HiSPARC IN ENGLAND

A PILOT STUDY INVESTIGATING THE STATUS OF THE HIGH-SCHOOL PROJECT ON ASTROPHYSICS RESEARCH WITH COSMICS IN BRISTOL AND THE VICINITY

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February 2014

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Abstract

Studies have highlighted an alarming decline in young people's interest for science studies and mathematics in Europe (OECD, 2006; Osborne et al. 2003; Krapp & Prezel 2011; Dinescu et al. 2011). Despite the growing enrolment rates in science and technology, the relative numbers among the overall student population have been decreasing.

The High School Project on Astrophysics Research with Cosmics (HiSPARC) is an example of a motivational approach for high-school students, with the aim of encouraging them to choose a scientific career. It is a Dutch astroparticle-physics experiment in which high-school students are included in real scientific research. HiSPARC's educational goals are to offer the intellectual and technical challenges of scientific research to high-school students, to update science teachers on modern developments and to develop new teaching material for high-schools (Van Eijk et al. 2004). The project expanded to England in the academic year 2012/2013. Now, eleven English high-schools are participating and this number is growing.

This thesis contains a pilot study investigating the status of the HiSPARC experiment in England. The first research questions is: W*hat have students, participating in HiSPARC in the academic year 2012/2013 learned?* The research question was answered by means of interviews with five students. It seems that most students are not able to explain what cosmic rays are. They do know that these particles come from space, but are not able to give specific sources. Also, most of the students cannot explain the technology used in the HiSPARC detectors in order to measure cosmic rays, and how one is able to deduce shower direction. Students have been working on their assignments without fully understanding the physical principles involved, meaning that most of them have been working at a superficial level which led to not keeping on to the acquired knowledge (Ebbens and Ettekoven, 2009).

The second research question of this thesis is: W*hy do students participate in HiSPARC?* This question was answered with the aid of a questionnaire. The majority of the students participate in HiSPARC because they experience the content as exciting. Students state that they like the fact that they are contributing to cutting-edge physics which is beyond the normal remit of science courses. Therefore, the second most important reasons to participate is because HiSPARC differentiates itself from other science courses. It challenges the students, and therefore, they think they will have an advantage over others when applying for university.

Why do teachers participate in HiSPARC? is the third research question. In order to answer this research question interviews with 5 teachers were conducted. Teachers state that

they participate in HiSPARC because they want to offer real science to high-school students. Being involved in cutting-edge physics projects is not only fun for the students but can also help them to get into good universities. Teachers think that the most important goals of HiSPARC are to engage students in astrophysics research, to network with other schools, and to partner with a leading university.

The last research question is: T*o what extent are the educational goals of HiSPARC reached?* The intellectual and technical challenges are being brought to high-school students participating in HiSPARC in England. The goals set by teachers are in agreement with this. Some teachers however, state that they lack the knowledge about cosmic rays which they need to fully support their students. Whether participation in HiSPARC stimulates pupils to choose for a career in science or technology cannot be concluded from this research.

Samenvatting (Dutch abstract)

Verschillende onderzoeken benadrukken een alarmerende afname in de interesse voor wetenschappelijke studies en wiskunde onder jongeren in Europa (OECD, 2006; Osborne et al. 2003; Krapp & Prezel 2011; Dinescu et al. 2011). Ondanks het groeiende aantal inschrijvingen bij wetenschappelijke en technologische opleidingen is het relatieve aantal inschrijvingen ten opzichte van de totale populatie afgenomen.

Het High School Project on Astrophysics Research with Cosmics (HiSPARC) is een voorbeeld van een motivatie programma om middelbare scholieren te stimuleren om te kiezen voor een wetenschappelijke carrière. Het is een Nederlands astrodeeltjesfysica experiment waarin middelbare scholieren betrokken worden bij wetenschappelijk onderzoek.

HiSPARC streeft ernaar om de intellectuele en technische uitdagingen die wetenschappelijk, onderzoek biedt, op middelbare scholen aan te dragen. Ook heeft het project als doel om docenten op de hoogte te houden van moderne ontwikkelingen. Verder ontwikkelt HiSPARC nieuw lesmateriaal om op middelbare scholen aan te bieden (Van Eijk et al. 2004). Het project is in het academische jaar 2012/2013 uitgebreid naar Engeland waar momenteel elf scholen deelnemen, maar dit aantal groeit nog steeds.

Dit rapport bevat een pilot studie die de status van HiSPARC in Engeland heeft onderzocht. De eerste onderzoeksvraag is: *Wat hebben leerlingen, die deelnamen aan HiSPARC in het academische jaar 2012/2013, geleerd.* De vraag is beantwoord doormiddel van een interview met vijf leerlingen. Het lijkt er op dat de meeste studenten niet in staat zijn om uit te leggen wat kosmische straling is. Ze weten dat deze deeltjes uit de ruimte komen, maar kunnen geen specifieke bronnen van kosmische straling noemen. Ook weten studenten niet welke technologieën in de HiSPARC detectoren worden gebruikt om kosmische straling te meten en hoe je de richting ervan kan reconstrueren. Omdat de leerlingen tijdens het werken aan de opdrachten niet goed wisten waar ze mee bezig waren zijn ze slechts oppervlakkig te werk gedaan en kon de stof niet beklijven (Ebben en Ettekoven, 2009).

De tweede onderzoeksvraag van dit rapport is: *waarom nemen leerlingen deel in HiSPARC?* Deze vraag is beantwoord met behulp van een vragenlijst. De meerderheid van de leerlingen die deelnemen aan HiSPARC doen dit omdat ze de inhoud spannend vinden. De leerlingen vinden het leuk om deel te nemen aan het project omdat ze op deze manier bezig zijn met geavanceerde natuurkunde wat verder gaat dan dat zij normaal tijdens wetenschappelijke vakken doen. Dit is dan ook de tweede reden voor leerlingen om deel te

nemen. Verder vinden de leerlingen het een uitdaging om deel te nemen en denken zij dat het ze gaat helpen om op een goede universiteit toe te worden gelaten.

Waarom doen leraren mee in het HiSPARC project? is de derde onderzoeksvraag. Vijf docenten werden geïnterviewd om deze vraag te beantwoorden. Leraren geven aan dat zij op hun school graag moderne wetenschap aan willen bieden. In dergelijke natuurkunde projecten betrokken te zijn is niet alleen leuk voor de leerlingen maar zal hen volgens de leraren ook helpen om op een goede universiteit toe te worden gelaten. De leraren denken dat het doel van HiSPARC is om leerlingen te betrekken bij astrofysica, om te netwerken met andere scholen en dit te verbinden met een vooraanstaande universiteit.

De laatste onderzoeksvraag is: *in hoeverre zijn de educatieve doelen van HiSPARC gehaald*. De intellectuele en technische uitdagingen worden op middelbare scholen en leerlingen aangeboden. De doelen die de leraren stellen voor HiSPARC komen hiermee overeen maar de meeste leraren geven wel aan dat zij niet genoeg weten over kosmische straling om hun leerlingen voldoende te ondersteunen. Of de deelname in HiSPARC leerlingen ook daadwerkelijk stimuleert om te kiezen voor een wetenschappelijke carrière kan niet worden geconcludeerd uit dit onderzoek.

Preface

This thesis is written within the framework of my Master in Science Education at the University of Twente. I performed this educational research under supervision of Dr J.J. Velthuis, Dr J. van der Veen and F. Binkhorst MSc during a twelve week internship at the University of Bristol.

A pilot study was conducted investigating the status of the HiSPARC experiment in England. During this study the knowledge students have gained by participating in the project was examined. Also, the motivation for high-school pupils to be involved in the project was measured. Furthermore teachers have been asked why they joined the HiSPARC collaboration and how they implemented HiSPARC in the curriculum. This thesis gives a number of recommendation in order to bring HiSPARC in England to the next level.

In chapter 1 the problem is introduced. In the second chapter the research questions are presented. Chapter 3 gives a brief introduction to the English education system. The theoretical framework which is used in this thesis is given in chapter 4. The methods designed to answer the research question are shown in the fifth chapter. The results are presented in chapter 6. The research questions are answered in the conclusion & discussion section in chapter 7. A list with recommendations for improving the HiSPARC project in England can be found in chapter 8. For those who want to know more about the physics involved in the HiSPARC experiment an introduction to cosmic rays and the HiSPARC experiment is included in appendix A.

Contents

Chapter 1: Introduction

This chapter illustrates the decline in young people's interest in studying science and mathematics which has been observed in Europe. It also describes the HiSPARC experiment, which is one of many projects aiming to stimulate pupils to pursue a scientific career. This is a Dutch astro-particle-physics experiment in which high-school students are included in real scientific research. The project expanded to England in the academic year 2012/2013. The goal of this thesis is to investigate the status of HiSPARC after being operational in England for one year.

1.1 Science interest decline

Studies have highlighted an alarming decline in young people's interest in studying science and mathematics in Europe (OECD, 2006; Osborne et al. 2003; Krapp & Prezel 2011; Dinescu et al. 2011). Despite the growing enrolment rates in science and technology studies, the relative numbers among the overall student population has been decreasing. The OECD states that for some disciplines, such as mathematics or physical sciences, particularly worrying trends have been observed.

It seems that student decisions about what to study and which career paths to take are primarily based upon their interest in a particular field, and on their perception of job prospects in that field (OECD, 2006). Accurate knowledge about professions and career prospects in science and technology are therefore very important. However, these are fraught with stereotypes and incomplete information. Positive contact with science and technology at an early age can have long-lasting impact.

Many factors influence students' attitudes, such as curricula, gender, teachers, cultural factors and other variables (Osborne et al. 2003). Negative experiences at school, such as uninteresting content and poor teaching, tend to have a very negative influence on young people's future choices. Osborne et al. (2011) and OECD (2006) state that gender is, next to the quality of teaching, also a crucial variable. The proportion of woman choosing to study science and technology courses still remains below 40% (OECD, 2006). The negative stereotypes should be eliminated, in order to increase the number of female students in science and technology courses and thus the overall number of students.

The problem can be solved by differentiating teaching according to each student's readiness and learning profile. This can lead to a significant improvement in learning physics, and implicitly to an increase in interest and motivation for the study of this subject (Dinescu et al. 2011).

Another approach to problem is given by the Beta[1]-mentality model (2011). This model divides pupils into four groups: Specific-Betas (31%), Career-Betas (28%), People-Orientated-Generalists (28%), and Non-Betas (13%). The Specific-Betas are most likely to already be intrinsically motivated to pursue a scientific career. The Career-Betas and People-Orientated-Generalists are pupils who can be stimulated to do so. Overall, 87% of all pupils can (potentially) be motivated to pursue a scientific career. Knowing which group a student belongs to can subsequently help a teacher to encourage them to choose a scientific career.

1.2 HiSPARC

The High School Project on Astrophysics Research with Cosmics (HiSPARC) is an astro-particle-physics experiment, and an example of an motivational approach for high-school students. High-schools can join the project, and receive a building kit to construct their own detector station. High-school students build their very own cosmic ray detector and learn more about cosmic rays. Through installing the detector and analysing the data, students can contribute to real scientific research.

The project started in 2003, when the Subatomic Physics Department of the University of Nijmegen started a network of cosmic ray detectors in the Netherlands ("About HiSPARC", 2014). It was called the "Nijmegen Area High School Array" (NAHSA). They placed one detector station on the roof of the university and asked high-schools in the vicinity to take part in the measurement of cosmic ray showers. In a short period of time, the network expanded very rapidly. A little later, it was decided to place more detectors at scientific institutes and schools in the vicinity. The name was changed to HiSPARC, and more schools participated. Now, there are multiple clusters with over 100 detector stations in the Netherlands. A few years ago, HiSPARC expanded abroad, with stations being installed (for example) in Denmark and the United Kingdom. For more information about the physics involved in the project see Appendix A.

[1] In the Netherlands, science is divided in three groups: Alpha, Bèta and Gamma sciences. Alpha, Bèta, and Gamma scientists study respectively: the products of human behaviour, the not-human nature, and human behaviour.

1.2.1 HiSPARC Goals

The HiSPARC experiment has goals of equal importance, as stated in the strategy plan written by Van Eijk et al. (2004):

1. To bring forward the intellectual and technical challenges offered by scientific research to high-school students. This to stimulate the choice for a career in science or technology and to let students with a humanities or social science profile get acquainted with the questions and methods of modern science.
2. To update science teachers on modern developments and to bring forward and develop new teaching material for high-schools. This to bridge the gap between the content and method of science teaching in high-schools on the one hand, and the nature and practice of modern scientific research in academic and industrial laboratories on the other.
3. To detect and measure cosmic particles of the highest energies. Neither the acceleration to these energies nor the transport through intergalactic space is well understood. Both are subject to scientific research. The primary energy as well as the primary direction of the cosmic particle can be determined taking the interaction with the atmosphere into account.

1.3 HiSPARC in England

In 2012, the first detector was deployed in England at the University of Bristol. Now, eleven English high-schools are participating, and this number is growing. Most of the participating high-schools are located in Bristol and the vicinity. The participating schools each have their own detector, and students have been analysing the data they have gathered.

HiSPARC is mainly responsible for the development of teaching material resources, software and hardware. These resources are shared with the University of Bristol, where the resources are translated and adapted for high-schools in the UK. The University of Bristol then distributes the material to participating high-schools. Students work on HiSPARC outside of school hours, and teacher can contact the University of Bristol for technical support. The students can contact other schools through their teacher in order to discuss their project results. This hierarchy is shown in Figure 1-1. HiSPARC in England is supervised by the Particle Physics department of the University of Bristol.

Most of the current teaching material has been translated, but is not yet ready for use by the high-schools. The implementation of teaching material is hindered by differences between the Dutch and British school systems. The curricula in both countries differ from each other and in fact the education systems in England, Wales, Scotland and Ireland also differ from each other. Furthermore, schools in the UK have a choice of curricula, with slight differences between them.

1.4 Problem

The goal of this thesis is to describe the current status of HiSPARC in England in a detailed way. During the transfer from the Netherlands to England, teaching material has been translated and adapted for use. Students have been working on HiSPARC and the number of participating schools is increasing. However, as HiSPARC in England is still in its initial phase, some aspects might need to be improved. This does not only include the teaching material, but also, for example, the place of HiSPARC in the curriculum; the way it is taught; teacher knowledge of astro-particle physics etc. It is hoped that by providing a detailed overview of HiSPARC's current status, insights will be gained and implemented in future research, and consequently an improvement will be made in the learning achieved by HiSPARC students.

In this case-study, the significant cultural differences between schools in England have been considered. First, there is a division between state (government funded) and private (free-charging) schools. Private schools, in general, have far more resources then state schools. Sometimes, due to nationwide shortage, state schools are forced to employ physics teachers, who do not hold a physics degree. Furthermore, some schools (both state and private) are single-sex, and there is a division between high-schools and sixth-form colleges.

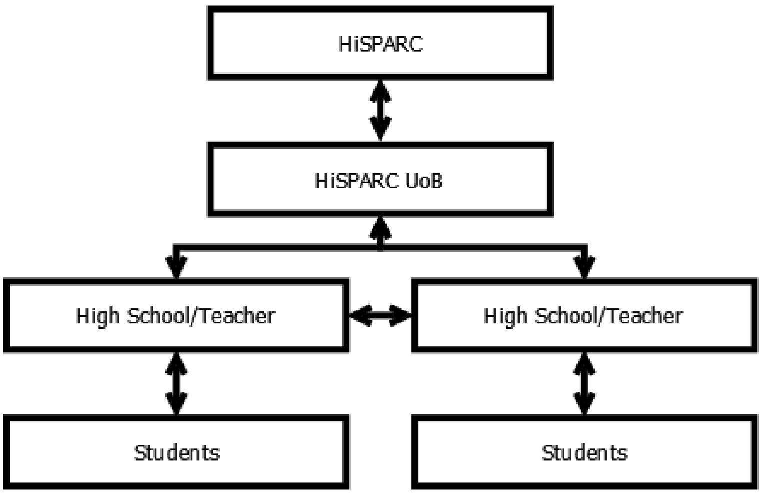

Figure 1-1 The HiSPARC hierarchy

Chapter 2: Research questions

The current status of HiSPARC can be evaluated in an illustrative case-study, which may lead to insights for future research. This study will include a pilot study to investigate what the involved students have learned from their participation so far and why these students chose to participate.

The success of HiSPARC in England is difficult to estimate, for several reasons. Firstly, HiSPARC in England is extra-curricular. Therefore, it is expected that only students with a positive attitude towards science are involved in the project. But, as the project is offered at different schools, students' attitudes might be different at each school. Also, students' attitude towards science might differ with gender or year.

The motivation to participate is an indication of what the students expect to gain through participation. If these expectations are not met, then this might lead to a negative experience which in turn will lead to a poorer attitude towards science (OECD, 2006). Therefore, it is necessary to investigate the factors which motivate students to participate in HiSPARC.

Also, at most schools in England, a lot of other extracurricular activities are offered. This means that HiSPARC has to compete with other projects. However, students are important for keeping the project running by, for example, maintaining the detectors. Therefore, besides the educational goals set by HiSPARC, it is important to motivate students to participate in the HiSPARC experiment in order to keep the project functioning.

The quality of teaching which students receive is of great importance in the development of a positive attitude towards science (Osborne et al. 2003). Therefore, it is necessary to investigate students' opinions about the available teaching resources and, and the method by which teachers implement HiSPARC at their school. Also, it is important to quantify teachers' knowledge of astrophysics, and the ability of teachers to answer students' questions. Investigating teachers' beliefs about how to engage students in the study of physics may give insight into teachers' reasons for choosing to participate in the HiSPARC experiment.

The educational goals formulated by Van Eijk et al. (2004) do not necessarily have to match the goals set by the university of Bristol, or high-school teachers. Some universities demand students' involvement in extra-curricular activities during high-school. Therefore, the goals within high-schools might change from 'stimulate students to pursue a scientific career' to 'stimulate students to pursue a scientific career at a good university'. The subtle difference being that only students with a positive attitude towards science learning will participate.

The educational goals of the HiSPARC experiment state that the project aims to stimulate students to choose a scientific career, and to bridge the gap between high-schools and universities. The project has only been recently implemented in England, and therefore may not yet be fully adapted to the intricacies of the English school system. However, measuring the extent in which the HiSPARC goals are met may prove useful when determining the next steps to take in developing the HiSPARC experiment in England.

The research questions which need to be answered in order to give an extensive description of the current status of HiSPARC in England are:

"What is the current status of HiSPARC in England?"

1. What have students learned, by participating in HiSPARC in the academic year 2012/2013?
    a. What do students know about cosmic rays?
    b. What do students know about the HiSPARC detector?
    c. What do students know about scientific research?
    d. Have students been in contact with students of other schools?
2. Why do students participate in HiSPARC?
    a. Is there a gender difference observed in the participating students?
    b. Is there a level difference observed in participating and non-participating students?
    c. Is there any difference observed between students' attitudes towards science with respect to gender, age, HiSPARC experience, school or type of school?
    d. What is the motivation for high-school students to participate in HiSPARC?
    e. What is the reason for students to participate according to teachers?
    f. How can (lower sixth) students be motivated to participate in HiSPARC?
3. Why do teachers participate in HiSPARC?

a. What are teachers´ beliefs about engaging students in subject of physics?
b. Why do teachers participate in HiSPARC?
c. How do teachers implement HiSPARC in the physics curriculum?

4. To what extent are the educational goals of HiSPARC reached?

Chapter 3: Education in England

Originally, HiSPARC was a Dutch project. The transfer from the Netherlands to England may be hindered by differences between the educational systems. This chapter gives a brief introduction to the English education system and secondary school in particular. First, some general information is given about the school year and the structure of primary school education. After that, secondary school education is discussed, followed by the common path to university.

Note that each of the countries in the United Kingdom has a separate education system. The Scottish government, the Welsh government and the Northern Irish Executive are responsible for Scotland, Wales and Northern Ireland respectively. The 'Department for Education' is the UK government department responsible for education in England.

The information in this chapter was acquired from "The Department for Education" (2013) and Steve Carruthers, a HiSPARC teacher at Bristol Grammar School.

3.1 General

Schooling is compulsory in England for all children between 5 and 16 years of age. Children enter school the September after their fourth birthday. However, many children from age two to four attend pre-school. In England, children are placed according to their age group and are not tested for placement by skill level or previous years of completed education. The school year runs from September to July, and is divided into three terms. The Autumn term runs from September to Christmas, the Spring term from January to Easter and the Summer term runs from April to July. Each term lasts approximately 12 weeks. A half-term holiday is given in the middle of each term. These holidays are usually held in October, February and May. Christmas and Easter holidays are normally two weeks long, and the summer holiday is normally six weeks long.

3.2 English Schools

At schools in England, the Head Teacher is responsible for the school. At a state school the Head Teacher is assisted by a governing body. This body is made up of parents, teachers and representatives from the local community. The school governors have responsibility for finance, curriculum, buildings, health and safety, and other areas. They are usually elected once every four years. Staff governors are elected by the school staff. Parent governors are elected by parents of children at the school.

Although there is no legislation specific to school uniforms, the vast majority of schools in England have a school uniform or dress code. The governing body can specify a uniform which pupils are required to wear. The Department for Education encourages schools to have a uniform, as they believe it can instil pride; support positive behaviour and discipline; encourage identity with, and support for, school ethos; ensure pupils of all races and backgrounds feel welcome; protect children from social pressures to dress in a particular way; and nurture cohesion and promote good relations between different groups of pupils ("The Department for Education", 2013).

3.3 Primary school

Primary schools are for children aged 4 to 11 years. Ages 4 to 7 are also referred to as Key Stage 1, and ages 7 to 11 as Key Stage 2. The subjects taught at primary schools are specified by the National Curriculum, which also sets out Standard Attainment Targets (SATs) to be reached. Pupils are tested on SATs at the end of each key stage in the compulsory core subjects of English, Mathematics and Science.

3.4 Secondary School

Between the ages of 11 and 16, children attend secondary school. 93% of English children attend state schools. The other 7% of children attend private schools (also called 'independent schools'). These are schools funded by fees paid by parents. Private schools are independent of many of the regulations that apply to state schools. A small group of UK private secondary schools are confusingly called 'public schools'. These are more expensive than other private schools, and are considered to be more prestigious and traditional. They were traditionally boys' boarding schools, but many are now co-educational, and most now accept day-pupils as well as boarders.

State secondary schools must follow the National Curriculum. Assessment of the children takes place at Key Stages 3 and 4. The General Certificate of Secondary Education

(GCSE) is the general examination for 16 year olds. Private schools do not have to follow the National Curriculum and meet Standard Attainment Targets, although most will follow the GCSE curriculum, as this is a nationally recognised set of qualifications.

Most pupils stay in school after the minimum leaving age of 16. Education for 16-18 years old is referred to as Sixth Form. The first year of the Sixth Form is called Lower Sixth, the second and final year is called the Upper Sixth. In the Lower Sixth, students study for AS (Advanced Subsidiary) Level exams, usually in four subjects. Most pupils drop one of their AS subjects at the end of the Lower Sixth, and then continue to study the other three subjects in the Upper Sixth. They then take ´A´ (Advanced) Level examinations in these three subjects. An AS Level qualification is worth half of a full ‘A’ Level qualification. This ‘A’ Level system is the usual route to university and college, depending on the grades attained in these examinations.

3.4.1 Specialisation

At the end of Year 9, students usually select around 10 subjects to study in more detail. Other subjects are dropped at this point. Some subjects are compulsory; for example English, Mathematics and Science. These subjects are studied in Years 10 and 11 and students are tested during their GCSE exams. Many Schools complete GCSE courses in two years, but pupils in some schools start working towards their GCSEs in Year 9 and take three years to complete their courses. Many GCSE courses involve course-work and most have at least one written exam at the end. Course-work is usually a project or essay which is marked at school, but which counts towards a candidate’s final GCSE mark.

After taking GCSEs, students may leave school. They can, for example, move on to a technical or training college, or seek employment. However, more academic students usually go on to Sixth Form for a further specialisation. Lower Sixth students usually study three or four subjects. In Upper Sixth they normally specialise in three subjects.

3.5 Applying for university

During the last year of their ‘A’ Levels, students can apply for placement at universities. Applications to UK universities courses are made through the Universities and Colleges Admissions Service (UCAS). Students apply for courses and then have to wait for universities to make them an offer.

These offers are commonly conditional, as students apply before they have taken their final examinations. Some universities set expected marks for students. Universities may also specify which subjects these grades are to be in.

At some universities, it is conventional that students are invited for an interview or audition. During these interviews, students may be asked to provide examples of their work such as a portfolio or an essay. Being involved in relevant extra-curricular activities enhances a student's likelihood of being accepted at a chosen university.

English Education System	Key Stage	School Year	Age	Testing
Primary	1	Reception	4-5	
		Year 1	5-6	
		Year 2	6-7	Key Stage 1 SATs
	2	Year 3	7-8	
		Year 4	8-9	
		Year 5	9-10	
		Year 6	10-11	Key Stage 2 SATs
Secondary	3	Year 7	11-12	
		Year 8	12-13	
		Year 9	13-14	Key Stage 3 SATs
	4	Year 10	14-15	
		Year 11	15-16	GCSEs
Sixth Form	Lower Sixth	Year 12	16-17	AS Level
	Upper Sixth	Year 13	17-18	A Level

Table 3-1 Stages in the English education system

Chapter 4: Theoretical framework

The first research question of this thesis is: What have students learned, by participating in HiSPARC in the academic year 2012/2013? In order to justify any conclusions regarding the answer to this question, one has to know how students learn. Ebbens and Ettekoven (2009) define a useful learning theory which is directly associated with how students learn, and is derived from Boekaerts and Simons (2003). This learning theory is described in the first paragraph of this chapter.

One of the sub-questions is how to motivate lower sixth students to participate in HiSPARC. At most of the participating schools, a wide range of extra-curricular activities are available to choose from. Therefore a lesson is needed to introduce these new students to the HiSPARC project. The ARCS model designed by Keller will be used to design motivational instructional material, and is described in the second paragraph.

In order to answer the question of why teachers decide to participate in HiSPARC, it can be useful to know why these teachers teach physics. Belo (2013) investigated teachers' belief about teaching physics, and how they think students can be engaged in learning physics. Understanding teachers' beliefs may show why they participate in HiSPARC and what they want to achieve through the collaboration.

4.1 How students learn

Ebbens and Ettekoven (2009) distinguish three different ways in which students learn that are important in the process of effective and active learning (Table 4-1). When developing HiSPARC teaching material, it is important to utilise all three ways in the teaching resources.

1. Learning focused on *control*. This form is about learning facts and concepts, learning to control skills and to understand facets and concepts. The learning activities aiming at *controlling knowledge* are 'remembering' and 'understanding'.
2. Learning focused on *keeping on to* what was learned. Students will retain newly learned knowledge when they link this to knowledge which they already possess. To

do this, students must first activate their prior knowledge. The learning activity aiming at *keeping on to*, is ‘integrating’.

3. Learning focused on *agility*. In this form, (creative) application of the acquired knowledge is important. The Students should be able to use this knew knowledge in absence of the teacher. The learning activity aiming at *agility* is ‘creative application’.

Learning form	**Learning activity**
Learning focused on *control*	To remember and to understand
Learning focused on *keeping on to*	Integrating
Learning focused on *agility*	Creative application

Table 4-1 Three forms of learning, four learning activities (Ebbens and Ettekoven, 2009)

All three forms of learning and the associated learning activities are equally important in the process of effective and active learning. When either of the three forms is not given enough attention, students’ learning will not be complete. They will either possess lots of knowledge but not understand how to apply it, or will be practically skilled but lack the wisdom, resulting in superficial actions.

The four learning activities are summarized and specified in Table 4-2.

Learning activity	**Specific activities**
Remembering	Listening, practising, reading, describing, appointing, telling, defining, …
Understanding	Exploring, discussing, translating, distinguishing, deriving, summarising, defending, …
Integrating	Comparing, planning, correlating, analysing, forecasting, judging, indicating, …
Creative application	Selecting, speculating, creating, designing, proving, evaluating, hypothesising, building, developing, arguing, …

Table 4-2 Four learning activities with specific student learning activities (Ebbens and Ettekoven, 2009)

4.2 The ARCS model

High-school pupils are an important part of the HiSPARC experiment. They keep the project going by, for example, maintaining the detector stations. In England however, there are many other extra-curricular activities in which pupils can be involved. In order to motivate students to participate in HiSPARC, the ARCS model will be used to design a motivational lesson to introduce students to the project.

In 1987, Keller designed a systematic design process to motivate a learner. The model defines four major conditions, Attention, Relevance, Confidence, and Satisfaction (ARCS), that have to be met for people to become and remain motivated. These conditions are defined below:

- *Attention* is the first condition. It is not only an element of motivation but also a prerequisite for learning. It is not enough to only gain a student's attention; sustaining it is equally important throughout the period of instruction. Following Keller (1987) the goal is to: 'find a balance between boredom and indifference versus hyperactivity and anxiety'.
- *Relevance* is important when answering the question: 'Why do I have to study this?'. Instruction can be made relevant by, for example presenting future career opportunities. But people also obtain a feeling of relevance when a course of instruction satisfies their the need for affiliation or achievement.
- *Confidence*, or expectancy to succeed, can influence a student's persistence and accomplishment. In order to generate or maintain motivation, one must foster the development of confidence despite there being some level of competitiveness and external control. The learner must form the impression that some level of success is possible if some effort is exerted.
- *Satisfaction* enables people to feel good about their accomplishments. People are, in general, more motivated to complete a task if the task and reward are defined. However, students may experience the defining of tasks and rewards as controlling, which may decrease their enjoyment. One must try not micro-manage a task, and to encourage the development of intrinsic satisfaction.

Design strategies are found in the tables given in Appendix B. Each category has its own strategies. When designing course materials these strategies must be considered.

4.3 Teachers' belief systems

Teachers are important in the learning process, and they influence the attitude of the students (Osborne et al. 2003). How HiSPARC teachers are trying to stimulate their students to learn the physics contents can be investigated by using Belo's thesis (2013).

Belo (2013) investigated teachers' beliefs systems about the goals and pedagogy of teaching and learning physics. Effective ways for making physics comprehensible and for motivating students to learn physics concepts were examined. Most beliefs expressed by teachers reflect two goals, namely 'learning and understanding conceptual physics' and 'learning and applying problem-solving and inquiry skills'. The practical implications being:

1. let students conduct inquiry and engage in hands-on activities,
2. let students solve challenging and carefully selected problems,
3. try to make (abstract) physics content come alive for students,
4. let students collaborate with peers, and
5. take the diversity of students and their personal characteristics into account.

Furthermore, teachers think that education should focus not only on the transmission of core subject knowledge and students' qualification for higher education, but also on learners' construction of knowledge, responsibility for their own learning processes, collaboration with peers, and the adoption of a critical attitude.

Also, with respect to teachers' beliefs about the regulation of students' learning processes, teachers hold similar beliefs about the importance of not only teacher-regulated learning of physics content, but also student-regulated learning and students' active knowledge construction.

But Belo (2013) also showed that teachers differ in their priorities concerning the goals of physics education, and the extent to which their beliefs about the pedagogy of teaching and learning physics reflect student-regulated learning. In addition, the relationship between beliefs about the nature of physics and science and beliefs about the goals and pedagogy of teaching and learning physics is not straightforward.

Chapter 5: Methodology

This chapter describes the methods used to answer the research questions formulated in Chapter 2. A student interview was designed to measure the knowledge acquired by students involved in HiSPARC during the academic year 2012/2013. A student questionnaire was designed to measure the attitude of students towards science and their motivation to participate in HiSPARC. In order to measure teachers' beliefs about science teaching, their motivation to collaborate in the HiSPARC experiment and to get an idea about the students' level of knowledge and understanding a teacher questionnaire was developed.

In Appendix G a table is shown, specifying which question are answered by the different methods.

5.1 Student interview

The goal of the student interview was to gain an overview of students' learning after one year of participation in HiSPARC (research question 1 and 4). All pupils involved (N=5) were Upper Sixth students at the time of this research. Convenience sampling was used to select the interviewees. The interview was divided into two parts: a knowledge test and a general section. The knowledge test measured the knowledge students had gained through their participation in the HiSPARC project; the general section was designed to understand what students did to acquire this knowledge and their opinion of the HiSPARC teaching resources. The interviews were conducted by the author and were recorded.

5.1.1 Knowledge test

The knowledge test was divided into three parts: cosmic rays, detection of cosmic rays and doing scientific research. Each subject contained four questions; all questions requiring a qualitative answer.

5.1.1.1 Questions

The cosmic-ray questions were designed to measure what the students know about this phenomenon. Answering these questions would show an understanding of what HiSPARC aims to measure and what typical energies these cosmic rays possess.

Knowledge about how HiSPARC measures cosmic rays was tested in the second set of questions. First, students were asked what happens to a cosmic-ray particle on entering the Earth's atmosphere. The concept of the shower created by a primary particle is important in understanding how the detector discriminates between a cosmic ray and background noise, and when understanding how particle direction can be deduced. The question about the principles employed by the HiSPARC detector was included to question understanding of the measurement of cosmic rays.

In order to check students' learning about how scientific research is conducted, four questions were designed. These questions were proposed as the most important, according to PhD students of the Particle Physics Department at the University of Bristol.

After each section the student was asked whether the knowledge they have just been describing was gained through participation in the HiSPARC project or not. The questions designed for the knowledge test of the student interview were:

Cosmic rays

1. What are cosmic rays?
2. Where do they come from?
3. How much energy do they possess?
4. How do they obtain their energy?

Measuring cosmic rays

1. What happens with cosmic rays when entering the Earth's atmosphere?
2. How can we know for sure if a hit measured by the station was caused by a cosmic ray?
3. What technologies are being used in the HiSPARC detectors?
4. How can one reproduce the cosmic-ray particle's direction?

Scientific research

1. What are the basic steps when doing scientific research?
2. Is it necessary to formulate a hypothesis before you start with your research?

3. How can you check whether the data you are using for your HiSPARC analyses are reliable?
4. Is it necessary to do the same research multiple times?

5.1.1.2 Scoring

Students' answers were judged by the author. For each answer 1 point could be scored. If the question could not be answered (sufficiently), a score of 0 points was given. The score was calculated from the ratio of points over total points. Scores were also be checked per subject.

An additional score was given based on the answer students gave to the question which asked whether the knowledge was acquired by participating in the HiSPARC project. Each correct answer was marked with a true or false value to obtain a ratio of correct answers gained by HiSPARC participation divided by the total amount of correct answers.

5.1.2 General questions

The general questions were subdivided into three parts: networking, supervision, and opinion. These questions were designed to gain an overview of students' activities while working on HiSPARC; whether they were supervised; and their opinion about the HiSPARC experiment.

The networking enquired as to whom the students had collaborated with while participating the project. The amount of time a student spends on a certain activity, the regularity and the quality of supervision influences the ability to retain newly acquired knowledge. Students were also asked for their opinion about HiSPARC. The students interviewed had been working on HiSPARC for one year. Their participation included several aspects, e.g. astro-particle physics, particle detection, building detectors, conducting scientific research, working in groups and programming. The interview can be found in Appendix C.

5.2 Student questionnaire

The student questionnaire was designed to measure the attitude toward science learning of students currently participating, and others willing to participate, in HiSPARC, and their motivation to participate (research question 2). The questionnaire was designed using the questionnaire developed by Tuan et al. (2005). This questionnaire contained six scales: self-efficacy, active learning strategies, science learning value, performance goal, achievement goal and learning environmental stimulation. Four of these scales were used in the HiSPARC questionnaire, namely: self-efficacy, science learning value, achievement goal and learning environmental stimulation.

The first three selected scales were used to measure students' attitudes towards science learning. A selection was made to shorten the questionnaire to a reasonable length, while retaining as much information as possible.

In the last scale, the environment was the HiSPARC experiment. Next to a selection of questions from the original questionnaire, some additional questions were added. This learning environmental stimulation scale is the part of the questionnaire which researches students' motivation and aims to measure why students are involved in HISPARC.

Two questionnaires were developed: one for students already participating in HiSPARC i.e. upper sixth students (N=19), and one questionnaire for students new to HiSPARC i.e. lower sixth students (N=42). Students were selected from a convenient sample. The questionnaires for upper sixth and lower sixth students can be found in respectively Appendix D and Appendix E.

The rating scale used was a 5-point Likert scale, as in the original questionnaire of Tuan et Al. (2005). The results of the questionnaire were used to investigate differences in students' attitude towards science learning, and their motivation for participating in HiSPARC in upper and lower sixth classes with respect to their gender, age, HiSPARC experience, school or type of school.

5.3 Teacher questionnaire

The teacher questionnaire was designed to answer research questions 2, 3 and 4. It investigated HiSPARC teachers' beliefs regarding making physics comprehensible for secondary school students, specific ways to motivate students, and teachers' reasons for taking part in the HiSPARC collaboration (N=5). It also provided an overview of the level of the students involved in the project. The teachers were selected from a convenient sample. All teachers were physics teachers at different schools.

The initial questions were about the background of the teacher. The questions about physics teaching were derived from Belo (2013). A selection was made in order to investigate the reasons that the teachers taught physics, and their beliefs about the most effective ways to motivate learners. The motivation for teachers to participate in the HiSPARC project was also investigated. Teachers were asked whether it was their choice to participate. Also, to check for any discrepancies in HiSPARC goals set by the different parties involved, teachers were asked what they thought the main goal of the project was. As different teachers may implement HiSPARC differently at their school, a question was included which asked teachers how they implement HiSPARC in the physics curriculum. Teachers may have had ideas about how to develop the HiSPARC project further, so questions were added in order to investigate what teachers would change and how they felt this could be accomplished.

Teachers were also asked to say something about the students who were involved in HiSPARC. Questions were asked about the number of students, gender, level, and the reasons for their participation. This added information to that gathered by the student questionnaire.

As each school is able to choose from a range of examining boards, teachers were asked which examining board had been chosen by their school. Most of the schools offer other extra-curricular activities, so teachers were asked to give a list of these activities in order to see what HiSPARC must 'compete' with.

The questionnaire was developed, tested, and improved with the cooperation of Bryan Murphy, physics teacher at the Bristol Cathedral Choir School. It is attached in Appendix F.

5.4 Observations

Observations were used in addition to the questionnaires and interviews to answer the research questions. These observation include the observation of four lessons at different schools, and also conversations with HiSPARC teachers, their colleagues, HiSPARC students, and students new to HiSPARC.

5.5 Motivational introduction lesson design

An introduction lesson to motivate lower sixth students was designed, which followed the ARCS model (Research question 2). It included a presentation and a practical assignment. It aimed to give lower sixth students an introduction to HiSPARC though a 'hands-on' activity. The systematic design process included in the ARCS model was used. It is separated into the following steps: define, design, develop and evaluate, as shown in Table 5-1.

DEFINE Classify the problem Analyse audience motivation Prepare motivational objectives	**DEVELOP** Prepare motivational elements Integrate with instruction
DESIGN Generate potential strategies Select strategies	**EVALUATE** Conduct developmental try-outs Assess motivational outcomes

Table 5-1 The motivational design model (Keller, 1987)

The presentation included an introduction to cosmic rays and HiSPARC, and was adjusted each time it was given, to account for time constrictions and group size. The practical task, included ‘hands-on’ work with a spark chamber and scintillator (a mini HiSPARC detector). Three versions were made, of which two were used. The objectives of the practical assignments were to calibrate the photomultiplier tube’s High Voltage, and to investigate the influence of the scintillator orientation on the number of particles measured. The lesson was evaluated and improved after each delivery. The calibration version of the designed practical assignment is given in Appendix H.

Chapter 6: Results

In this chapter the results of the student interview, student questionnaire and teacher questionnaire are presented.

6.1 Student interview

In total 5 Upper-Sixth students were interviewed (N=5) out of a total of about 50 students. Of the five interviewees, two are male, and three female. All students were involved in HiSPARC for one year during the academic year 2012/2013. Students were selected from a convenient sample. Students at School II and School IX were interviewed. Both schools are independent schools. These were the only schools where an interview was possible. Table 6-1 shows which students were interviewed.

Student	School	Age	Gender
A	School II	17	Male
B	School II	17	Male
C	School IX	17	Female
D	School IX	17	Female
E	School IX	17	Female

Table 6-1 Students were interviewed (N=5) to investigate their learning during their participation in HiSPARC.

6.1.1 Knowledge test

The results of the knowledge test are given in Table 6-2. Scores are relative scores; absolute scores can be found in Appendix J. Whether the knowledge was gained by students' participation in HiSPARC is given as percentage of total correct answers. Only one student was able to answer almost all the questions correctly. Students all indicated that when they were able to answer the cosmic ray and HiSPARC specific questions, this was due to their participation in the HiSPARC experiment. Student B noted that he already knew something about cosmic rays before he was involved.

Students scored more highly on the more general questions about scientific research. According to the students, knowledge about the process of scientific research was not gained through involvement in HiSPARC, but rather from other science classes (The exception to this was the question about how to check whether HiSPARC data is reliable). The question about how to check whether HiSPARC data is reliable was not generalised by any student. All students think that comparing data with data of other station is sufficient.

	Cosmic rays		Particle Detection		Scientific research	
Student	**Score [%]**	**Gained by HiSPARC [%]**	**Score [%]**	**Gained by HiSPARC [%]**	**Score [%]**	**Gained by HiSPARC [%]**
A	25	100	0	0	100	25
B	75	67	100	100	100	50
C	25	100	50	100	75	0
D	50	100	50	100	100	0
E	0	0	0	0	50	0

Table 6-2 Results of the knowledge test. Most students failed to answer the HiSPARC related questions.

6.1.2 General questions

The results of the general questions are divided into three parts: networking, supervision and opinion. The networking part gives a summary of students' answers to the question of whom they have been working with. In the supervision paragraph students' answers have been summarised to give a description of what students have been doing and whether they were supervised when working on HiSPARC. The opinion part gives an overview of the vision of students about HiSPARC.

6.1.2.1 Networking

The interviews were conducted at two schools. Students at both schools stated that they had been working in pairs. Students of School IX stated that they had contacted students at Schools II and IV, but had never cooperated with these students. Students of School II said that they were never able to contact other students.

6.1.2.2 Supervision

Students at School II had been working on HiSPARC once a week. One hour long sessions were scheduled every Wednesday. Students were supervised during this session. No final research reports had been produced yet, but this is still in progress. Students seemed to be content with the amount and quality of the supervision from their teacher, and the feedback which they had received.

Students at School IX were able to join a HiSPARC club and met once a week during lunch break on Wednesdays. Students worked on their assignments for 45 minutes. Students' opinions about the amount of time spent on HiSPARC varied. Two students said it was sufficient; another said she would probably spend more time on HiSPARC if possible. During the sessions there was at least one teacher available for supervision. Students at School IX were also content with the quality of supervision and feedback which they received from their teacher(s).

6.1.2.3 Opinion

The aspect of HiSPARC which students learned most about is summarised in Table 6-3. The students who indicated that they learned most about astrophysics from HiSPARC (Students B and D) are also the students who scored highest in the cosmic ray part of the knowledge test.

Student	The aspect of HiSPARC the student learned most about:
A	Working scientifically
B	Astrophysics
C	Data processing
D	Astrophysics
E	Building

Table 6-3 The aspects of HiSPARC which students learned most about.

The most enjoyable aspects of HiSPARC, according to the interviewed students, are depicted in Table 6-4. For three out of five students, the aspect which the students enjoyed most corresponds to the aspect which students learned the most about.

Student	The aspect of HiSPARC the student enjoyed most:
A	Processing data
B	Astrophysics, programming
C	Processing data
D	Building
E	Building

Table 6-4 The aspects of HiSPARC which students enjoyed most

The reason why students enjoy working on HiSPARC is given in Table 6-5. All students agree that it is interesting to work on HiSPARC although some students were more specific than others.

Student	Reason that working on HiSPARC is enjoyable
A	More scientific, more specific, contribute to real science
B	Interesting
C	Interesting
D	Interesting
E	Contribute to proper science

Table 6-5 Reasons for students to find working on HiSPARC enjoyable.

During the HiSPARC sessions, all interviewed students had been working through the Starting Assignments document (Appendix I), distributed by the University of Bristol. The students´ views on the level of the exercises are summarised in Table 6-6. Student B, the student scoring highest on the knowledge test, was the only one indicating that the exercises are too easy.

Student	Students' opinion about the level of the exercises
A	Challenging
B	Too easy
C	Challenging
D	Challenging
E	Challenging, (some are confusing)

Table 6-6 Students' opinions about the level of the exercises in the starting assignments.

The students also commented on the appearance of the material. The opinions given in Table 6-7 are all about the starting assignments. The booklet containing these assignments is the only one which the students have been working with.

Student	Students' opinion about the appearance of the teaching material
A	Standard, Ok
B	Ok
C	Ok
D	Ok
E	A little boring

Table 6-7 Students' opinion about the appearance of the teaching material.

Some students had a clear idea about what to change about HiSPARC. Their opinions are given in Table 6-8. Three out of five students want to include more theoretical work.

Student	What students would change about HiSPARC
A	More theory, more guidance through exercises
B	More science
C	More networking with schools abroad
D	More theory
E	Involve more people

Table 6-8 Students' vision about what to change about HiSPARC

6.2 Student questionnaire

The attitude and motivation questionnaire was filled out by lower sixth (N=42) and upper sixth (N=19) students. Most of the students were male (72%). The upper sixth students were involved in HiSPARC in the academic year 2012/2013, and were asked to fill out the questionnaires during HiSPARC visits, or by their teachers. The Lower Sixth students, willing to participate in HiSPARC, filled out the questionnaire directly after being introduced to the project. An overview of the number of respondents per variable is given in Table 6-9.

Variable	Categories	Frequency	Percent
Gender	Female	17	27.9
	Male	44	72.1
Age	16	24	39.3
	17	29	47.5
	18	5	8.2
	21	1	1.6
	28	1	1.6
	Unknown	1	1.6
HiSPARC experience	0 (lower sixth)	42	68.9
	1 (upper sixth)	19	31.1
School	School I	8	13.1
	School II	21	34.4
	School IV	3	4.9
	School V	5	8.2
	School VIII	14	23.0
	School IX	10	16.4
Type of school	Independent	31	50.8
	Comprehensive	11	18
	College	19	31.1

Table 6-9 Overview of data sample (N=61). Number of students are given per gender, age, experience, school and type of school.

6.2.1 Attitude

More than 70% of the students agreed or strongly agreed with the first 12 statements of the questionnaire (or disagreed or strongly disagreed in the inverse statements), indicating that students involved or getting involved in HiSPARC have a positive attitude towards science. Questions 12 and 13 were more often answered with ‘no opinion’. By comparing means and using a T-Test, no significant differences were found in attitude with respect to gender, age, experience, school or type of school. Means and standard deviations of the total attitude score are given in Table 6-10.

6.2.2 Motivation

The questionnaires included 11 reasons to participate in HiSPARC. The means and standard deviations for each statement are given in Table 6-11. Pupils seem to be involved because they think that the project is exciting and different from other science courses and they think it will get them into a good university. No students indicated that their participation was compulsory.

Total Attitude			
Variable	**Categories**	**Mean**	**St. Deviation**
Gender	Female Male	53.0 52.8	4.4 5.2
Age	16 17	52.0 53.3	5.1 4.9
HiSPARC experience	0 1	53.2 52.2	5.4 3.9
School	School I School II School IV School V School VIII School IX	54.1 52.4 49.7 56.2 51.4 54.4	4.4 4.8 2.5 2.4 6.4 4.2
Type of school	Independent Comprehensive College	53.0 52.9 52.9	4.6 4.4 6.0

Table 6-10 The mean of total attitude is shown per variable. No significant differences are observed in attitude with respect to gender or experience. The maximum score in total attitude is 65.

I am willing to participate in HiSPARC because…	Mean	St. Deviation
…the content is exciting	4,1	0.7
…it is different from other science courses	4,1	0.7
…it is challenging	3,9	0.7
…it will help me into a good university	3,8	0.8
…I will benefit from it in other science courses	3,7	0.9
…it is changeable	3,5	0.9
…it will help me to get a good job	3,3	0.8
…lectures are given by an external teacher	3,1	0.7
…the teachers pays attention to me	3,0	0.9
…my parents told me to	1,6	0.9
…it is compulsory at my school	1,2	0.5

Table 6-11 Mean score and deviation of the motivational questions of the student questionnaire. Recall that a five point Likert scale was used (1 to 5)

6.3 Teacher questionnaire

The teacher questionnaire was completed by five teachers (N=5). Ten participating HiSPARC teachers were asked to fill out the questionnaire. An overview of the participating teachers and their backgrounds and interests is given in Table 6-12. This table includes their experience, science degree and science teaching degree. Only male teachers filled out the questionnaire. Most teachers had not obtained an MSc or PhD in physics.

Teacher	School	Age	Teaching experience (years)	Science degree	Science education degree	Interests
A	I	52	33	Nature of Science	Unknown	Kinetic theory, waves, and associated maths. (not particle physics)
B	II	35	5	BSc Physics and Music	Postgraduate Certificate of Education	Stationary waves, resonance, and particle physics.
C	III	49	25	Electrical & electronics engineer	Physics Postgraduate Certificate of Education	Astro and particle physics
D	IV	31	3	MSc Mechanical Engineering	Science Postgraduate Certificate of Education	Mechanics of Materials
E	V	51	27	Electrical engineering	Maths and Science Postgraduate Certificate of Education	All

Table 6-12 An overview of the teachers that filled out the teacher questionnaire.

Teacher	What, for you as a teacher, are the fun parts of physics education? Please explain why.
A	The basic practical activities, and teaching the fundamentals.
B	I enjoying seeing children excited about learning, asking challenging questions and thinking deeply about the answers. I like giving them responsibility for their learning, for instance setting up and explaining how to perform an experiment, and then watching them enjoy learning from it.
C	I still get a kick out of how humans are able to make any sense at all of the universe.
D	Seeing the pupils talk about physics outside of the classroom, even if they just watch the Big Bang Theory they are still engaged with the subject
E	Practical work. The investigative approach.

Table 6-13 Teachers' answers to the question what they think that the fun parts of physics education are.

6.3.1 Physics teaching

The answers to the physics teaching questions of the questionnaires are presented per question. When teachers gave similar answers, these have been summarised. The given answers are presented in a table to give a clear overview.

When asking teachers what the fun parts of physics education are, the answers in Table 6-13 are given. Three teachers think that practical assignments or experiments are the fun part of physics teaching.

The image that most students have about physics according to these teachers is in general ‘difficult’. Teacher C however thinks that physics is ‘gradually becoming more cool’ and at School IV, a boys school, Teacher D thinks ‘the students are engaged with the subject very well’. He also mentions the strong maths department which supports the students as they study physics.

All teachers agree that students need to be motivated in order to learn science effectively. A-level students (upper sixth), however, are already motivated according to the teachers. The methods which teachers considered to be most effective in motivating students to learn content are given in Table 6-14.

Teacher	**What do you consider (effective) ways of motivating your students to learn the content? Please explain why.**
A	Making it relevant and match with pupils’ interests.
B	I put as much effort as possible into being a good teacher; by being enthusiastic, positive, clear, finding a variety of learning activities, marking work clearly, giving personalised comments on marked work, and spending time planning lessons well.
C	Finding bizarre, unusual or controversial contexts. Using technology.
D	Make it simple – they don’t always want to see Maltese crosses and vacuum tubes – they want to see everyday experiments with everyday stuff they can relate to
E	Engagement. Make the lessons interesting

Table 6-14 Effective ways to motivate students to learn physics content according to the teachers

Besides the importance of motivating pupils to learn science, teachers also think it is important to stimulate them to pursue a scientific career. Some teachers have other motivations to stimulate the pupils (see Table 6-15)

Also, teachers find it important to keep their pupils informed about science degree courses after secondary school. The means by which they do this differ, as can be seen in Table 6-16.

Teacher	Do you think it is important to motivate students to pursue a scientific career? Please explain why or why not?
A	Yes, because accountants are dull. The country is desperate for engineers and scientists. But the government isn't doing a lot about it.
B	Yes – I encourage them, especially if they show interest themselves. I might suggest it to pupils (particularly during Year 8 & 9, the most important years for choosing a career), and I might suggest or encourage pupils to take A-Level Physics – sometimes in front of their parents at parents' evening, or in their report. We have a STEM coordinator who does organise a tremendous amount of activities, trips, talks, competitions and events in school to encourage and enthuse pupils to engage in scientific pursuits.
C	It's important to motivate students for any career. We do need more scientists and we try hard to expose them to the opportunities and encourage this route as an option. They make their own decisions though of course.
D	Yes, because it is challenging and rewarding. It also gives them the best future opportunities in which ever career they choose
E	Yes, if they have the aptitude. We need able people to study hard things.

Table 6-15 Reasons to stimulate pupils to pursue a scientific career

Teacher	Do you inform your students about science degree courses after secondary school? Please explain why or why not.
A	Definitely. There are some Oxbridge material students. I try to match pupils to universities.
B	Yes, we have a great careers department which is highly equipped to advise and inform students about their options. We run extra support sessions for students interested in taking Physics and Engineering at Oxbridge / Russell Group Universities – to help them prepare for interviews, we order Physics journals (Physics Review) and we keep a selection of prospectuses in the department from Universities offering Physics & Engineering courses.
C	Yes, within the post 16 guidance curriculum.
D	I do – not just physics, but all technical subjects
E	Yes, constantly.

Table 6-16 Reasons to inform pupils about science degree courses after secondary school

6.3.2 HiSPARC and HiSPARC students

The answers to the HiSPARC related questions are given per school; this results in a clear overview of the status of HiSPARC at these schools. At all schools, HiSPARC is extra-curricular, and each school has more of these after-school activities. These activities are not described, as there are too many of them to do so, and at some schools this information is confidential.

HiSPARC at School I

Teacher A decided to participate in HiSPARC himself. He made the decision in order to show the pupils what real physics is like. The project is not launched yet, because the school has not yet obtained a detector. According to teacher A, the main goal of HiSPARC is "to make pupils go to their university interviews and blow the admission tutors away with their knowledge about cosmic rays, detection, data handling, presenting data and coming up with a conclusion. Which is cutting edge science and which it is way beyond what we normally do at school."

Teacher A has a plan to bring HiSPARC to the next level: Cooperate with, for example, the music department. Making HiSPARC interesting for non-physicists. Writing music about cosmic rays and make a movie about the building process.

The pupils that will be involved in HiSPARC are mostly A-level students. However, there are some very keen younger students who would like to be involved.

HiSPARC at School II

The Head of Physics and the STEM coordinator at School II decided to join the HiSPARC collaboration. Teacher B was made responsible when he joined the school. The main reasons for the school's participation are: "We thought it would be fun for our students. It also encourages them to learn about particle physics and cosmic rays, and shows them some practical examples of physics in action. And, it is a great thing to talk about when applying for university."

School II built their detectors in the academic year 2012/2013 and have implemented HiSPARC at their school as described by Teacher B: "We have built detectors, which was excellent as it gave students hands-on experience and ownership of the project. Now we run a weekly activity to discuss and analyse the data, working through the starting assignments booklet and then the students choose a project of their own to research. We have also attended the Bristol area conference and intend to do so again. Students have also built a weather station using a Raspberry Pi computer in computing club, and want to use that to record accurate pressure and temperature data.”

The goal according to Teacher B is: “To engage young people in an important area of scientific research, and also to add to current research about cosmic rays.”

School II would like to see a UK HiSPARC conference organised, and more regular visits from university staff members in order to answer questions that the teacher himself cannot answer. Teacher B remarked that students would like to visit the Particle Physics Group at the University of Bristol in order to see the research happening there. Furthermore, Teacher B asked for more training and information for staff: “as students are asking me questions that I’m not sure about! Some guidance on how to support different research projects / what the students should expect to find, e.g. would we expect to see more coincidences in day or night / in high or low pressure. What ‘professional’ cosmic ray experiments are currently taking place? Does our data match with theirs?”

In the academic year 2012/2013 there were 13 students involved in the project, which is 22% of the total amount of the students who studied physics in the lower sixth at School II during that year. About 40% of the total lower sixth students helped to build the detectors. In the academic year 2013/2014 16 pupils were involved; three of them are girls (19%).

HiSPARC at School III

At School III it was Teacher C who decided to join the HiSPARC experiment. He wanted to become a member to: ”offer-real world cutting-edge research for kids.” The detector was installed November 2013. School III is currently the only school to implement HiSPARC amongst younger pupils (years 10 and 11), so that the school gains a group of pupils who are already interested in HiSPARC by the time they joint the sixth form.

Teacher C would like more straightforward teaching material for students, which would combine theory and research projects. In the academic year 2012/2014, ten Year 11 students were participating, of a total number of 180. The participating students are all ‘higher ability’ (grade A/B) students according to Teacher C, but he is not sure of the reasons for their participation.

HiSPARC at School IV

Teacher D decided at School IV to participate in HiSPARC. He wanted to offer the students: “something a bit different, and real physics research”. The detectors were built in the academic year 2012/2013, but “the data tasks have not captured the students´ imaginations as much at the moment”.

The goal of HiSPARC according to Teacher D is: “to link schools together and link what we do in Bath with a cutting edge university.”

At School IV there have been some troubles financing the purchase of the detector and this is what Teacher D would like to change: “We were sold it as the IOP would be able to fund it more, but I have spent a lot of time applying for funding which has not always been successful. More central funding for the project would be very good.”

About 40% of A-level students have participated in HiSPARC in the academic year 2012/2013, of which 15% were girls. Though School IV is a boys´ school, they have a co-educational sixth form. The students who participated are “generally the brightest and most motivated students”. Teacher D would like to try and make HiSPARC part of the physics curriculum.

HiSPARC at School V

School V built their detector during the academic year 2012/2013. Teacher E is responsible for HiSPARC at School V, but was employed after the decision was made to participate in HiSPARC. He wants HiSPARC to be an extra stimulus for able students and thinks that main goal of HiSPARC is to engage younger people in cutting-edge science.

Teacher E would like to: “spread the geographical area and international collaborations between high schools and colleges so students can interact.”

About 15% of students at School V participated in HiSPARC, all of them are boys. The ability level of the students is, judged by Teacher E, high: “The students involved all think they may want to pursue physics at a higher level”.

6.4 Observations

At four schools, lessons were observed in sixth form classes. In total, nine schools were visited. The most important observations at each school, which are not covered in previously given results, are depicted in this paragraph.

HiSPARC at School IV

During the visit to School IV, no lower sixth students were present to be introduced to HiSPARC. Only three upper sixth students were present. Some ideas were given to the teacher, Teacher D, to introduce the students to HiSPARC by himself. No status update has been received on this process.

Due to time constraints, it was not possible to interview the three upper sixth students. Instead a conversation was held with all the students at the same time. During this conversation it was observed that the students were not able to explain what cosmic rays are, nor where they come from and how they acquire their energy. Also, students did not know what technology is used in the HiSPARC detectors. Students had built the detectors, and although some had started working through the Starting Assignments, they had not invested a lot of time or effort into this.

HiSPARC at School VI

School VI is an independent girls' school, and the teacher responsible for HiSPARC is Teacher F. School VI school was the first school in Bristol to obtain a HiSPARC detector. Teacher F decided to postpone continuation of HiSPARC until they upgraded their detector. There are plans to acquire a telescope and weather station. Therefore, the lower sixth students of the academic year 2013/2014 have not been introduced to HiSPARC yet.

It was not possible to interview upper sixth students involved in the project in the academic year 2012/2013. Teacher F states that students have been analysing data using the Starting Assignments, but he thinks that the material lacks statistics. Students are able to identify trends, but are not able to conclude whether the trends are significant are not.

HiSPARC at School VII

Lower Sixth students were introduced to HiSPARC during a visit to School VII. This is a high school which joined the project during the academic year 2013/2014, but as yet has not obtained a detector. Teacher G presented her ideas on how to implement HiSPARC into the normal curriculum. She developed teaching material for different subjects in which she included technologies used in the HiSPARC detector (for example showing a photomultiplier tube when explaining the photo-electric effect).

6.5 Motivational lesson

The presentation was given at seven different schools, and the practical assignment at three. At most of the schools the lesson was voluntary. At School VIII the lesson (presentation and practical assignment) was organised during a regular physics class. The number of students attending the sessions varied from 3 to 30. All students were lower sixth students. The success of the lesson differed from school to school. A great difference in students' background knowledge was observed. At the end of most of the lessons, students were asked to fill out the questionnaire if they were willing to participate in HiSPARC. All students filled out these questionnaires. At School VIII some students praised HiSPARC in their comments, but claimed to have not enough time to participate in the project.

Chapter 7: Conclusions & Discussion

In this chapter, the research questions will be answered in order to illustrate the current status of HiSPARC in England. The second paragraph of this chapter contains a discussion on the used method and the implications for the drawn conclusions.

7.1 Conclusions

What have students learned, by participating in HiSPARC in the academic year 2012/2013?

Four out of five interviewed upper sixth students were not able to explain what cosmic rays are. They know that the particles come from space, but the most common origin of cosmic rays given by the students was 'the Sun'. Also, most of the students do not know what technologies are used by HiSPARC detectors in order to measure cosmic rays, and how one is able to deduce shower direction. They do have knowledge of the basic steps of scientific research; know why it is necessary to formulate a hypothesis; and understand why it is important to repeat the same research multiple times. However, knowledge about scientific research is not gained by students' participation in HiSPARC, but by science classes. The conversation with other students confirmed that students who participated in HiSPARC in the academic year 2012/2013 have not learned much about cosmic rays or the detectors.

At all schools with a HiSPARC detector installed in the academic year 2012/2013, students had built the detectors and worked on the Starting Assignments for a maximum of one hour per week. (At some schools, students had only built the detector station and had not even worked through any of the Starting Assignments). Teaching material about the theory of cosmic rays does not seem to have been distributed amongst students. Without knowing what they were dealing with, students have been working on their assignments at a superficial level. Ebbens and Ettekoven (2010) state that there are three forms by which students learn (learning focused on control, keeping on to, and agility), and that these three forms are equally important in the process of effective and active learning. Currently, schools are not able to implement all these three forms, meaning that the work of the students is currently superficial.

Why do students participate in HiSPARC?

Students participating in HiSPARC are mostly male (72% of the students included in this research were male). All teachers thought that the participating students were of ‘high ability’. Also, all students had a positive attitude towards science learning. No significant difference was observed with respect to the type of school, year or gender. This indicates that only students who already have a positive attitude towards science decide to participate in HiSPARC. This is a trivial conclusion, as all students participating are sixth form students who have already independently decided to specialise in physics.

Considering that all students involved in HiSPARC have a positive attitude towards science, it is not surprising that students participate because they think the content is exciting. Students are given the opportunity to contribute to cutting-edge physics which is beyond what they normally do in science courses. Therefore, the second most important reason to participate is because HiSPARC is different from other science courses. It challenges the students, and by being involved in this challenging project, participating students gain an advantage over others when applying to good universities. Teachers think that students participate in HiSPARC because it is fun, they want to be involved in higher-level physics, and to gain experience which can be useful in admission interviews at universities. This is in agreement with students’ motivation to participate in HiSPARC.

A motivational lesson was created to encourage lower sixth students to participate in HiSPARC. Most of the students filled out the questionnaire directly after the session, showing that they were willing to participate in HiSPARC. However, at most schools the session was voluntary and therefore only students already willing to participate in HiSPARC were present. Only School VIII scheduled the HiSPARC session during a regular physics class. At School VIII, all students filled out the questionnaire, but many students stated in the comments that they would probably not participate because of other extra-curricular activities. Taking these comments into account, 14 students (60%) were willing to participate in HiSPARC after the introduction lesson.

Why do teachers participate in HiSPARC?

Teachers involved in this research stated that they find it important to motivate their students. They try to do this by making physics relevant, interesting, simple, finding controversial context, using technology, being enthusiastic, being clear, using different learning activities, and giving personalised comments. Some teachers gave very short answers to the questions posed, therefore one cannot conclude whether their ways of motivating students actually differ. It can be expected that teachers use a subset of the ways described above to motivate the students.

All teachers agreed that students need to be motivated to pursue a scientific career. The reason to motivate the students differs per teacher. Some specifically stated that there is a need for engineers and scientists, but others stated that it is important to motivate them irrespective of the students' career choices. Also, all teachers inform their students about science degree courses. Most teachers however, did not mention why and how they do this.

The teachers seem to differ in their beliefs about making physics comprehensible for secondary-school students, and specific ways to motivate students. The practical implications that resulted from Belo´s (2013) research seem to be partly included in the lessons of the participating teachers. They let their students conduct research, use hands-on activities, let them solve challenging problems, bring abstract physics to life, and let students work in groups.

Teachers participate in HiSPARC because they want to offer real science to high-school students. Being involved in cutting-edge physics projects is not only fun for the students, but can also help them to get into good universities. Teachers think that the most important goals of HiSPARC are to engage students in astrophysics research, network with other schools, and work with a leading university.

To what extend are the educational goals of HiSPARC reached?

Recalling educational goals of HiSPARC set by Van Eijk et al (2004), it can be concluded that the intellectual and technical challenges are currently being provided to students participating in HiSPARC in England. The goals set by teachers are in agreement with this. Some teachers however, state that they lack knowledge about cosmic rays which they need to fully support their students. A lack of knowledge might lead to negative experiences and hence negative attitudes towards the subject by students (Osborne et al. 2003). Teachers would like more training to solve this problem. The University of Bristol develops and distributes teaching resources to collaborating high schools. Whether participation in HiSPARC encourages students to pursue a career in science or technology cannot be concluded. Only sixth form students currently participate and they already possess positive attitudes towards science. Students with a humanities or social profile are not likely to choose to participate in HiSPARC and, at some schools, are even not allowed to participate. Other extra-curricular activities seem to be a more logical choice for these students.

7.2 Discussion

The student interview was designed to measure student knowledge about cosmic rays, the HiSPARC experiment, and scientific research. It also investigated the activities students have undertaken while working on HiSPARC, and sought their opinion on the supervision and the teaching material which they have received. The original aim was to interview a few students at each participating school, however due to time constraints this was not possible, and only five students were interviewed at two schools. Both of these schools were private schools, and therefore, the sample is not representative. However, observations by the researcher at other schools were in agreement with the results obtained from the interview. An interview seems to be the easiest way to measure the knowledge that students acquired through participating in HiSPARC. In an oral exam one can get a clear idea what students know. Also the contact with the students gives additional information. It would also be possible to create a written test, which may increase the sample size because the teachers would be able to administer the tests themselves, and it would no longer be necessary to visit schools to gather data.

The student questionnaire was designed to measure students' attitude towards science and their motivation to participate in the HiSPARC experiment. The questions were derived from Tuan et al. (2005). Though the attitude part was a shortened version (a subset of questions selected from the original), the questionnaire enabled the measurement of students´ attitudes towards science learning. However, the usefulness of the results is arguable. As all participating students are sixth form students already specialising in physics, it was to be expected that these students already had a positive attitude towards science learning. It might have been more useful to use the Bèta-mentality model to determine what kind of students are involved in HiSPARC. These results could have been used in the development of teaching material. The motivation part of the questionnaire covered 11 reasons for students to participate in HiSPARC. A few main reasons were clearly found.. There might, however, still be other reasons as to why students participate in HiSPARC which were not covered by the questionnaire. The questionnaire was filled out by 61 students, at six schools of different types, which is assumed to be slightly more than half of the total students involved, and also half of the collaborating schools making the sample representative.

The teacher questionnaire was developed to measure teachers' beliefs about engaging students in the study of physics, focusing on their beliefs about making physics comprehensible for secondary school students and specific ways to motivate students. At first, the questionnaire was designed as an interview using Belo (2013). However, due to time constraints it was changed to a questionnaire in order to be able to acquire a larger sample size. Five out of eleven contacted HiSPARC teachers filled out the questionnaire. Most of the teachers did not answer the questionnaire completely. This might be because of the structure of the questionnaire. Questions from the interview were directly copied to the questionnaire. Often teachers failed to answer the secondary questions (for example, teachers said that they found it important to stimulate students to pursue a scientific career, but failed to mention why).

This research was conducted at the beginning of the academic year 2013/2014. Students involved in HiSPARC had been working on the project for only one year. Eight schools were HiSPARC members in the Bristol cluster during this period. There are no records for students who participated in the academic year 2012/2013 and applied for university courses. This limited this study to only investigate upper sixth students with one year experience of the HiSPARC project and lower sixth students who were new to the project. Therefore, this study was not able to investigate whether students are stimulated to choose a career in science or technology through participating in HiSPARC. The same limitation prevented this study from investigating to which extent the gap between science teaching in high schools on the one hand, and practice of modern scientific research in academic on the other is bridged.

Chapter 8: Recommendations

One of the most important conclusions is that students involved in HiSPARC in the academic year 2012/2013, have not learned much about cosmic rays and the technologies used by the HiSPARC detectors. Pupils lack theoretical knowledge. A teaching module about cosmic rays is available, in which students can acquire more theoretical knowledge regarding the phenomenon, and can also learn how the HiSPARC detectors work. This module should be distributed amongst students. It is unknown why this module is not yet made available to students at most schools. The problem could be solved by creating one module for HiSPARC in England; for example, a textbook with an introduction to cosmic rays and HiSPARC and a workbook with exercises about the theory and practical assignments in which the students learn to use HiSPARC data. Such a module would lead to more guidance for students. At the beginning of the course, they would be able to acquire more theoretical knowledge, and by answering questions they would gain a better understanding of the particles which HiSPARC aims to measure. After the theoretical part of the course, students would start to download and analyse the data. This solution is rather traditional, but most of the material is already available and therefore it would be relatively easy to implement. There are, however, other possibilities to teach astro-particle physics to the students.

For example, HiSPARC pupils should also be able to learn from former pupils involved in the project. Publishing students' results on the HiSPARC website would give pupils the chance to review each other's work, and to learn from doing so. They could, for example, observe how a formal research paper is structured, learn the nature of research which former pupils have undertaken.

Another promising solution might be collaboration with the Astrophysics Department of the University of Bristol (HiSPARC is directed from the Particle Physics Department). If students of the University of Bristol gave lectures to high-school pupils, this would increase cooperation between high schools and the University. These classes could either be held at the University; at schools inviting pupils from other schools; or online. The latter option could prove popular, as pupils could watch instructional videos at their own pace, and would not have to travel to take part in short classes thus increasing course uptake. One of the reasons why these classes by University students might be useful is that some teachers state they lack the theoretical knowledge about cosmic rays and the methods to detect cosmic rays themselves in order to support their students sufficiently. As stated in the conclusions, this problem can lead to negative experiences by students and therefore must be solved. Most teachers do not have a Master degree in physics and therefore more training is necessary. However, due to time and resource constraints, it is difficult to organise a central training course for teachers. Teaching material for teachers should therefore be developed. Teacher training could also be organised in the same ways as the recommended solutions for students (online or offline classes by university students). Once teachers understand more about cosmic rays and the technologies used by HiSPARC detectors, they would also be able to use their knowledge in the normal physics curriculum. In this way, students could learn more about astrophysics and HiSPARC before starting the sixth form.

In order to keep HiSPARC running in England (and the rest of the United Kingdom), students need to be motivated each year to participate in the project. As there are many extra-curricular activities available at most schools, HiSPARC must continue to offer 'something extra'. At some schools, in Bristol and the vicinity, teachers are taking care of the problem themselves. At other schools, the University of Bristol is responsible for the motivation of lower sixth pupils. However, as the number of participating schools increases, the University will not be able to cover all schools. Therefore it is important that teachers receive training enabling them to introduce HiSPARC to their students themselves.

The effectiveness of the motivational lesson (presentation and practical assignments), which is designed to introduce lower sixth students to HiSPARC, has not been tested. Though students seemed to enjoy the lesson, it is not known how many of these students actually went on to participate in the project. The students willing to participate did fill out the questionnaire, and therefore one could check how many of these students actually decided to get involved in the project, during the academic year 2014/2015.

It would be interesting to use the Bèta-mentality model for future research. Identifying which group HiSPARC students fit best into might lead to insights into how to improve the introduction lesson, and other teaching materials. At this point, the Specific-Beta students are most likely to be participating in HiSPARC. The Career-Betas also might be participating because their involvement might lead to admission at a good university. The People-

Orientated-Generalists (28%) are probably not participating but, do have the potential to pursue a scientific career.

Students who started to participate in HiSPARC during the academic year 2012/2013 will start applying for universities in 2014. It would be interesting to know whether these students mentioned HiSPARC in their admissions interviews, and if they did so, how the admissions tutor reacted. A few students from each participating school will probably mention HiSPARC on their Curriculum Vitae. In the academic year 2014/2015, the first HiSPARC students will begin their university courses. It would be useful to create a HiSPARC alumni network. In this way, students could be contacted in order to investigate one of the important goals of HiSPARC: bridging the gap between the content and method of science teaching in high schools on the one hand, and the nature and practice of modern scientific research in academic and industrial laboratories on the other.

Reflection

The purpose of this reflection is to look back at this thesis and analyse what the implication of the results are and also what parts went well and which parts went less good. Reflection will be executed regarding the STARR method.

Situation

In the framework of my Master in Science Education I conducted an educational research study. The study was executed during a 12 week long internship in Bristol, United Kingdom starting in September 3rd 2014. One supervisor was responsible for the internship at the University of Bristol. The other two were responsible for the produced thesis.

Task

As a result of the transfer of HiSPARC to England, I was accepted as an intern at the University of Bristol to improve and develop teaching material and to introduce Lower Sixth students to the HiSPARC experiment. I planned to design a lesson for Lower Sixth students they would enjoy and in which they were able to participate. This HiSPARC session was supposed to be offered at as many schools as possible (around 11 schools). By visiting different schools I wanted to 'discover' the English education systems and the cultural differences between schools in England en the Netherlands.

During my internship I had the possibility to conduct my educational research which focussed on the status of HiSPARC in England. I tried to investige what students have learned by participating in project for one year and why they participated. Also I wanted to know why teachers are participating in the project and whether the goals are reached. Describing the status of HiSPARC in a thesis would lead to insights for future research to bring HiSPARC in England to the next level.

Action

In order to improve the teaching material I first interviewed a teacher to determine what parts of the material needed to be improved. In the Starting Assignments the step between two chapters was not straight forward enough. An additional chapter was added to guide the students in the step from closed to open research assignments. Teachers appreciated the improvement, but no real feedback has been returned.

A motivational HiSPARC session was created for Lower Sixth students which consisted of a presentation to introduce the students to cosmic rays and the experiment and a ‘hands-on’ activity with a spark chamber and an extra scintillator counter. The idea of using the spark chamber during HiSPARC sessions was not only appreciated by the University of Bristol supervisor but also by teachers.

For my thesis I wrote a research proposal. The main goal of the research was to investigate the status of HiSPARC in England. The research questions were:

- What have students, participating in HiSPARC in the academic year 2012/2013, learned?
- Why do students participate in HiSPARC?
- Why do teachers participate in HiSPARC?
- To what extend are the educational goals of HiSPARC reached?

The proposed methods to measure this were student interviews and questionnaires as well as a teacher questionnaire. The methods were designed using relevant literature. I believe that my research proposal was accepted by my supervisors. Though the original proposal was changed several times after receiving feedback, my supervisors accepted the proposal. Their input was crucial in defining the problem and setting up the pilot study as it was performed.

Results

The improved teaching material has not been tested yet and no feedback has been received from teachers. Therefore, it is not known if the changes have resulted in a better guidance of students through the exercises.

The complete motivational session was only conducted at four schools. Making appointments with teachers was problematic and at most school only limited time (<1 hour) was available for an introduction to HiSPARC. At five schools a presentation was given lacking the participation of the students. Most of the students that attended the session however, were very enthusiastic. It is expected that this is due to the voluntary nature of the session at the schools except for one. Teacher all thought that the lesson was inspiring, not only for the students but also for themselves.

The most important results of the pilot study, presented in this thesis are that students participate in the project because the content is exiting, but that they have not learned much about cosmic rays and HiSPARC after one year of participation. Another important outcome is that teachers state that they lack the knowledge to sufficiently support their students.

Reflection

During the whole process I worked hard to achieve a good result. In particular in the beginning I did my best to improve the teaching material and design the motivational session to visit schools as soon as possible. Unfortunately, I did not receive any feedback from teachers to the changes I made regarding the teaching material. Therefore I do not know if the changes were as useful as I intended them to be.

The motivational session was a great success at schools were this lesson could be performed in one long or two shorter sessions. Though the material had to be adjusted after each session, I was really pleased with how students elaborated on it. Students were really enthusiastic and from one student I even received a thank you note by email. Difficult during the sessions was to assess the level of the students which was different at each school. This taught me to adjust my talk to the students. It made me improvise by skipping or extend certain parts of the presentation. Each time I evaluated the lesson and improved or adjusted it for a next session. These skills will be useful in the future to anticipate to what extend the group really understands what they are dealing with.

During the research I regularly checked with my supervisors for feedback, but worked individually most of the time. This led to a research that was conducted by myself but was improved using the feedback of my supervisors and other specialists. The results of the pilot study are not very positive for the project. But I am very happy with the outcome as it has led to some recommendations which will bring HiSPARC to the next level.

The conclusion that the HiSPARC students have a positive attitude towards science is rather trivial. I would have used another questionnaire for students if I was to conduct the same research again and linking this for example with the Bèta-mentality model.

The internship at the University of Bristol and conducting research for HiSPARC have improved my research competences which will be useful in the future for solving problems in a structured way. I have learned how to formulate specific research questions and how to design a method to answers these research questions. The internship, above all, really improved my English.

Acknowledgements

My internship Bristol was a great success and I would like to thank all people that have made this time so great. A few people I would like to thank in particular. First I want to thank Jaap Velthuis for giving me the opportunity to do my internship for HiSPARC at the University of Bristol. Secondly I would like to thank Merlin Fisher-Levine for letting a ‘complete’ stranger living in his house. Furthermore I want to thank Steve Carruthers for helping me to write the chapter about the English education system and checking my thesis for grammar mistakes. I also want to thank Bryan Murphy, Paul Foster, Kevin Daws and Paul Stillwood for their contributions to this thesis. I want to thank Jan van der Veen en Floor Binkhorst for their feedback on my thesis. Though the number of meetings during my research were limited and brief, you really helped improving the quality of my thesis. Last, but not least, I want to thank Sarah Janus for her help setting up my research and reading my thesis multiple times, giving feedback, tips, and her support in the process.

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Appendix A HiSPARC physics

This appendix gives a brief introduction to the physics involved in the HiSPARC experiment. It discusses the discovery, composition and the origin of cosmic rays particles. The technologies used in the HiSPARC detector, such as scintillators and photomultiplier tubes are discussed, along with a technique to deduce particle direction.

A.1 Cosmic rays

In the late nineteenth century, a series of important discoveries were made which led to the particle physics aspect of astronomy. X-rays were discovered by Röntgen in 1895; later radioactivity was discovered by Becquerel in 1896 and by Pierre and Marie Curie 1898. In the meantime, the discovery of the electron was made by Thomson in 1897. At the time it was assumed that radioactivity came from within the Earth’s crust, as discovered by Becquerel. But in 1909, the German physicist Wulf measured a reduced intensity of radioactivity with decreasing altitude inside a cave in Valkenburg. He suggested that the radiation might come from above. In 1910, Wulf repeated the same measurements on the Eiffel tower, expecting the radiation to increase with increasing altitude. However, Wulf measured a reduced intensity at the top of the Eiffel tower. Hess repeated this experiment in a balloon in 1911. These measurements, conducted at a height of 5 km, showed that there should be a source of ionizing radiation which becomes stronger with increasing altitude. In 1925, it was Millikan who first proposed the term ‘cosmic rays’. Once the Geiger-Müller counter was developed in 1928, the particle nature of cosmic rays was established by Bothe & Kolhörster, in 1929.

Cosmic rays mainly consist of protons ($\approx 85\%$), followed by α particles ($\approx 12\%$). Elements with a nuclear charge $Z \geq 3$ represent only a 3% proportion of charged primary cosmic rays (Grupen, 2005). Their energies vary from less than 10^9 eV to 10^{20} eV per nucleon. The relative abundance of elements in both cosmic rays, and the solar system are shown in Figure A-1. The light elements, lithium, beryllium and boron are much more abundant in cosmic rays, due to the splitting of nuclei when interacting with the interstellar medium. The abundance of cosmic rays depends on the energy (Kampert et al. 2012). Therefore, Figure A-1 will change with energy.

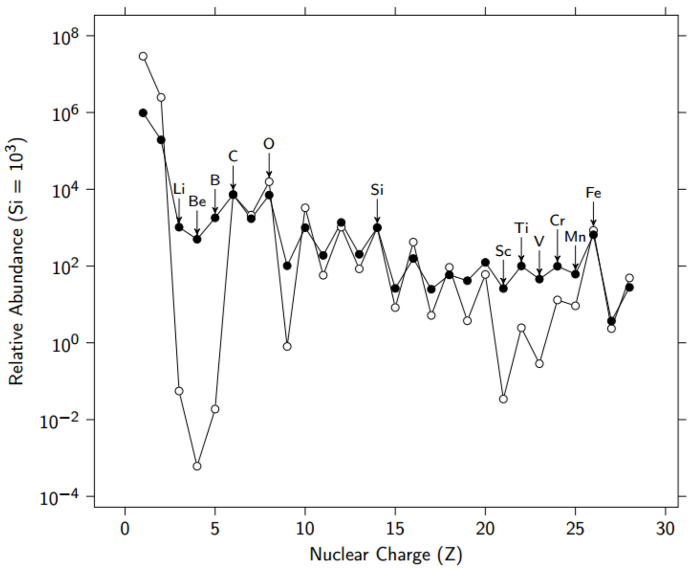

Figure A-1 Relative abundances of elements in the Solar System (open circles) and cosmic rays (closed circles). The relative abundances are normalized, with the abundance of silicon (Si) set to 1000 (Fokkema, 2012)

A.1.1 Origin

One nearby source of cosmic rays is the sun. Protons can be accelerated in time-depended magnetic fields which appear as sunspots. These particles can reach energies in the GeV range (Grupen, 2005). As can be seen in Figure A-2, these energies account for only a small amount of the total energy range in which cosmic rays are observed.

The highest-energy cosmic rays possess macroscopic energies, and their origins are likely to be associated with the most energetic processes in the Universe: supernova explosions, magnetic gas clouds or highly magnetised spinning neutron stars, such as pulsars, accreting black holes, and the centres of active galactic nuclei (Grupen, 2005). The galactic magnetic field, however, deflects cosmic ray particles at energies below 10^{14} eV, such that the direction of arrival is not correlated with the direction of the source, and thus appears highly isotropic. At energies above 10^{19} eV, however, the direction of arrival should be in correlation with the direction of the source. Nevertheless, no significant correlation with the galactic plane has (yet) been found (Abreu et al. 2013), which could be proof of extra-galactic sources.

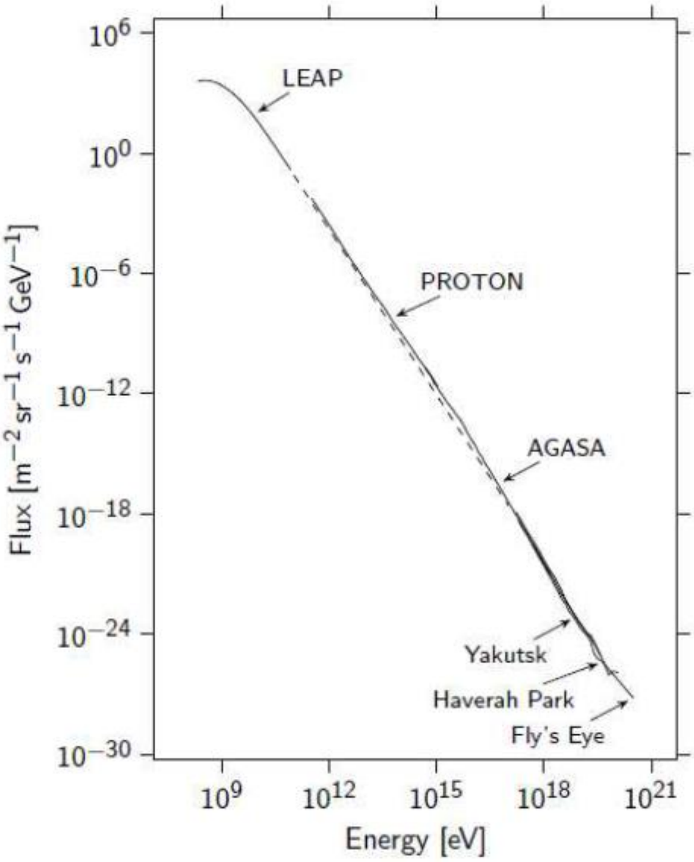

Figure A-2 Cosmic-ray flux (Fokkema, 2012)

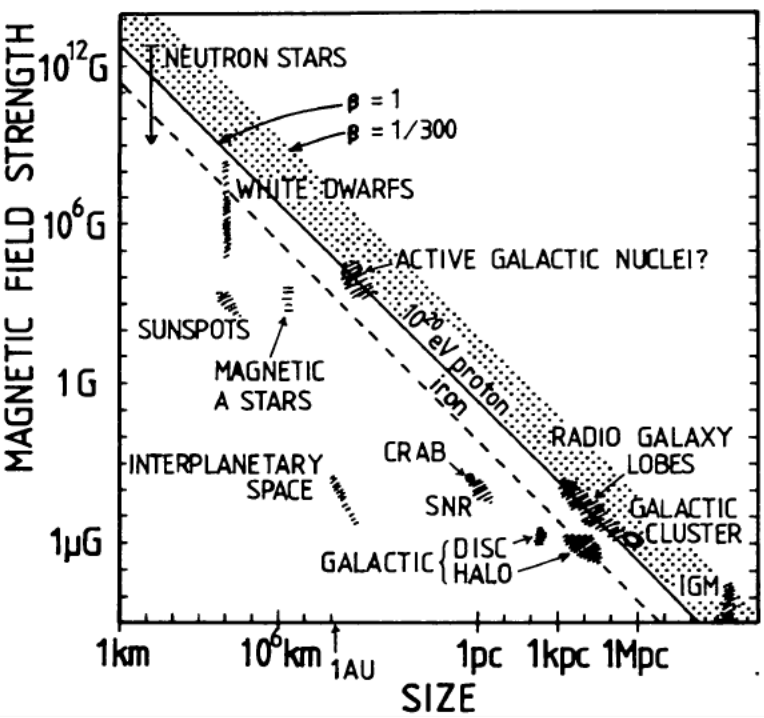

Figure A-3 Hillas plot. Size and magnetic field strength of possible sites of particle acceleration. An object below the diagonal line cannot accelerate protons (Hillas, 1984).

Hillas (1984) tried to identify the sources of cosmic rays by studying various acceleration mechanisms. All of these mechanisms need strong magnetic fields and large sizes, in order for particles to acquire large energies. These sizes should be larger than the Larmor radius for charged particles to acquire these large energies. The Larmor radius (also known as the Gyroradius) is the radius in which charged particles with mass m, velocity v and atomic number Z rotate within a magnetic field B.

$$r_{Larmor} = \frac{mv}{ZeB}$$ **Equation A.1**

In the case of relativistic particles, $m = \gamma m_0$; where m_0 is the rest mass of the particle and γ is the Lorentz factor. Furthermore $v \approx c$ and the Larmor radius becomes:

$$r_{Larmor} = \frac{\gamma m_0 c}{ZeB}$$ **Equation A.2**

From the Hillas plot in Figure A-3 one can see that when the size of a source is large enough, a relatively small magnetic field is sufficient to accelerate charged particles. More information about the acceleration process can be found in Grupen (2004).

A.2 Cosmic rays in the atmosphere

Cosmic rays traveling toward Earth will travel through the atmosphere. The column density of the atmosphere is much denser than that of the interstellar matter. The mean free path of the particles is significantly shortened and cosmic rays will undergo interaction with particles inside the atmosphere. The first interaction of primary cosmic rays with the atmosphere is at a height of about 15 km to 20 km (Fokkema, 2012).

Photons, for example, lose energy through Compton scattering and pair production. Charged particles lose most of their energy through ionization losses, Bremsstrahlung and Rutherford scattering. In addition, they lose a small amount of energy due to synchrotron radiation and Cherenkov radiation. At high energies, hadronic processes can take place, such as nuclear fragmentation, resonance creation and multi-particle creation.

All of these processes will lead to the creation of secondary particles initiating an avalanche. Each of these secondary particles can undergo the same processes creating tertiary particles and so on. The totality of secondary particles is called a cascade. If a large number of secondary particles is able to reach ground level, the cascade is called an extensive air shower which can have a footprint of several km^2 (Fokkema, 2012).

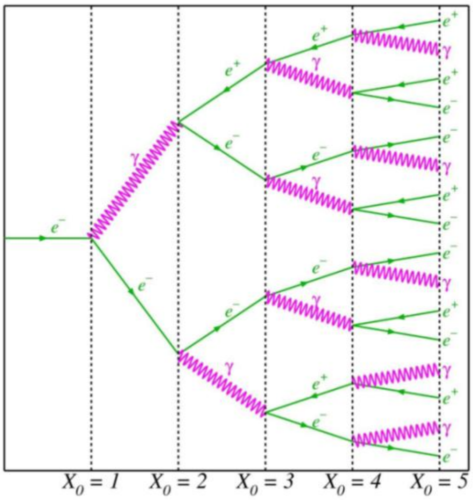

Figure A-4 An electromagnetic cascade. An incoming electron produces Bremsstrahlung after about one radiation length. Pair production occurs when a photon traverses about one radiation length inside the atmosphere.

An example of an electromagnetic cascade is depicted in Figure A-4. Here the primary particle is an electron, which interacts with the electromagnetic field of atomic nuclei. The electron loses energy by radiating a photon (Bremsstrahlung). When the emitted photon has enough energy, it can create an electron-positron pair once within the vicinity of a nucleus. The electron and positron then undergo Bremsstrahlung and this process continues, up to the point where the photon energy is too low to produce an electron positron pair ($E = 2m_e$).

Hadronic cascades are initiated by cosmic-ray nuclei interacting with nuclei inside the atmosphere. These interactions mainly result in the creation of a resonance decaying either into a nucleon and a pion or kaon. Charged pions decay mainly into muons, electrons and neutrinos whereas neutral pions decay into photons. Kaons have many decay modes but mainly decay into pions, muons, electrons and neutrinos. The photons and electrons created can again initiate electromagnetic cascades.

The two types of cascade both develop in different ways. The development of the hadron cascade is much more stochastic than that of the electromagnetic cascade. Also, the hadrons produced in the hadronic processes travel in almost the same direction as the parent nucleus. The shower in its totality, however, can be assumed to be conical (Fokkema, 2012). The front of the shower propagates with the velocity of light, c.

A.3 The HiSPARC detector

The HiSPARC experiment is designed to detect air showers and deduce shower direction and energy (Fokkema, 2012). HiSPARC is a high school experiment, and therefore low-cost technologies are preferred. The HiSPARC detector utilizes plastic scintillators. These scintillators are cheap and are fairly easy to maintain but are also highly efficient. By combining the scintillator with a photomultiplier tube, one is able to convert the energy deposited by the ionising particles into an electrical signal.

The combination of multiple detectors (two or four) is called a station. Stations are placed at high schools in the vicinity of scientific institutions. All the stations together are called a cluster. In the Netherlands seven clusters are active. The technologies used by HiSPARC detectors to detect cosmic rays are briefly discussed in the next paragraphs.

A.3.1 Plastic scintillator

The scintillators used in the HiSPARC detector are plastic scintillators which are solutions of organic scintillators (the fluors) in a solid plastic solvent (the base) (Fokkema, 2012). Ionizing particles traversing the scintillator cause luminescence via ionization and excitation. Deexcitation of the molecules occurs by emitting photons (scintillation light). The base is not transparent to its own scintillation light. The emitted photons excite the fluors, which in turn emit scintillation light. The base is transparent for the scintillation light emitted by the fluors. The scintillator is wrapped in aluminium foil and pond liner to maximize the light yield.

A.3.2 Photomultiplier tube

The photons traverse the plastic scintillator and are subsequently collected by a photomultiplier tube. Here, photo-electrons are created at the cathode through the photo-electric effect. These electrons are accelerated and focused on a series of dynodes, placed under a high voltage. Each primary electron hitting a dynode can release multiple secondary electrons. A photomultiplier tube has multiple multiplying stages, resulting in measurable electrical pulse.

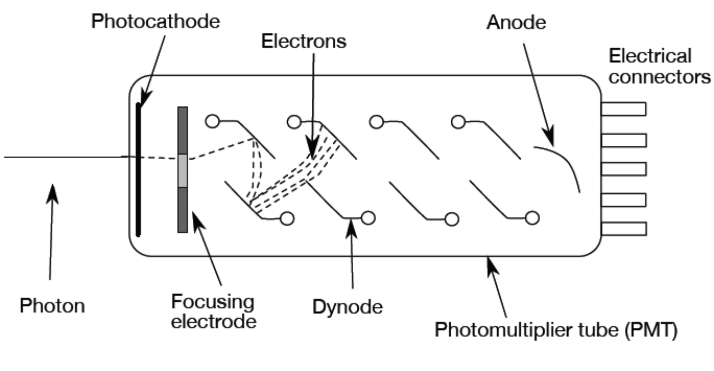

Figure A-5 Schematic diagram of a photomultiplier tube.

A.3.3 Shower detection

Using more than one detector in a station allows the system to be triggered only by coincidences between two detectors. In this way, one can be sure that the detection was caused by a cosmic-ray shower and is not by background radiation or photomultiplier fluctuations. The detectors are placed in either an equilateral triangle or a diamond geometry. This allows direction measurements of the shower to be made by a single station. Shower direction can be calculated using the differences in arrival time in the several detectors. In one spatial dimension, the arrival time difference Δt for two detectors (or stations) by a distance r is given by (Figure A-6):

$$\Delta t = \frac{r \sin \theta}{c} \quad \textbf{Equation A.3}$$

In the two-dimensional case the correct equation is given by:

$$\Delta t = \frac{r \ \sin \theta \cos \phi}{c} \quad \textbf{Equation A.4}$$

This, however, is only true under the assumption that the bulk of the particles are travelling in a thin disk in the shower front. For more information about shower angle reconstruction see Fokkema (2012).

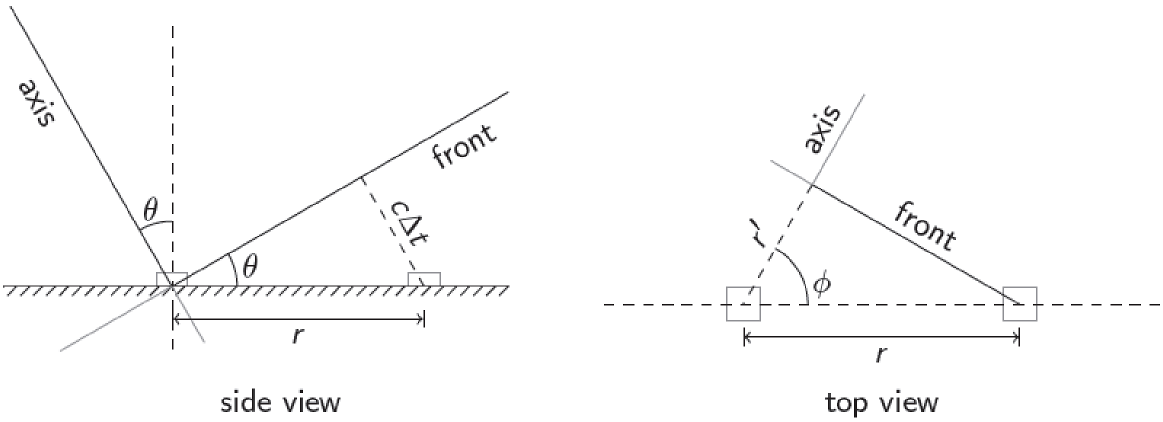

Figure A-6 The shower front has different arrival times in detectors separated by a distance *r*. The arrival time difference depends on the shower direction. (Fokkema, 2012)

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Appendix B ARCS design strategies

Table 1
Attention Strategies

A1: Incongruity, Conflict
- A1.1 Introduce a fact that seems to contradict the learner's past experience.
- A1.2 Present an example that does not seem to exemplify a given concept.
- A1.3 Introduce two equally plausible facts or principles, only one of which can be true.
- A1.4 Play devil's advocate.

A2: Concreteness
- A2.1 Show visual representations of any important object or set of ideas or relationships.
- A2.2 Give examples of every instructionally important concept or principle.
- A2.3 Use content-related anecdotes, case studies, biographies, etc.

A3: Variability
- A3.1 In stand up delivery, vary the tone of your voice, and use body movement, pauses, and props.
- A3.2 Vary the format of instruction (information presentation, practice, testing, etc.) according to the attention span of the audience.
- A3.3 Vary the medium of instruction (platform delivery, film, video, print, etc.)
- A3.4 Break up print materials by use of white space, visuals, tables, different typefaces, etc.
- A3.5 Change the style of presentation (humorous-serious, fast-slow, loud-soft, active-passive, etc.).
- A3.6 Shift between student-instructor interaction and student-student interaction.

A4: Humor
- A4.1 Where appropriate, use plays on words during redundant information presentation.
- A4.2 Use humorous introductions.
- A4.3 Use humorous analogies to explain and summarize.

A5: Inquiry
- A5.1 Use creativity techniques to have learners create unusual analogies and associations to the content.
- A5.2 Build in problem solving activities at regular intervals.
- A5.3 Give learners the opportunity to select topics, projects and assignments that appeal to their curiosity and need to explore.

A6: Participation
- A6.1 Use games, role plays, or simulations that require learner participation.

Table 2
Relevance Strategies

R1: Experience
- R1.1 State explicitly how the instruction builds on the learner's existing skills.
- R1.2 Use analogies familiar to the learner from past experience.
- R1.3 Find out what the learners' interests are and relate them to the instruction.

R2: Present Worth
- R2.1 State explicitly the present intrinsic value of learning the content, as distinct from its value as a link to future goals.

R3: Future Usefulness
- R3.1 State explicitly how the instruction relates to future activities of the learner.
- R3.2 Ask learners to relate the instruction to their own future goals (future wheel).

R4: Need Matching
- R4.1 To enhance achievement striving behavior, provide opportunities to achieve standards of excellence under conditions of moderate risk.
- R4.2 To make instruction responsive to the power motive, provide opportunities for responsibility, authority, and interpersonal influence.
- R4.3 To satisfy the need for affiliation, establish trust and provide opportunities for no-risk, cooperative interaction.

R5: Modeling
- R5.1 Bring in alumni of the course as enthusiastic guest lecturers.
- R5.2 In a self-paced course, use those who finish first as deputy tutors.
- R5.3 Model enthusiasm for the subject taught.

R6: Choice
- R6.1 Provide meaningful alternative methods for accomplishing a goal.
- R6.2 Provide personal choices for organizing one's work.

Table 3
Confidence Strategies

C1: Learning Requirements
- C1.1 Incorporate clearly stated, appealing learning goals into instructional materials.
- C1.2 Provide self-evaluation tools which are based on clearly stated goals.
- C1.3 Explain the criteria for evaluation of performance.

C2: Difficulty
- C2.1 Organize materials on an increasing level of difficulty; that is, structure the learning material to provide a "conquerable" challenge.

C3: Expectations
- C3.1 Include statements about the likelihood of success with given amounts of effort and ability.
- C3.2 Teach students how to develop a plan of work that will result in goal accomplishment.
- C3.3 Help students set realistic goals.

C4: Attributions
- C4.1 Attribute student success to effort rather than luck or ease of task when appropriate (i.e. when you know it's true!).
- C4.2 Encourage student efforts to verbalize appropriate attributions for both successes and failures.

C5: Self-Confidence
- C5.1 Allow students opportunity to become increasingly independent in learning and practicing a skill.
- C5.2 Have students learn new skills under low risk conditions, but practice performance of well-learned tasks under realistic conditions.
- C5.3 Help students understand that the pursuit of excellence does not mean that anything short of perfection is failure; learn to feel good about genuine accomplishment.

Table 4
Satisfaction Strategies

S1: Natural Consequences
- S1.1 Allow a student to use a newly acquired skill in a realistic setting as soon as possible.
- S1.2 Verbally reinforce a student's intrinsic pride in accomplishing a difficult task.
- S1.3 Allow a student who masters a task to help others who have not yet done so.

S2: Unexpected Rewards
- S2.1 Reward intrinsically interesting task performance with unexpected, non-contingent rewards.
- S2.2 Reward boring tasks with extrinsic, anticipated rewards.

S3: Positive Outcomes
- S3.1 Give verbal praise for successful progress or accomplishment.
- S3.2 Give personal attention to students.
- S3.3 Provide informative, helpful feedback when it is immediately useful.
- S3.4 Provide motivating feedback (praise) immediately following task performance.

S4: Negative Influences
- S4.1 Avoid the use of threats as a means of obtaining task performance.
- S4.2 Avoid surveillance (as opposed to positive attention)
- S4.3 Avoid external performance evaluations whenever it is possible to help the student evaluate his or her own work.

S5: Scheduling
- S5.1 Provide frequent reinforcements when a student is learning a new task.
- S5.2 Provide intermittent reinforcement as a student becomes more competent at a task.
- S5.3 Vary the schedule of reinforcements in terms of both interval and quantity.

Appendix C Student interview

Interview Student HiSPARC

Name? School? Gender? Age? Years of HiSPARC experience?

Knowledge
HiSPARC is all about measuring cosmic rays.

1. What are cosmic rays?
2. Where do they come from?
3. How much energy do they possess?
4. How do they obtain their energy?

Which of these questions would you have been able to answer if not participating in HiSPARC?

The HiSPARC detectors are measuring cosmic rays.

5. What happens with cosmic rays when entering the Earth's atmosphere?
6. How can we know for sure if a hit measured by the station was caused by a cosmic ray?
7. What technologies are being used in the HiSPARC detectors?
8. How could you reproduce the cosmic-ray particle's direction?

Which of these questions would you have been able to answer if not participating in HiSPARC?

By analysing the data you are doing actual scientific research.

9. What are the basic steps when doing scientific research?
10. Is it necessary to formulate a hypothesis before you start with your research?
11. How can you check whether the data you are using for your HiSPARC analyses are reliable?
12. Is it necessary to do the same research multiple times?

Which of these questions would you have been able to answer if not participating in HiSPARC?

Networking

13. When working on HiSPARC, did you do this in a group? If yes, with how many people? If no, why not?
14. Have you been working with students of other high schools in the vicinity? If yes, which high school(s)? If no, why not?
15. Have you been working with student of high schools abroad? If yes, which high schools(s)? If no, why not?

Supervision

16. How many hours have you spend on HiSPARC per week?
17. Do you think this is sufficient?
18. Have you been producing reports (of research assignments or research of your own)? If yes, how many?
19. Have you had any feedback from your teacher? If no, do you know why not?
20. Do you get supervised during your work on HiSPARC? If yes, how many hours a week?
21. Do you think this is sufficient?

Opinion
You have been working on several aspects of HiSPARC. Astro-particle physics, particle detection, building detectors, conducting scientific research, working in groups and programming.

22. From which aspect of HiSPARC did you have learned the most?
23. Which aspect did you enjoy the most?
24. Why do you like working on HiSPARC?
25. What do you think of the level of the exercises?
26. What do you think of the appearance of the material?
27. If you had the chance, what would you change about HiSPARC?

28. Do you have any other comments?

Appendix D Upper sixth questionnaire

Name (not compulsory):______________________________

School:______________________________

Gender:______________________________

Age:______________________________

Years of HiSPARC experience:______________________________

Questions		Strongly disagree	Disagree	No opinion	Agree	Strongly agree
1.	Whether the science content is difficult or easy, I am sure that I can understand it.	1	2	3	4	5
2.	I am not confident about understanding difficult science concepts.	1	2	3	4	5
3.	I am sure that I can do well on science tests.	1	2	3	4	5
4.	When science activities are too difficult, I give up or only do the easy parts.	1	2	3	4	5
5.	I think that learning science is important because I can use it in my daily life.	1	2	3	4	5
6.	I think that learning science is important because it will help me get a good job.	1	2	3	4	5
7.	I think that learning science is important because it will help me get into a good university.	1	2	3	4	5
8.	In science, I think that it is important to learn to solve problems.	1	2	3	4	5
9.	During a science course, I feel most fulfilled when I attain a good score in a test.	1	2	3	4	5
10.	I feel most fulfilled when I feel confident about the content in a science course.	1	2	3	4	5
11.	During a science course, I feel most fulfilled when I am able to solve a difficult problem.	1	2	3	4	5
12.	During a science course, I feel most fulfilled when the teacher accepts my ideas.	1	2	3	4	5
13.	During a science course, I feel most fulfilled when other students accept my ideas.	1	2	3	4	5
14.	I am participating in HiSPARC because the content is exciting.	1	2	3	4	5

15.	I am participating in HiSPARC because it is changeable.	1	2	3	4	5
16.	I am participating in HiSPARC because the lectures are given by an external teacher.	1	2	3	4	5
17.	I am participating in HiSPARC because the teacher pays attention to me.	1	2	3	4	5
18.	I am participating in HiSPARC because it is challenging.	1	2	3	4	5
19.	I am participating in HiSPARC because it is different from other science courses.	1	2	3	4	5
20.	I am participating in HiSPARC because I benefit from it in other science courses.	1	2	3	4	5
21.	I am participating in HiSPARC because it will help me get a good job.	1	2	3	4	5
22.	I am participating in HiSPARC because it will help me get into a good university.	1	2	3	4	5
23.	I am participating in HiSPARC because my parents told me to.	1	2	3	4	5
24.	I am participating in HiSPARC because it is compulsory at my school.	1	2	3	4	5

Comments:

Appendix E Lower sixth questionnaire

Name (not compulsory):______________________________

School:______________________________

Gender:______________________________

Age:______________________________

Questions		Strongly disagree	Disagree	No opinion	Agree	Strongly agree
1.	Whether the science content is difficult or easy, I am sure that I can understand it.	1	2	3	4	5
2.	I am not confident about understanding difficult science concepts.	1	2	3	4	5
3.	I am sure that I can do well on science tests.	1	2	3	4	5
4.	When science activities are too difficult, I give up or only do the easy parts	1	2	3	4	5
5.	I think that learning science is important because I can use it in my daily life.	1	2	3	4	5
6.	I think that learning science is important because it will help me get a good job.	1	2	3	4	5
7.	I think that learning science is important because it will help me get into a good university.	1	2	3	4	5
8.	In science, I think that it is important to learn to solve problems.	1	2	3	4	5
9.	During a science course, I feel most fulfilled when I attain a good score in a test.	1	2	3	4	5
10.	I feel most fulfilled when I feel confident about the content in a science course.	1	2	3	4	5
11.	During a science course, I feel most fulfilled when I am able to solve a difficult problem.	1	2	3	4	5
12.	During a science course, I feel most fulfilled when the teacher accepts my ideas.	1	2	3	4	5
13.	During a science course, I feel most fulfilled when other students accept my ideas.	1	2	3	4	5
14.	I am willing to participate in HiSPARC because the content is exciting.	1	2	3	4	5

15.	I am willing to participate in HiSPARC because it is changeable.	1	2	3	4	5
16.	I am willing to participate in HiSPARC because the lectures are given by an external teacher.	1	2	3	4	5
17.	I am willing to participate in HiSPARC because the teacher pays attention to me.	1	2	3	4	5
18.	I am willing to participate in HiSPARC because it is challenging.	1	2	3	4	5
19.	I am willing to participate in HiSPARC because it is different from other science courses.	1	2	3	4	5
20.	I am willing to participate in HiSPARC because I will benefit from it in other science courses.	1	2	3	4	5
21.	I am willing to participate in HiSPARC because it will help me get a good job.	1	2	3	4	5
22.	I am willing to participate in HiSPARC because it will help me get into a good university.	1	2	3	4	5
23.	My parents told me to participate in HiSPARC.	1	2	3	4	5
24.	Participating in HiSPARC is compulsory at my school.	1	2	3	4	5

Comments:

Appendix F Teacher Questionnaire

	Personalia
Q1	Name:
A	
Q2	School of employment:
A	
Q3	Gender:
A	
Q4	Age:
A	
Q5	Years of teaching experience:
A	
	Background:
Q6	Do you have a degree in physics? If yes, what kind of degree and what is your specialisation? If no, do you have a degree in another field of science?
A	
Q7	Do you have a degree in physics education? If yes, what kind of degree and what is your specialisation? If no, do you have a degree in another field of education?
A	
Q8	Are there any physics topics you are specifically interested in?
A	
Q9	To what extent does your school management take into account your interests as a physics teacher?
A	
	Teaching
Q10	What, for you as a teacher, are the fun parts of physics education? Please explain why.
A	

Q11	What image does the subject of physics have among your students?
A	
Q12	Is it necessary to motivate your students for learning physics? Please explain why or why not. If yes, in what way are you motivating your students?
A	
Q13	What do you consider (effective) ways of motivating your students to learn the content? Please explain why.
A	
Q14	What does the physics curriculum at your school look like? And why did you choose this curriculum.
A	
Q15	For which examination did you/your school choose? Please explain why.
A	
Q16	Do you think it is important to motivate students to pursue a scientific career? Please explain why or why not?
A	
Q17	Do you inform your students about science degree courses after secondary school? Please explain why or why not.
A	
	HiSPARC
Q18	Is the decision to participate in the HiSPARC experiment yours? If no, whose decision was it?
A	
Q19	What was the main reason to become a HiSPARC member? Are there others reasons to participate?
A	
Q20	How did you/will you implement HiSPARC at your school? Please explain why you did this.
A	
Q21	What is/are, in your opinion, the goal(s) of HiSPARC?
A	
Q22	If you were able to, would you change something about HiSPARC in the UK? If yes, what

	would you change?
A	
Q23	If you were able to, would you change something about HiSPARC in general? If yes, what would you change?
A	
Q24	Do you have any ideas on how we can take HiSPARC to the next level?
A	
	HiSPARC students
Q25	Which percentage of your students chose to participate in HiSPARC last year(s)?
A	
Q26	Which percentage of your students, participating in HiSPARC, is boy/girl?
A	
Q27	What can you say about the level of the students choosing to participate in HiSPARC?
A	
Q28	Is participation in HiSPARC compulsory? If no, what do you think, is the reason for students to participate in HiSPARC?
A	
	Other extra-curricular activities
Q29	Is HiSPARC an extra-curricular activity at your school?
A	
Q30	Are there other extra-curricular activities students can choose from? If yes, what activities are available?
A	

Appendix G Methods used to answer research questions

		Student interview (N=5)	Student Questionnaire (N=61)	Teacher Questionnaire (N=5)	ARCS model	Observations
1.	What have students learned, by participating in HiSPARC in the academic year 2012/2013?	X				X
	What do students know about cosmic rays?	X				X
	What do students know about the HiSPARC detector?	X				X
	What do students know about scientific research?	X				X
	Have students been networking with students of other schools?	X				X
2.	Why do students participate in HiSPARC?		X	X		X
	Is there a gender difference observed in the participating students?		X	X		X
	Is there a level difference observed in the participating students?	X		X		X
	Is there any difference observed between students' attitudes towards science with respect to gender, age, HiSPARC experience, school or type of school?		X			
	What is the motivation for high-school students to participate in HiSPARC?		X			X

		Student interview (N=5)	Student Question naire (N=61)	Teacher Question naire (N=5)	ARCS model	Observations
	What is the reason for students to participate according to teachers?			X		
	How can (lower sixth) students be motivated to participate in HiSPARC?				X	X
3.	Why do teachers participate in HiSPARC?			X		X
	What are teachers´ beliefs about engaging students in subject of physics?			X		
	Why do teachers participate in HiSPARC?			X		X
	How do teachers implement HiSPARC in the physics curriculum?			X		X
4.	To what extend are the educational goals of HiSPARC reached?	X	X	X		X

Table G-1 Methods used to answer the research questions presented in Chapter 2.

Appendix H HiSPARC practical activity

PMT Calibration & Flux measurement

G. Osinga

1 Introduction

In order to let the HiSPARC detectors work properly, the photomultiplier tubes (PMTs) should be calibrated. The efficiency of the PMTs depends on the applied high voltage (HV). If this voltage is too low, the signal will not be amplified. If the HV is too high you might blow op the PMT. In this practical assignment you will learn how to calibrate a PMT. Also you will make an estimate of the cosmic ray flux.

2 Cosmic ray detection

This chapter contains the theory underlying the physical processes involved in this practical assignments.

2.1 Scintillator

Scintillation is the process where ionizing particles losing energy in a material cause luminescence. In other words, when a particle traverses a scintillator, it emits light. The most commonly applied scintillators are plastic scintillators. They are solutions of organic scintillators in a solid plastic solvent. The scintillation is caused by ionization and excitation of the electron. After excitation, the molecule quickly decays to its ground state emitting a photon.

2.2 Photomultiplier tube

Photons produced inside the scintillator are collected at the cathode of a PMT (see figure 2.1). There, photoelectrons are released through the photoelectric effect. These photoelectrons are accelerated and focused onto a system of dynodes. For each primary electron hitting a dynode, two to five secondary electrons are released. A PMT can have around 14 of these multiplying stages and therefore can have an overall multiplying factor of 10^5 . In figure 2.2 a schematic overview of a PMT is shown. Because of the high gain of the PMT the few incident photons produce a measurable pulse at the output of the multiplier.

2.3 Spark chamber

The spark chamber was developed between the late 1940s and the early 1960s, with contributions from many people. It is a variation on a particle detector first demonstrated

Figure 2.1: A picture of a photo multiplier tube

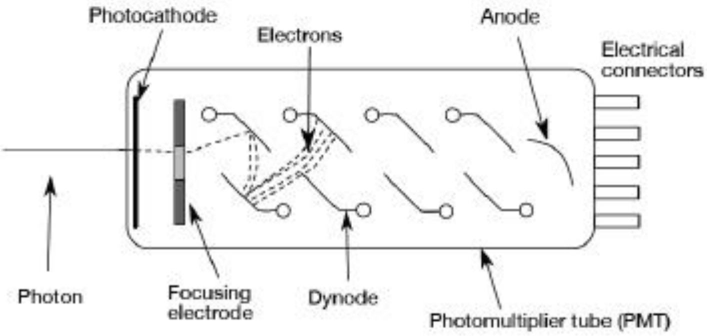

Figure 2.2: Schematics of a photo multiplier tube

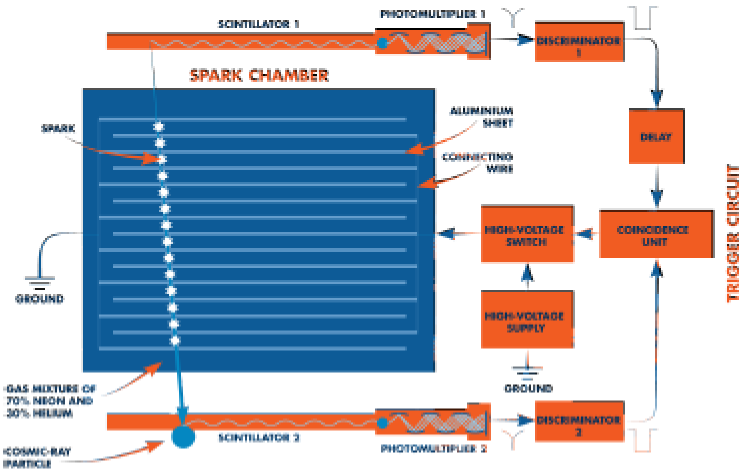

Figure 2.3: Schematic overview of a spark chamber

by Hans Geiger and Walther Müller (GM-counter) at the University of Kiel, in 1928. Spark chambers were the first widely used track-visualisation devices. Large-volume spark chambers were used in the discovery of the muon-type neutrino, in 1962.

The schematics of a spark chamber are depicted in figure 2.3.

The cosmic-ray particle crossing the scintillator causes light to be emitted. A part of this light travels to the photomultiplier, where it is converted into an electronic signal. The discriminator gives a binary (yes/no) response, producing a square-wave signal if the output from the photomultiplier is above a noise threshold, or no signal otherwise. A length of cable is used to delay the signal from discriminator 1 by the time taken for the cosmic-ray particle to travel between scintillator 1 and scintillator 2.

As the cosmic-ray particle crosses the neon-helium gas mixture inside the chamber, it causes ionisation along its path, locally decreasing the electrical resistance.

When the coincidence unit records signals arriving simultaneously from the two discriminators, it triggers the switching on of the high-voltage supply for a short time interval. This creates large electric fields between neighbouring aluminium sheets in the spark chamber. The large electric fields create current flows along the paths of lowest electrical resistance, meaning where the cosmic-ray particle caused ionisation. These current flows are seen as sparks.

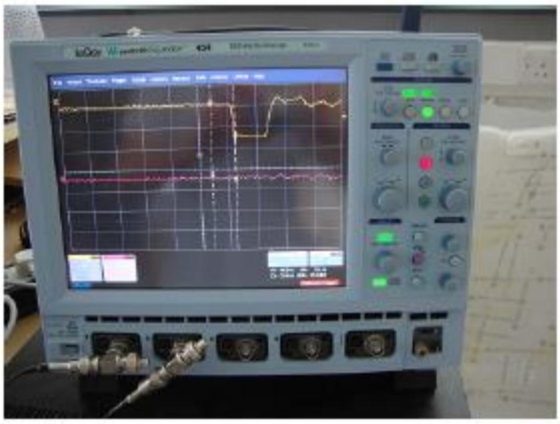

Figure 3.1: The yellow (top) line represent the signal from the coincidence module of the spark chamber. The pink (bottom) line represents the signal from the scintillator. A cosmic ray particle traversed the spark chamber but not the scintillator.

3 Practical assignments

Now you know how the equipment works, you can start with the practical assignments. Let's assume that the spark chamber and the PMTs inside the spark chamber are calibrated and are functioning properly. Whenever the assignment states that you have to do something with the PMT or scintillator, it means that you have to you do something with the scintillator which lies on top of the spark chamber.

The scintillators inside the spark chamber are not only switching on the HV of the spark chamber but also trigger the oscilloscope to show the output of the scintillator on top of the spark chamber. This means you will only be measuring particles traversing trough all the scintillators. In figure 3.1 you see that a cosmic ray traversed the scintillators inside the sparc chamber. The 'external' scintillator however is not hit by this particle as you can see from the pink line. In figure 3.2 you can see the event that a particle traversed the scintillator and the spark chamber.

3.1 PMT callibration

Make sure the HV of the PMT is connected and switched on. At 0V the PMT will most certainly give no signal. The HV source is analog. Each turn equals 500V.

Important: Never apply more than 1900 Volts on the PMT or else it might break!

Exercise 1 : Turn the HV up to 1500V and count how many times a cosmic ray passes through the spark chamber and how many through the scintillator in two minutes. Divide the tasks among your group: Timing, counting and writing down the information.

Figure 3.2: A cosmic ray traversed the scintillator and the spark chamber.

Exercise 2 : Repeat the previous exercise by increasing the HV to 1600 Volts. And then to 1700 Volts. Etc.

Important: Never apply more than 1900 Volts on the PMT or else it might break!

Exercise 3 : Set the HV of the PMT to 0 Volts

Exercise 4 : Create efficiency plots by plotting the applied HV on the x-axis and the number of counts on the y-axis. At which HV is the PMT most efficient?

3.2 Cosmic ray flux

Exercise 5 : At the point where the PMT is most efficient, compare the number of particles traversing the spark chamber with the number of particles counted by the scintillator in two minutes. Why is the number different?

Exercise 6 : Measure the (effective) surface area of the spark chamber and the scintillator.

Exercise 7 : Calculate the number of particles that traverse the scintillor per square meter per second

Exercise 8 : Calculate the number of particles that traverse the spark chamber per square meter per second

The number of particles traversing through a surface area in a certain amount of time is called flux.

Exercise 9 : Compare the cosmic ray flux through the scintillator and the spark chamber. Is there still a difference? If yes, what might cause this difference? How should we change our setup to get a better estimate?

Appendix I Starting Assignments

The Starting Assignments document is too large to attach to this document. In order to obtain these resources, please contact the author.

Appendix J Knowledge test results

	Question	Student	1	2	3	4	5
		Gender	Male	Male	Female	Female	Female
		School	School II	School II	School IX	School IX	School IX
Astro-particle physics	1	Score	0	1+	1	1	0
		HiSPARC	True	False	True	True	True
	2	Score	1	1+	0	1	0
		HiSPARC	True	True	True	True	True
	3	Score	0	1	0	0	0
		HiSPARC	True	True	True	True	True
	4	Score	0	0	0	0	0
		HiSPARC	True	True	True	True	True
Particle-detection	5	Score	0	1+	1	1	0
		HiSPARC	True	True	True	True	True
	6	Score	0	1+	0	0	0
		HiSPARC	True	True	True	True	True
	7	Score	0	1	1	1	0
		HiSPARC	True	True	True	True	True
	8	Score	0	1+	0	0	0
		HiSPARC	True	True	True	True	True
Scientific research	9	Score	1	1+	1+	1	0
		HiSPARC	False	False	False	False	False
	10	Score	1	1+	1	1	1
		HiSPARC	False	False	False	False	False
	11	Score	1	1	0	1	0
		HiSPARC	True	True	False	False	False
	12	Score	1	1+	1	1+	1
		HiSPARC	False	True	False	False	False
	Total	Score	5	11+	6	8	2
		HiSPARC	9	9	8	8	8

Table A-8-1 Absolute scores of the knowledge score. Whether the knowledge is gained from participation in HiSPARC is shown by the statements 'True' and 'False'. When the student was able to give an extensive answer, a '+' sign is shown next to the score.