy to kinetic energy…
[Teacher] Ok…
[Student] And then, overall, the kinetic energy … well, it is conserved. From the foot, transferred to the ball…
[Teacher] Mmm… Why does potential energy enter the picture?
[Student] Because it is resting… from the beginning… was our thought…
[Teacher] Mmm… It does not have any kinetic energy. But the kick is at some level, so the ball does not gain speed by changing height…
[Student] No…
[Teacher] So, do you really think potential energy is involved? A leading question perhaps, but …
[Student] No.
[Teacher] No, it is not involved. The ball does not gain velocity due to, for example, that we drop it
[Student] Yeah…
[Teacher] But … we use our muscle to set our leg in motion … So, we use that kinetic energy to give the ball kinetic energy. So, what I am after in this question is to make you think about what happens during the collision. Is there any other energy form …
[Student] Elastic
[Teacher] Elastic, exactly.

To summarize, my impression is that the activity was indeed level one effective, with the reservation that there was, when it comes to the domain of ideas, a shift from collision physics towards motion physics. Level two efficiency – the “learning level” – is out of scope in this work (follow-up was not possible, since the activity was executed in the end of my VFU period).

6.2.2 Failures and surprises

No severe failures could be found in the didactical design, but there were a few surprises and some overestimation of the students’ prior knowledge and skills.

In general, the students’ digital competence was overestimated. Manoeuvres that I anticipated to come naturally often required assistance (proper use of right-click menus in Windows, handling of files in Windows Explorer, opening of files using particular programs such as Paint, etcetera). For lab report writing, I assumed that second year students would be familiar with the Equation Editor from earlier lab reports, but hey were not. The background of this is not related to a flaw in the design cycle, but rather to the fact that I, at the time of execution, have not followed these students for more than a few weeks.

Since the curriculum content in focus was supposed to be physical impulse, it is also interesting to note that most students used Newton’s second law, $F = ma$, to estimate the force without really noticing the close relation to the law of impulses, $F \cdot dt = mv_2 - mv_1$. Perhaps, the activity (e.g. discussion questions) could be reworked to put more emphasis of this link. In this sense, the connection to impulse and Newton-seconds could be improved. This was, however, discussed explicitly in the follow-up session.

Furthermore, I was surprised that the conceptual difficulties in understanding how to use images to determine velocities and acceleration. One could describe this problem by saying that the students had difficulties in separating three relevant phases: before collision – during collision – after collision. Several groups calculated the final velocity using frames where the collision is still in progress. Perhaps,
this may depend on an eager to finish tasks rather than lacking conceptual understanding (being hands-on, before being mind-on). Still, I did not really anticipate these complications, and this is a slight shortcoming in the planning. Similarly, many groups had difficulties separating the collision time from the time between the two frames used to estimate the final velocity. Overall, the actual work shifted towards general motion physics, and did not only deal with collision physics. This also meant that the analysis required more time than anticipated.

When it comes to lab reports, one clear shortcoming of the laboratory instruction did not explicitly mention that sources of uncertainties were to be treated. This should, on the other hand, be part of a long-term effort to build up competence in writing science reports. The next generation lab instruction should be better linked to long-term work on report writing in general (not only regarding uncertainties).

Finally, it was very interesting to compare field notes and audio recordings to the content in lab reports. From the lab reports, it was obvious that several groups had made conceptual mistakes related to fundamental motion physics (acceleration/velocity). My impression after the lessons, and also after listening to the audio recordings, was that most of these fundamental misconceptions and problems were sorted out during the activity. This is an interesting example of how a teacher’s impression of progress and performance differs from what actually has happened, and also an example of how powerful reports can be for formative assessment.

### 6.2.3 Smartphone pitfalls

No major pitfalls related to the use of smartphones could be identified, despite that “bring your own device”-approaches are known to create challenges. When it comes to video analysis, smartphones enable quick and efficient data collection, since movie recordings and movie transfer are straightforward. In situations where several students have smartphones that does not support framerates as high as 240 frames per, grouping may be an issue. Since almost all had phones supporting 240 fps, the students organized themselves. In the end, it turned out that one group worked with a 60 fps video, making it difficult to visualize the collision and estimate collision time in an adequate manner. One group experienced problems in stepping through the frames using the Photos application, resulting in incorrect estimation of time intervals (unknown reason, the approach worked well for all other groups).

However, it should be noted that this activity requires the teacher to be comfortable with solving minor general technical complications with e.g. file transfer, standard software and general computer handling (the students also used their own laptop computers). In addition, in order to give adequate feedback to students and identifying mistakes, the teacher should be capable of analysing student movies efficiently e.g. by developing their own tools in MatLab or Python, or by using available software for video analysis. Manual analysis of student films using Paint, as done by the students, is time-consuming and not well suited as a base for feedback to students regarding their analysis. Skipping analysis of all student films may result in that some misconceptions are not identified and dealt with. The reason is that when working with problems without a given answer, as here, students may reach a reasonable answer even when doing significant conceptual errors (errors cancelling out, or values for a hard kick passing as reasonable values for a soft kick – things that were encountered a few times during evaluation of student films).

### 6.2.4 Brief remarks on questionnaire outcome

Most students seemed to have found the task interesting and fun, but there are at the same time several remarks that it was a tough task that required a lot of time and effort. When it comes to how the students perceived the purpose of the activity, there is a wide spread of formulations, from content-centred statements like “to learn about collisions” or “to learn about impulse”, to more general statements like “coupling physics to everyday life” or “learning how to use technical tools for measurements”. No answer described the purpose in terms of football kick analysis.
7 Conclusion

The purpose of this work was to handle of a didactical problem related to practical work encountered during actual teaching, and thus represent didactical design research in the form of teacher research. In a sense, the work can be described as a formalised, and more systematic, approach to ordinary instructional development. Following the didactical design cycle, it turned out that an important part of the design work was to take into account the extensive literature on the known issues of practical work (didactical knowledge input to activity design). Personally, being an experimental physicist with quite some experience in laboratory instruction at university level, I must say that the literature was somewhat of an eye-opener, while still rather commonsensical than controversial. The purpose categories, Hodson’s critical questions and the risk factors of practical work was useful foundations when designing and fine-tuning the actual activity. Particular emphasis was put on avoiding focus on doing (recipe-style/cook-book lab), only requiring educationally worthwhile equipment and software (by using smartphones and laptops only, the activity is something that could be described as the result of Occam’s razor applied to practical work), not making the activity isolated from other parts of the course (well connected to prior and subsequent instruction). The introduction of the discussions questions was of particular importance, and was perhaps the most important impact of the systematic design process. If these questions would have been left out, it could easily have turned into a lab where students aimed at getting “correct” values for the football kick, and thus lacking the metacognitive aspects known to be important for learning. The designed activity worked well, and students clearly got highly engaged in the task. Smartphone activities in general, and video analysis in particular, constitute an interesting way to address the many known issues of practical work in science education (see section 6.1). In particular, it may be a good way to bridge the gap between the everyday world of students and the world of scientific instrumentation and data collection: the smartphone is indeed a powerful pocket laboratory!

Regarding the formulated research questions, it can be concluded that the main failure, or shortcoming, was an overestimation of how well the students could use their prior knowledge on motion in this practical setting (distinction between average velocity including the acceleration phase and final velocity, confusions regarding collision time and time interval used to determine final velocity). This is a problem related to risk factor RF1 in section 6.1.3, and the aspect was thus not ignored in the design process. As a consequence, more time was needed to complete the analysis work, and there was a slight shift from collision physics towards motion physics. However, the addition of discussion questions, originally made to account for risk factor RF5, ensured that the intended coverage of collision physics was not lost. Another interesting surprise was the gap between performance perceived during the activity and from audio recordings, and the performance revealed by the content of the laboratory reports. For example, several groups made some fundamental mistakes regarding velocity and acceleration calculation. As the teacher, my impression was that these problems were handled during the activity, but some groups apparently went under the radar.

No pitfalls related to the use of smartphones could be identified. However, a teacher doing this kind of video analysis (where the answer differs between groups, since they all kick and film differently) should be capable of analysing student films in an efficient way. If not, doing proper evaluation of student work, and providing adequate feedback, may become overwhelmingly time consuming. This is a potential pitfall, setting certain requirement on teacher competence. Skills in high-level programming such as MatLab or Python is recommended. This is related to risk factor RF12. In principle, given that programming from 2018 will become compulsory, I would suggest that both teachers and students would learn how to handle images and videos using a high-level programming language like Python. In fact, this would be an excellent further development of this laboratory activity.
8 Discussion

Without a solid assessment of learning outcome (level 2 efficiency), it is of course questionable to jump to any conclusions regarding the value of smartphone activities. In addition, during a subsequent lesson, where I made some demonstrations using an air track, it became clear that practical activities have significant drawbacks when it comes to conceptual development. Despite the minimalistic nature of the smartphone lab, it did take quite some time (students are not that used to computer analysis). With air track demonstration and ordinary problem solving based on different topics (rockets, bullets, car crashes), one can cover a lot of examples and initiate good discussions of great value for conceptual understanding. I believe that Kirschner and Meester (1988) is on to something important when refers to the work of Kreitler and Kreitler (1974) and emphasise the following:

An experiment may provide a demonstration of a concept, but it is only one, single demonstration. Since concept formation requires exposure to a maximally wide range of instances, it follows that performing an experiment, which is costly in both the time and resources, can scarcely be considered an economical and efficient means of achieving concept formation (Kreitler & Kreitler, 1974)

In fact, Kreitler and Kreitler (1974), are very critical to the idea of experiments as a way towards concept formation:

Contrary to common educational practice and expectation, experiments do not facilitate the formation and acquisition of concepts. They may however be used, as they are in science, after the formation of the concept as deductions designed to demonstrate the idea’s possible manifestations. In this role, experiments may help not only in developing conceptual thinking and imagination, but also in fostering scientific practices in the classroom.

I guess this is, more or less, a valid argument against excessive use of open inquiry. I any case, these insights are well worth considering when trying to find a good balance between theoretical and practical activities. Conceptually, the students may have learnt more if recorded movies together, but I did demonstration style video analysis. But, the students are also supposed to develop skills in practical work, digital tools and data acquisition (Skolverket, 2017), so there is a trade-off between content of the Physics 1a course, and the aim of physics subject and the programmes in general. For reasons given in preceding sections of this thesis, I believe that video analysis based on smartphones may be a valuable approach in this balancing act: it will teach students to do physics on their own, with familiar, non-alienating equipment. In my opinion, it is a good way to use new technology to address what Hofstein and Kind (2012) call the biggest challenge for practical work:

The biggest challenge for practical work, historically and today, is to change the practice of ‘manipulating equipment not ideas’. The typical laboratory experience in school science is a hands-on but not a minds-on activity. This problem is related to teachers’ fear of loosing control and speed in the classroom and giving students more responsibility for their learning.

On the other hand, the instructional format may not be the most important aspect, and what suits one teacher may not suit another. As Hodson (1993) put it:

Much depends, also, on the teacher's enthusiasm, personal warmth and willingness to listen to the views of others. Indeed, many of the differences in learning outcomes between experimental and control groups can be attributed to such factors (Lederman, 1986). In short, as Miles and Deventer (1961) concluded, some thirty years ago, the teacher is often the major variable: “No one method of instruction, in and of itself, is better than others. Success is dependent on the instructor and what he (sic) does.”
Combination of 7 images, being 10 frames, apart from an iPhone 240 fps slow-motion movie


10 Appendix A – Video analysis lesson

This appendix describes the lesson on video analysis that preceded the student activity. This lesson follows after rather complete treatment of motion, forces and Newton’s laws as well as energy (corresponding to chapters 3-5 in Pålsgård, Kvist, and Nilson (2011), the textbook used in the course).

The first part of the lesson was a brief introduction to collisions (firmly linking it to Newton’s laws). The following content was discussed in whole class lecture, using a whiteboard (here translated into English):

![What happens during collisions?](image)

After that, high-speed photography was discussed as a way to study fast processes, deformations, collisions etc. The story of Muybridge’s work on trotting horses and the early days of fast photography is discussed, and some fascinating slow-motion movies are shown.

After this, the lesson starts to cover video analysis of a bouncing ball. A drawing of the following kind was made on the whiteboard to set the stage:
This is followed by showing the results of studying a bouncing ball with an iPhone recording at 240 frames per second (collision captured in three-four frames). The six images below are from a processed version of this movie, where ball positions have been marked each frame. It is noted that this video analysis is made using a high-level programming language (MatLab), an approach that the students cannot use.

Scale calibration using the known ball diameter (108 pixels = 0.18 m) is discussed (the ruler shown in video could not be read due to poor resolution, but was not needed) The free fall is investigated, and the excellent agreement with observed positions and theory is emphasised (see graph below). The ball is falling down on frames 61, 98 and 100, and bouncing up on frames 107, 109 and 170.
After this, the focus is on the collision, and the change in speed is calculated, the acceleration is estimated using the collision time estimate, and finally the average collision force is estimated using the law of impulses.
Appendix B – Lab instruction

The following laboratory instruction was distributed to the students:

Sparka fotboll – impuls i vardagen
Laborationshandledning

Laborationens syfte
Förutom att ni ska lära er vilken kraft det finns i era telefoner, och hur kraftfull videoanalys kan vara för att förstå händelseförlopp är tanken att laborationen ska ge er ett konkret möte med fysikens impulsbegrepp, nämligen vad som händer när en kraft verkar under en viss tid.

Hastighetsförändring och begreppet impuls är i speciellt fokus, men arbetsprocessen är minst lika central (få fram data från filminspelnings, hantera osäkerhet i mätvärden, systematisk undersökning, datorstött arbete). Kopplar vi det hela till Skolverkets beskrivning av ämnet fysik, så kommer vi (förutom att beröra centralt innehåll som rörelse, krafter, impuls och rörelsemängdsmoment) att omfatta följande omnämda aspekter (förmågor):

- använda datorstödd utrustning för insamling, simuleringsberäkning, bearbetning och presentation av data
- planera, genomföra, tolka och redovisa experiment och observationer samt förmåga att hantera material och utrustning

Laborationen kommer att föregås av ett exempel i videoanalys baserat på slow-motion-inspelnings av en studsande boll med hjälp av en smartphone, vilken ska tjäna som bas för efterföljande mer teoretiskt arbete med rörelsemängd.

Er uppgift
Er huvuduppgift är att ta uppskatta medelkraften som verkar på en boll under en spark. För att lösa detta kommer ni att behöva använda er av impulslagen, en omskrivning av Newtons andra lag. Under arbetet med detta kommer det att visa sig att ni behöver bestämma bollens acceleration och hastighet, samt den tid som bollen är utsatt för en kraft. För att göra detta ska ni spela in en film med hjälp av slow-motion-läget (högst antal bilder per sekund, nya telefonger kan ofta filma med upp till 240 bilder per sekund). Er rapport skall innehålla redogörelser för era uppskattningar av

- Bollens hastighet efter sparken
- Bollens acceleration under sparken
- Kollisionstiden, d.v.s. tiden under vilken fot och boll är i kontakt
- Medelkraft på bollen under sparken

samt en diskussion av

- Vilka energiomvandlingar som sker när man sparkar en boll
- Vilken kraft som verkar på foten under sparken
- Hur ni tror att kraften på bollen varierar under kollisionstiden

Instruktioner för arbetet
1. Spela in när en av er sparkar iväg en fotboll. Använd slow-motion-funktionen på era telefoner, inställd på så högt värde på bilder/sekundra som möjligt (på en iPhone ska ni använda er av 240 bilder per sekund, om er telefon inte tillåter över 200 bilder per sekund kommer analysen inte att bli särskilt bra tyvärr).
   - Försök sparka bollen rakt fram (inte i höjdled). Detta kommer att förenkla analysen
   - Filma sparken rakt från sidan
   - Se till att ni filmar på ett avstånd som gör att ni får med lite av bollens flykt (en längd på tre till fyra bolldiametrar utrymme bör räcka)
   - Kontrollera att filmen blivit bra

2. För över filmen till er dator. Se till att lär er stega fram bildruta för bildruta
   - Under Windows kan man göra detta genom att öppna filmen med applikationen Foton. Genom att högerklicka och välja “spara foton från denna video” kan man sedan stega sig fram i filmen, studera vad som händer och spara de bilder man vill ha till analys.
   - På Mac kan man stega sig fram i QuickTime, och få ut enstaka bilder via⌘+C och sedan i Preview-menyen välja File > New from Clipboard (och sedan spara). Man kan också göra sin analys i iMovie skulle jag tro.


4. Genomför analysen ni planerat i steget ovan.

5. Sammanfatta ert arbete i en rapport med förslagsvis nedanstående huvudrubriker (se till att ni behandlar alla frågor som nämnts ovan)
   - Inledning (kort beskrivning av experimentet, filmkamera, datorprogram ni använt under analysen och en översikt hur detta gått till)
   - Data erhållen från film (infoga stillbilder och beskriv kalibrering och avläsningar etc)
   - Uppskattning av medelkraft (beskriv använd teori, redogör för beräkningar)
   - Diskussionsfrågor (se lista med frågor ovan)

Lämna in rapport och er film till läraren (döp om filmen så ert namn framgår)

Arbetsform
Arbeta i par, rapportsskrivning i par eller enskilt efter överenskommelse.
Några frågor om bollsparks-laborationen

Vad uppfattar du att syftet med laborationen var?

Vad var bra med laborationen? Motivera!

Vad var dåligt med laborationen? Motivera!