University of Cape Town
Department of Physics

A STUDY OF POSTGRADUATE STUDENTS IN AN ASTROPHYSICS BRIDGING YEAR: IDENTIFYING CONTRADICTIONS IN A COMPLEX SYSTEM

Victoria Nwosu

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Abstract

Astronomy and Astrophysics have been designated one of the flagship areas of research in South Africa. As part of human capacity building in this regard, a postgraduate national teaching programme at the Honours and Masters level, the National Astrophysics and Space Science Programme (NASSP) was established by an interested of group universities and located at the University of Cape Town. Despite initial success the programme failed to recruit and retain black South African students. In order to address this problem a postgraduate bridging program, the Extended Honours Programme (EHP), was established as a one year pre-honours level educational intervention. The research described in this thesis is directed at trying to identify the nature of the problems faced by the EHP students during their transition from their previous institutions to UCT.

The Cultural Historical Activity Theory (CHAT) framework and its principle of contradictions and multivoiceness are employed to describe the NASSP as an activity system. According to the CHAT framework an activity system may experience four types of contradictions: primary, secondary, tertiary and quaternary. These four types of contradictions were identified and located within, and between, the components of the activity system. The major primary contradiction identified was in the “double nature” of the programme, essentially, a double bind between conceptual understanding and getting good grades. Several secondary contradictions, tertiary contradictions and historical disturbances were also identified. Other disturbances which did not map into any of the four established contradictions are also highlighted.

The methodology was further applied at the level of a single course where micro and macro tensions were detected in a key component of the EHP curriculum that had previously been identified as extremely challenging, namely, the intermediate level electromagnetism course. To this end this specific activity system was interrogated and inherent tensions including historical and systemic tensions were identified. These historical and systemic tensions were noted to create disturbances such as poor conceptualization of physical problems, mismatches in students’ and lecturers’ expectations and unproductive learning strategies.

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Terms, abbreviations and acronyms

- **AT**: Activity theory, (used interchangeably with CHAT)
- **CHAT**: Cultural Historical Activity Theory
- **Direct entry NASSP students:** Students who enrolled directly for the NASSP programme without going through the EHP
- **EBAPS:** Epistemological Belief Assessment for Physical Sciences
- **EHP**: Extended Honours Programme
- **EHP students**: NASSP students who started out with the EHP
- **E&M or EM**: Electromagnetism
- **HBU**: Historically Black Universities (HBU) used interchangeably as Historically Disadvantaged Institutions (HDI**).**
- **HDI**: Historically disadvantaged Institutions
- **HWU**: Historically White Universities
- **NASSP**: National Astrophysics and Space Science Programme
- **Post-EHP students**: EHP students in subsequent Honours and Master's years
- **PMM**: Personal Meaning MAP
- **SAAO:** South African Astronomical Observatory
- **SALT:** Southern African Large Telescope
- **UCT**: University of Cape Town

1. Introduction to the study

1.1. Thesis layout

This projects aims at identifying the contradictions in a system involving physics graduates from Historically Black Universities (HBU's) who enrol for a postgraduate bridging course at the University of Cape Town (UCT). Chapter one gives some background on the motivation for the project and the background of the National Astrophysics and Space Science Programme (NASSP) and Extended Honours Programme (EHP), its inception, formalities and regulations that govern the system.

In chapter two I give a brief introduction on preliminary studies on epistemology and some results from measuring students' epistemologies. I also explain the need for a broader framework to capture students' experiences in the NASSP system.

Chapter three provides the theoretical framework used in the study. It also gives the motivation for choosing the Cultural Historical Activity Theory (CHAT) framework. The chapter describes the CHAT principles, and the use of the activity system analysis. The central role of contradiction in CHAT is also highlighted in this chapter. I conclude by providing brief summaries of some exemplars which used activity theory as a framework for the study.

Chapter four gives details of data sources used in this study. It also describes the method of analysis.

Chapter five describes the context of the study with the aid of the unit of the activity system. It also provides a description of the nature of the research.

In chapter six the different categories of contradictions in the system are identified. Data which indicated the presence of a tension were analysed and categorized according to Engeström's four types of inner contradiction in a system.

In chapter seven I analyse some contradictions in a subsystem involving students in an intermediate level electromagnetism course. I show students' and lecturers' perceptions of the E&M course. Students' products in two E&M courses were also analysed using established learning taxonomies.

Chapter eight gives a summary of the study, researcher's insights into some of the issues raised, highlights of the thesis, and future work

1.2. Background

One of the flagship areas of science and technology in South Africa is astronomy and astrophysics (Whitelock 2009). Two major factors favouring astronomical and astrophysical studies in South Africa are its climate and geographical location. Former South African President Thabo Mbeki, in his State of the Nation Address in 2004, emphasised the national commitment to astronomy as one of the prioritised areas in science and technology (Brochure 2005).

To that effect, the Southern African Large Telescope (SALT), the largest single optical telescope in the southern hemisphere (http://www.salt.ac.za), and the Karoo Array Telescope (MeerKAT), a radio telescope of 80 dishes, each 12m in size, was inaugurated in 2005. There are also newer small telescopes that have been located at Sutherland because of its climate, position and infrastructure. Many of these are run as joint projects between SA and an international partner - the 1.4m Japanese-South African Infrared Survey Facility (IRSF) is the largest of these and has been successfully used for research and training since its opening in 2000. There are a number of small automated telescopes run for specific projects on behalf of individual institutes or consortia, including groups from Korea, UK, USA and Germany (Whitelock 2009). SA is also a partner in the highly successful international collaboration which operates the High Energy Stereoscopic System (HESS) in Namibia.

With these world class facilities and collaboration benefits, the future of astronomy in South looks increasingly promising. Hence since 2004, one of the nation's challenges is to broaden the relatively small community of astronomers in order to fully exploit these facilities and to be internationally competitive (Brochure 2005). Prior to 1994, most of the local optical astronomers had been born, and many of them trained, outside of Africa. The post-1994 investment in astronomy came with the assumption that this would change - that astronomers would find ways to interact with and influence South African science and that a cohort of indigenous astronomers would be trained and nurtured. The challenge has been to do this in such a way that these young scientists are the peers of their international contemporaries and not merely tokens to fill quotas (Whitelock 2009).

In 2000, during strategic planning exercises which followed the South African commitment to build SALT, the lack of SA astronomers, and the extreme lack of black astronomers was identified as the biggest threat to the future of astronomy in the country (Whitelock 2009).

It was realized that a major cause of the problem was the fact that very few black students continued to postgraduate studies. The NASSP was then established to train science graduate students through Honours, Masters and PhD degrees in astronomy.

However, after about six years of operation of the NASSP, the lack of successful participation of black South African students is still a major concern. The shortage of these students can be linked to a number of factors including the difficulties these students experience when negotiating the new and fairly foreign working environment. These difficulties include affective issues, general approaches to learning and studying, as well as lack of required content knowledge.

With this brief introduction, some motivating study questions that led to this research are highlighted below.

- Why are there so few black South Africans in the NASSP programme?
- What impediments do students from Historically Black Universities (HBU's) face that hinders participation?
- What are the underlying reasons for these impediments?
- Are there reasons that can be traced back to HBU's?

1.3. Academic Development Programme (ADP)

The EHP programme which I will discuss in more detail in later sections is hosted under the umbrella of the Academic Development Programme (ADP), part of the Centre for Higher Education (CHED) at UCT. Academic Development Programmes at universities such as the University of Cape Town were borne in the 1980's out of the need to redress the inequalities of the apartheid era. The apartheid legislation profoundly affected access to all the higher education institutions (Boughey 2003). It excluded black students and staff from established centres of excellence, throughout the 1960's and the 1970's (Scott, et al. 2005).

A hierarchy of segregation emerged in the 1960s. Separate education departments were set up to administer institutions for persons classified "European"(White), "Coloured" (persons of mixed ancestry), "Asiatic" (persons of Asian origin, generally referred to as Indian) and "Native" (also referred to as "Bantu", African or black). Resources were allocated along the same hierarchical lines: most were allocated to institutions designated for "Europeans", then to "Coloureds" and so on down the line (du Pré 2003). Thus resources were allocated unevenly and over time led to huge disparities in provisions, infrastructure, teaching resources, and quality of education.

In the early 1980s the poor learning conditions in black schools were acknowledged. This provided the justification for the establishment of the academic support programme (ASP) at UCT in 1980. (Scott, et al. 2005, Pavlich and Orkin 1993). Its mission was to organize help with study skills and additional tutorial support, offering language classes for black students since the majority of black students had English as a second language.

In the latter half of 1980, the term "academic development" had come to be used in most South African higher education institutions in preference to academic support, because it better indicated the purpose and compass of the field and because "support" had negative connotations. Academic development became broadly accepted as compromising four interrelated areas of focus: student, staff, curriculum and institutional development.

Most academic science support programmes involve a pre-degree "bridging or foundation programme" designed to assist students without the necessary background to be able to benefit immediately from lectures (Toor 1991, Boughey 2005). Generally, bridging programmes are offered in an attempt to compensate for the "under-preparedness" of students, before entering the "mainstream" programme (Kotecha, Allie and Volmink 1996). Unlike most bridging programmes which are designed for undergraduate degree studies, the EHP at the University of Cape Town is a one year post*graduate bridging intervention.* . The programme is offered to prospective graduate students from (HBU's) prior to attending the NASSP Honours course. This is a unique programme and the first of its kind in the country. A brief overview of the EHP is provided in section 1.6.

1.4. The Structure of the South African Education System

The South African education system has a unique structure. The higher education system consists of Public Universities, Universities of Technology and a College sector. South African universities offer Bachelor, Bachelor Honours, Master and Doctorate degrees, as well as undergraduate and postgraduate diplomas. Course work is structured in modules, with students registering in a unit/credit system. For the majority of the science courses the Bachelor degree takes 3 years to complete after which students enrol for a Bachelor Honours year. This graduate study year usually involves course work with a mini-thesis. The Masters programme generally takes two years to complete and the PhD degree takes about three years in general (See summary in Table 1).

Table 1. Typical South African Higher Education Structure for Physical Sciences.

Undergraduate	Graduate Studies		
3 years (BSc)	1 year Honours BSc (Hons)	2 years Masters (MSc)	3 years PhD

1.5. Overview of NASSP

The NASSP programme was established in 2003 to address the issue of raising the research and postgraduate profile of South African institutions, and transformation in the physical sciences. It aims to produce scientists with broad-based skills, useful in industry as well as for research in astronomy, astrophysics and space science. Thus graduates of the programme will be highly competitive for employment in industry as well as for research in other areas. With this in mind the emphasis of the programme is to train talented young South Africans of various backgrounds (Dunsby and Whitelock 2007-2009):

1. In research at the cutting edge of astrophysics and space science;
2. In general problem solving based on scientific methods;
3. In numerical calculations;
4. In using computational techniques;
5. In operating, maintaining, and perhaps also designing and manufacturing new research equipment at the South African Observatory (SAAO) and the Hartesbeesthoek Radio Astronomy Observatory (HartRAO);
6. In writing up research results in scientific papers and publishing them in international Journals of repute;
7. In presenting the research results in seminars and colloquia at research institutions, as well as national and international conferences
8. In working in a vibrant research team

An overview of its goal shows that for such a programme to achieve its goals, attention has to be paid to its structure.

1.5.1. Structure of NASSP

The NASSP is run as a two degree component: (1) leading to a Bachelor of Science in Honours after one year and (2) a Master's degree after 18 months. Afterwards students may enrol for a PhD. The programme was set up as a unique collaboration between nine Universities in South Africa including, University of the Free State, North-West University, University of Zululand, Rhodes University, University of the North West, University of South Africa, University of the Western Cape, University of the Witwatersrand, and the University of Cape Town, which hosts the programme.

NASSP lecturers include both UCT lecturers and members of the consortium who lecture for short periods, typically 3 weeks, and cover a breadth of topics. As all the NASSP students are situated at a single university, it offers them the opportunity to interact and learn from each other.

The BSc. Honours year deals with students who graduated from a three year degree with no significant astrophysics or space science component and provides a broad overview of the subject. The NASSP Honours curriculum is particularly intensive. Courses consist of a blend of theoretical and practical courses covering all major areas of modern astrophysics and space-physics, and are designed for students to acquire breadth as well as depth of knowledge. Specific courses offered are electrodynamics, astrophysical fluid dynamics, general relativity, and computational methods in astronomy. They are also trained in observational astronomy and research such as optical and infrared astronomy. The final component of the course involves a project and seminar written and presented by the students.

The Masters programme consist of 6 months of intensive course work and 12 months for a mini-thesis, The course work part consist of a wide range of advanced theoretical topics covering the research areas of many of the astronomers and astrophysicist in the country. The Masters coursework includes plasma physics, magneto hydrodynamics, cosmology, cataclysmic variables, extra galactic astronomy, advanced general relativity, high energy astrophysics, observational cosmology, stellar structure and evolution, geomagnetism and aeronomy, observational techniques and space technology. Students are expected to take between 5 and seven courses. On completion of the course work, students then proceed to do their theses either at UCT or other NASSP partner institutions which represent excellent throughput to the major centres around the country.

1.5.2. NASSP Enrolments

Students for the NASSP are recruited from all South African universities as well as universities from other countries in Africa. Between 15-20 people per year go through the Honours and Masters programme. This has been counted as a success when compared with the one or two people per year prior to the establishment of the NASSP. The recruitment of students from other African countries has been particularly successful. NASSP has enrolled students from Botswana, Ethiopia, Uganda, Zambia, Gabon, Kenya, Madagascar, Mozambique, Rwanda, Sudan, Zambia, Nigeria, and Zimbabwe. One of the fundamental objectives is to create an African network of astronomers who are bonded by the common experience of schooling and interlinked both professionally and personally (Dunsby and Whitelock 2007-2009).

Table 2. Number of BSc Honours and Masters students who have participated in NASSP from 2003-2008

Year	2003	2004	2005	2006	2007	2008
Honours	13	14	12	19	13	11
Masters	5	15	9	8	12	15

By the end of 2006 NASSP had produced 49 Honours graduates, over half of whom have gone on to do MSc and/or PhD degrees. Fifty percent of that NASSP intake has been students from other African countries.

The major challenge for the astronomy and space science community is to build a community of users for its facilities. Of equal importance, however, is the goal that the scientific complement should, in the longer term, reflect the national demographics of the country.

1.5.3. The way forward

In order to improve academic preparedness and consequently improve the participation of black South African students in the NASSP, a number of strategies and interventions were considered. The one eventually settled for was a two year Honours programme. Extended undergraduate degree programmes have proved to be a successful way of addressing the issue of unrealised potential. In this case the untapped pool of students that are needed are located primarily in physics departments at Historically Disadvantaged Institutions (HDI) (Kotecha, Allie and Volmink 1996).

Thus, the initiatives in the physics department at the University of Western Cape's (UWC) Masters in Materials Science *(*MATSCI) and Masters in Accelerator and Nuclear Science (MANUS) were investigated. The programme has had a successful record of providing physics training for black postgraduate students who have been drawn from the pool in question.

1.6. The design of the pre-Honours year

A special programme now called the NASSP EHP was put in place and also includes a recruitment aspect with a view to creating awareness and motivating students to apply for the EHP. These are initiatives to address the challenge of increasing the number of South African graduates in astronomy (Bharuth-Ram 2009).

1.6.1. The winter school

The winter school is the key awareness and recruitment process for the EHP. The majority of these students have not taken a course in astronomy at undergraduate level, neither are they familiar with astronomy in general. Recruitment to the school involves two black astronomers who visit HBU's to enlighten and recruit students for the winter school. The recruiters acknowledged that for many of the students they interacted with during the visits, it was the first time they had heard about astronomy and opportunities that exist in South Africa. It was therefore essential that outreach programmes that inform students about astronomy were carried out.

To that effect, the organizers of the school visited the physics departments at various HBU's to inform them about astronomy and NASSP and to invite applications for the winter school. The first NASSP winter school was held from 18-29 June 2007 in collaboration with the South African Astronomical Observatory (SAAO). 3rd year physics and mathematics students from HBU's were invited to attend. The aims of the school are as follows:

1. To expose more undergraduate students to NASSP and astronomy and therefore encourage more South Africans to consider careers in astronomy.
2. To establish friendly relations between the NASSP programme and the HBU's.
3. To facilitate interaction between undergraduate students and role models.
4. To provide recruitment ground for the NASSP Extended Honours Programme.

Requirements for application include a 300 word paragraph of motivation and an academic record. Applications for the winter schools started at 21 students and have increased over the years with 2011 having about 65 applications. A selection is then carried out largely based on academic records and motivation. Selected students are invited to the winter school held at the South African Astronomical Observatory (SAAO).

The winter school activities involves a 2 week stay at SAAO with mornings spent attending lectures delivered by reputable astronomers and afternoons doing computer exercises or experiments. Various visits, e.g. to SALT, are also arranged as were social events and opportunities to meet the current NASSP students.

The winter school also provided an opportunity to gauge the reactions of the students to astronomy, to Cape Town and to an extended programme as well as to get a sense of their level of preparation for the course.

As a gauge of their level of preparedness, I administered different diagnostics questionnaires and tests. For example in 2010, students completed a general physics content assessment, and an electromagnetism conceptual knowledge and problem solving skills assessment. They also completed an Epistemological Beliefs Assessment for Physical Sciences (EBAPS) (Elby n.d.) and a motivation/expectation survey. By allowing for the collection of data, and a more general observation of students, the winter school has helped highlight:

a. that the students had a genuine interest in astronomy.
b. that students are clearly prepared to work hard and long hours.
c. perceived gaps in the content knowledge of the students that would have to be addressed as part of any special interventions that might be put into place.

For the students the winter school provides an opportunity to:

a. perceive what astronomy is, and what astronomers are like.
b. see that the astronomy community are genuinely interested in them and are prepared to develop a scheme that would help them succeed.
c. show them what living and working in Cape Town would be like.

The survey that was administered on motivation and expectation from the winter school shows that majority of the students are motivated *intrinsically* with fewer *extrinsic* motivations (Lepper, Corpus and Iyengar 2005). Broad categories for reasons for interest in astronomy involved, wanting to know more about astronomy - the universe, stars, galaxies etc., wanting to apply existing skills to solve astronomical and astrophysical problems, wanting to realise a dream, wanting to find out the truth about the universe, passion and love for science, because it is a good career, desire to solve existing problems, wanting to develop skill to advance oneself, and because it is enjoyable. Two of the students' responses to interest in astrophysics is shown below:

Student A

> *The reason I am interested in astrophysics is to be one of the people or scientist who will cause a positive change for the bettering of our universe and be one of the astronauts in Africa.*
> *I am interested in research and in practice of physics in general. I was inspired by how Newton cause change to science. Astrophysics is one of my dreams to be the solution finders for the galaxies, universe and celestial bodies.*

Student B.

> *My interest in astrophysics started out around grade 9-10, I knew I wanted to become a scientist one day, this was evident from my level of curiosity, i grew up watching a lot of scifics and documentary, and in one of the documentary was Dr. Medupe, who also gave me the interest to continue studying further, i also watched 50/50 where prof cres was interviewed, these little things changed me or contributed to wanting to do Astrophysics. I also loved the field because it uses computation as a way to analyse data, and this is why I did computer science together with physics*

Most of the declared expectations of the students also matched with the goals of the winter school. The data also shows that students were willing to participate in the EHP programme. Example of students' written expectations from the winter school are stated below:

Student X

-to find out more about astrophysics

-to gain more knowledge about the history of astronomy, formation of the stars and their death and life time (life cycle of the stars)

-to know more about what might be done in prevention of the galaxies, planets and human nature

-be clarified on more issues on astrophysics or astronomy

Student Y

My expectation of the winter school is to learn more about astronomy as I am looking forward to be one of the nassp extended honours program. I want to become an astronaut.

The winter school was also an opportunity to gauge the level of willingness of students to participate in activities that are seen to fall outside of the "mainstream", in this case, the organisers of the winter school tried to ascertain how students would feel about being placed on an extended NASSP where they will now need two years to complete their BSc Honours as opposed to one year.

Generally, students have felt positive about the scheme and the winter school has been successful in making prospective students feel part of the process of where they might be placed should they choose to be part of NASSP.

In summary, the winter school, and preceding visits to historically disadvantaged institutions, have aided the dissemination of information about astronomy and astrophysics to local South Africans. A selection is made for students to attend the school, and students are then selected from the winter school attendees to enrol for the EHP. Students enrolling for the EHP have gone through the process shown in figure 1.

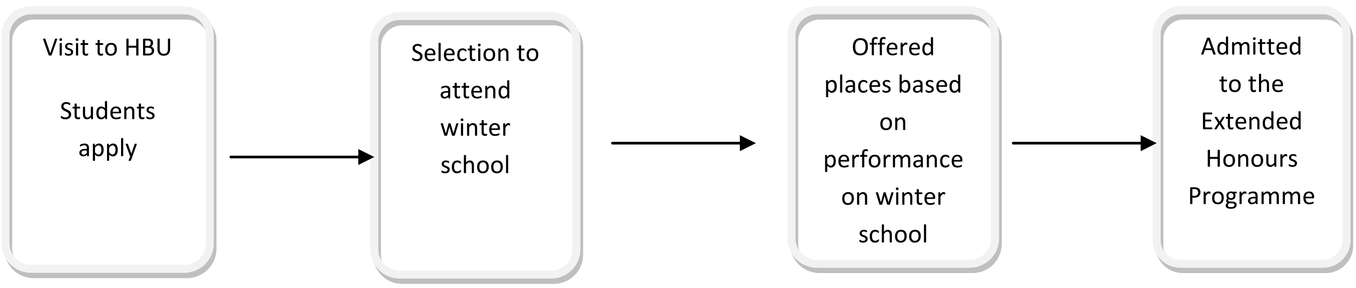

Figure 1. Diagram depicting general procedure for selection into the EHP

This procedure ensures that motivated and potentially good candidates are selected into the EHP. This means that students generally pass through two forms of selection before enrolling for the programme. It is important to emphasize this aspect as this shows that students enrolling for the programme have been successful in their preceding studies at their universities prior to enrolling for the EHP.

1.6.2. Structure of the Extended Honours Programme (EHP)

In conceptualizing the form and structure of the EHP, four strands of the curriculum were identified from the scoping exercise. These included mathematics, physics and computational aspects, communication and learning approaches as well as knowledge about astronomy. To date, the EHP has undergone two phases of development. In 2008 the pre-pilot intervention was run in such a way that 4 students were taught and mentored in a highly personalized manner. The main purpose was to establish whether a bridging year would be feasible in principle. Conversely, if it was not possible to show some measure of effectiveness with such an intensive mode of teaching it would be even more unlikely that a successful system could be set up which was not highly dependent on a particular individual for teaching and mentoring.

The second phase of the EHP was aimed at putting together a structure that could be run in a manner that was more systemically viable. A key aspect to this was developing curriculum offerings that addressed the specific needs of the students based on the experiences that were gained in the pre-pilot phase. To this end small teams have been developing and teaching the various strands that have been identified. Thus, the 2009 and 2010 curricula comprised both specially tailored courses as well as courses from the undergraduate offerings in the science faculty. About 10 lecturers and tutors have been involved per year in teaching related activities.

It should be noted that not all students on the EHP succeeds and gain entrance into the NASSP Honours or Master's programmes. Student's performances are also evaluated during the programme. However, this does not mean that this should be end of the road for some of these students and thus various arrangements to enrol students for further studies with other institutions are arranged.

Another related issue that has emerged is that the EHP cannot simply be a once-off intervention if students are to proceed successfully to PhD levels. Thus, tutoring and mentoring schemes over and above the normal schemes (regular Honours and Masters) presently in NASSP need to be put into place beyond the EHP year. A start in this regard was made in 2011.

The EHP has therefore provided a steady pipeline of black South African students into the NASSP programme. With further development the EHP can become a major, sustainable route for black South African students into NASSP and astronomy in general at all levels. The throughput of the EHP as at February 2012 is highlighted in the table below (Kotecha, Allie and Volmink 1996).

Table 3. EHP cohort numbers since inception as of February 2012. Numbers in brackets show maximum possible

	2008	2009	2010	2011	2012	Total
Join EHP	4	7	9	7	6	33 (33)
Pass EHP	4	6	7	5	NA	22 (26)
Join Honours		3	6	7	5	21 (22)
Join NASSP Masters			3	3	4	10
Join non-NASSP Astronomy Masters				2	1	3
Total number of EHP students engaged at Masters level						13 (16)

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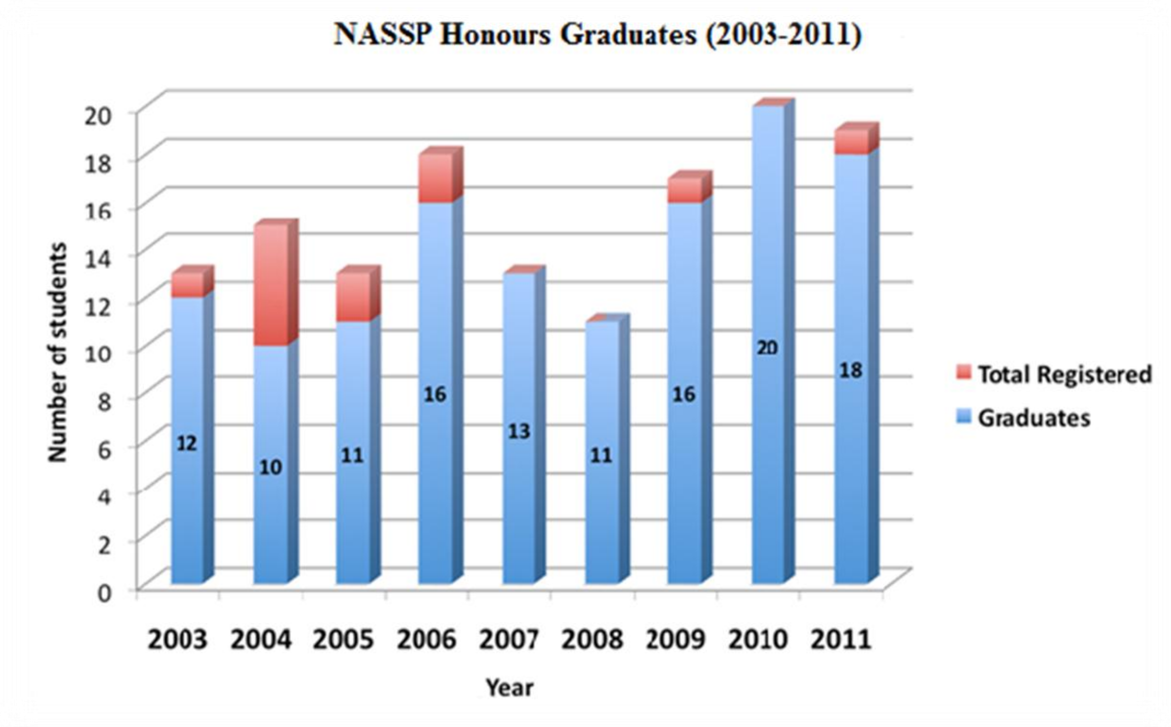


Figure 2. NASSP Honours graduate 2003-20011

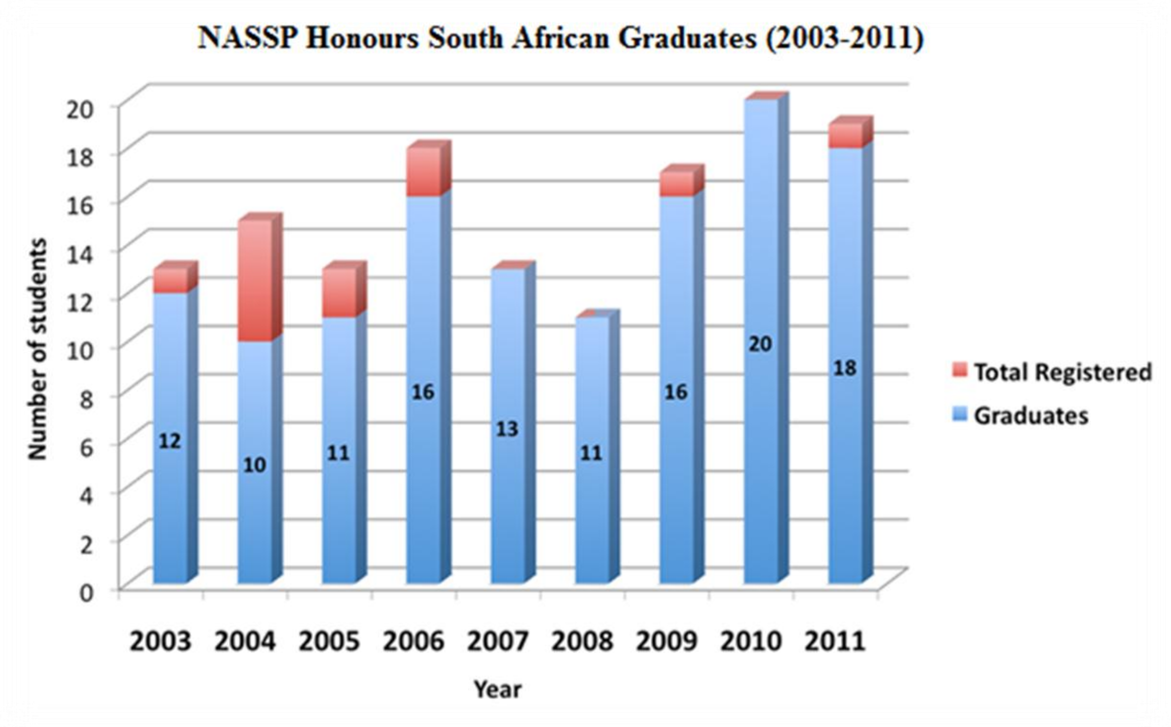


Figure 3. NASSP Honours South African graduates 2003-2011

Figure 2 shows the total number of students who enrolled for the NASSP in the year 2003-2011. It also shows the number of students who successfully graduated in each year. Figure 3 depicts the number of the graduates in these years who are South Africa citizens. Note that a good number of South African students joining the NASSP Honours programme come from the EHP students thus ensuring a steady flow of black South African students into the NASSP Honours year.

2. Preliminary work

Generally when students are not doing well, or struggling with learning or passing specific subjects, the "tea room discourse"[1] is usually

- that students are not working hard enough
- that students are not motivated or passionate
- that students lack self-efficacy
- that students were taught poorly previously
- that students may have epistemological issues impeding learning

The problem with these speculations without concrete research evidence of why students might be struggling with learning is that the proposed solution is then based on the speculation. If the speculation is that student are not hardworking in the sense of putting time and effort into learning the subject in question, then the proposed solution is that students must put in more time and work harder towards succeeding. However if this is not the problem, and the students are already working as hard as they can, then proposing that students should work harder in order for them to succeed will be of no use towards the goal of learning or succeeding in the subject or course in question.

Another quick assumption that is often made when students are not succeeding academically is that they are not motivated or passionate about what they are doing, and that reflects in their performance. The other variation to that is that students are not confident or lack self-efficacy in the course they are pursuing. If these speculative positions are held, solutions might centre on organising seminars or workshops and motivational speeches to motivate students to be passionate about the course in questions. However, if it happens that motivation and passion is not the problem, then the proposed solution will do no good in addressing the problem at hand.

The fourth and the fifth commonly speculated ideas go hand in hand. These are usually more sophisticated. When students perform poorly at postgraduate studies, it can be easily attributed to a poor learning experience in high school and undergraduate studies. At the early stages of this study we looked at students epistemologies.

[1] By tea room discourse we mean anecdotal speculative ideas often voiced by staff.

2.1. Epistemology in science education

At the early stage of this work I focused on probing students epistemologies as I thought the student's difficulties were only due to poor learning attitudes. Epistemology, broadly speaking is the theory of knowledge; it tries to answer questions such as: What is knowledge? How is it different form belief or opinion? How should knowledge be sought? What is the nature of knowledge?

Recent focus by science educators on epistemology stems from the effect of a learner's epistemology on learning. Lising and Elby (2005) outlined some motivating ideas for the recent focus on epistemology in physics education. These ideas include the fact that student epistemologies may affect their science learning and attending to epistemologies may help:

- Explain variation in students learning and outcomes.
- Create a more effective curricula.
- Produce better physics/science instructors.
- Promote productive attitudes and serve the students well beyond the course in question.

Epistemology has been broadly categorized into two spheres, namely public and personal epistemology.

- Public epistemology encompasses a student's ideas about the nature of knowledge and learning for society as a whole - or for a disciplinary community.
- Personal epistemology concerns a student's ideas about her own knowledge and learning (Perry 1970, Hofer and Pintrich 2002).

2.2. Personal epistemology

Research has showed that students' personal epistemologies have more impact in their learning than their public epistemologies (Hogan 1999). The idea of what constitutes personal epistemology is broad but most studies agree with the dimensions proposed by Hofer and Pintrich (1997). These dimensions include *certainty of knowledge* (ranging from conceptions of knowledge being fixed to being tentative and evolving), *simplicity of knowledge* (ranging from conceptions of knowledge as discrete pieces of information to highly interrelated concepts), *sources of knowledge* (ranging from conceptions of knowledge being derived from external authorities to conceptions of self as knower), and *justification for knowing* ("how knowledge claims are evaluated, including the use of evidence, the use they make of authority and expertise, and their evaluation of experts".)(Hofer and Pintrich 1997)

According to Schommer (1998) a person's system of epistemic beliefs has many substantial implications for learning:

- Students, who believe that learning occurs quickly, tend to read texts more superficially.
- Students, who believe that knowledge is certain, tend to learn facts by heart rather than understanding the meaning of the to-be-learned.
- Students, who believe that learning capabilities are determined by innate abilities, show less interest in activities designed to master complex challenges.
- Students who trust authorities do not tend to challenge the sources of information

However, as noted in a study by Lising and Elby (2005) there is a dual causal relationship between epistemology and learning. Students' epistemologies impact on their learning and the learning context can also shape their epistemologies. If students are exposed to more sophisticated learning approaches they are more likely to recognize when to use a more productive epistemological resource.

2.3. Sophisticated versus unsophisticated epistemology

Generally, researchers who study student's epistemologies have some consensus on what constitutes a sophisticated epistemology (Elby and Hammer 2001). According to this consensus, students should understand scientific knowledge as tentative and evolving, rather than certain and unchanging; subjectively tied to scientists' perspectives, rather than objectively inherent in nature; and individually or socially constructed rather than discovered. However when assessing student's epistemology based on these constituents one must take into consideration the context, and correctness of the item used to probe the epistemology and productivity of the context under study. For this work, the context played a big role in assessing how students' epistemology can impact their success in the NASSP Honours Programme and why I later decided to use a broader theoretical framework. I will discuss this in detail in later sections.

2.4. Probing Epistemologies

Probing students' epistemology is not a straight forward task. One reason this is the case is as a result of the categories of a person's epistemology. There is the personal and public epistemology; there is also the declared epistemology and epistemology in practice. Depending on the assessment tool used to probe epistemology it might not be easy to differentiate which category is being reflected. However, methods generally used include: interviews, questionnaires and observation of learning behaviours of students (Roth and Roychoudhury 1994). I started out by probing students' epistemologies by administering the Epistemological Belief Assessment for Physical Sciences (EBAPS) instrument; a validated instrument which is widely used for this purpose. I also conducted interviews and observed students' learning behaviours.

2.4.1. EBAPS

EBAPS consist of 30 Likert- scale, multiple choice and mini debate items designed to assess students' epistemologies; their views about the nature of knowledge and learning in the physical sciences. Each item on the instrument is scored from 0 to 4 where 0 represents least sophisticated beliefs and 4 the most sophisticated expert-like beliefs. The experts in this case are science educators who have been committed to teaching and improving the nature of learning in science. It was originally developed and validated by Andrew Elby, John Frederiksen, Christina Schwarz, and Barbara White at the University of California, Berkeley. *www2.physics.umd.edu/~elby/EBAPS/home.htm.* EBAPS probes students' views about the nature of sciences along five dimensions:

- *Structure of scientific knowledge*: Is physics and chemistry knowledge a bunch of weakly connected pieces without much structure and consisting mainly of facts and formulas? Or is it a coherent, conceptual, highly-structured, unified whole?
- *Nature of knowing and learning:* Does learning science consist mainly of absorbing information? Or, does it rely crucially on constructing one's own understanding by working through the material actively, by relating new material to prior experiences, intuitions, and knowledge, and by reflecting upon and monitoring one's understanding?

- *Real-life applicability:* Are scientific knowledge and scientific ways of thinking applicable only in restricted spheres, such as a classroom or laboratory? Or, does science apply more generally to real life? These items tease out students' views of the applicability of scientific knowledge *as distinct from* the students' own desire to apply science to real life, which depends on the students' interests, goals, and other non-epistemological factors.
- *Evolving knowledge:* This dimension probes the extent to which students navigate between the twin perils of absolutism (thinking all scientific knowledge is set in stone) and extreme relativism (making no distinctions between evidence-based reasoning and mere opinion).
- *Source of ability to learn:* Is being good at science mostly a matter of fixed natural ability? Or, can most people become better at learning (and doing) science? As much as possible, these items probe students' epistemological views about the efficacy of hard work and good study strategies, *as distinct from* their self-confidence and other beliefs about themselves.

An example of an EBAPS statement, probing student's epistemologies on the dimension of the structure of scientific knowledge is:

In physics and chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one.

(a) *The major formulas summarize the main concepts; they're not really separate from the concepts. In addition, those formulas are helpful for solving problems.*
(b) *The major formulas are kind of "separate" from the main concepts, since concepts are ideas, not equations. Formulas are better characterized as problem-solving tools, without much conceptual meaning.*
(c) *Mostly (a), but a little (b).*
(d) *About half (a) and half (b).*
(e) *Mostly (b), but a little (a).*

A = 4, B = 0, C = 3, D = 2, E = 1

The expert answer in this case is "A" and a student receives a score of 4 if he chose that option, the least sophisticated response is "B" with a score of 0.

2.4.2. Some results from EBAPS

I administered EBAPS to the 9 EHP students in 2009. The survey was administered before they had received any formal instruction in UCT. I started by analysing their responses based on EBAPS dimension. The raw data is shown in Table 4.

Table 4 . Students' scores on the EBAPS axes and overall score 2009

Students	SOK	NOL	RLA	EK	SAL	overall
S1	2.20	1.44	1.00	4.00	2.60	2.18
S2	2.15	2.69	1.25	3.33	2.40	2.33
S3	2.45	2.96	1.75	2.68	1.20	2.37
S4	2.85	3.44	3.63	3.00	3.00	3.05
S5	1.95	2.19	2.88	2.33	3.60	2.63
S6	1.35	2.69	2.63	2.00	3.40	2.42
S7	1.50	3.13	0.50	3.67	3.40	2.40
S8	1.70	2.38	2.00	1.67	2.20	2.07
S9	2.85	2.50	2.50	2.00	3.60	2.68

Table 5. Averaged scored on the different EBAPS dimensions

	SOK	NOL	RLA	EK	SAL
Average scores on the dimensions	2.11 (52.8%)	2.60 (65%)	2.01 (50.3%)	2.74 (68.5%)	2.82 (70%)
StdDev	0.51	0.55	0.93	0.77	0.76
Min	1.50	1.43	0.50	1.67	1.20
Max	2.85	3.00	3.63	4.00	3.60

I noted that the EBAPS results suggested that students have a more sophisticated epistemology on Evolving Knowledge (EK) and Source of Ability to Learn (SAL) and least sophistication in Real Life Application (RLA). Since the students were enrolled for an astrophysics course I suggest that their response to the dimension of Evolving Knowledge was related to the tentativeness of the field. Students' written responses were followed by detailed interviews on their epistemological stances.

EBAPS provided some information about students' epistemological stance; however at a point I was concerned about a number of issues. For one, since most of the EHP students were second language English speakers I was concerned about whether they properly understood all of the questions in the questionnaire. I later confirmed that there were some misinterpretations when I asked some other students with similar backgrounds to give their reasoning as to the EBAPS choices they had made.

I also noted that in general, physics and astronomy Honours courses in South Africa follow a more traditional lecturing format (e.g. "chalk and talk") and are examination driven. i.e. They have a similar structure to the undergraduate courses. However, the Honours year also includes a small project which requires deep content understanding and scientific reasoning in order to be successful. It appeared that these two modes of evaluation promoted conflicting learning strategies: surface learning (for examinations) and deep understanding of content (for the project). Therefore a broader framework was needed to better understand the underlying issues. The prevalence of systemic conflict and tensions within the program suggested a theoretical perspective which highlighted these issues. Hence the decision to use Cultural Historical Activity Framework (CHAT).

3. Cultural Historical Activity Theory

3.1. Why CHAT?

The goal of this study is to understand the nature of difficulties students from Historically Disadvantaged Institutions (HDI's) face as they transit from their undergraduate to graduate studies at UCT. With such a study, it is apparent, that one needs to understand "where the students are coming from" that is their previous learning experiences, the available resources for learning, the community they worked with while learning, the values of the community, and how this shaped their attitudes towards learning.

My aim is to probe the contradictions and tensions these students will face when they transit from undergraduate at HBU's to postgraduate at UCT. Their undergraduate experience, the NASSP, and the University of Cape Town, have their own, inherent traditions, rules, norms and values that governed their activities and objectives. Understanding the transition trajectory in terms of optimizing the possibility of learning can powerfully inform the creation of the necessary structures for their learning as they participate in activities.

The selection of Cultural Historical Activity Theory (CHAT) as a theoretical perspective was then influenced by the requirement for a framework of analysis that accounted for structural and historical factors (where students are coming from) and contradictions and tensions experienced during when students make these remarkable transitions.

3.2. Introduction to CHAT

An enduring problem for those who are interested in human learning has been understanding how cultural experiences shape how people think and act. Vygotsky's contribution to educational research is the way he modelled the recognition that all human action is shaped by what we know (Vygotsky 1978). Put in a simple way we do not simply act on the world or externalise our understandings, but do so in line with how we can make sense of it. The origins of CHAT can be traced back to Lev Vygotsky's work from the 1920s and early 1930s. It was further developed by Vygotsky's colleague Alexei Leont'ev. Vygotsky introduced mediated action as a concept to explain the semiotic process that enables human consciousness to develop through interactions with artifacts, tools, and social influences in an environment. These interactions are the fundamental building blocks for the construction of new meaning in a person's work. Put another way, mediated action involves an interaction between the individual and mediating artifacts or tools and signs, a semiotically produced cognitive tool that resulted from the interaction. Figure 4 is a useful representation of Vygotsky's basic (classical) action mediated triangle (Cole and Engeström (1993), Yamagata-Lynch 2010).

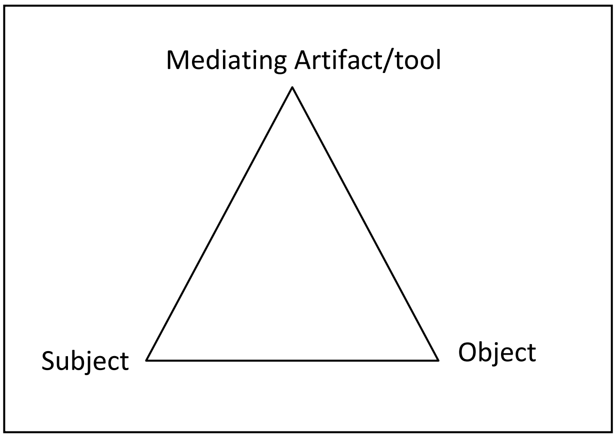


Figure 4. Vygotsky's action mediated triangle (Cole and Engeström 1993, p.5)

Engestrom has argued that a problem with this classical representation is that it does not fully reveal the societal and collaborative nature of actions (Engeström 1999c, 377-406) In other words, it does not depict actions as events in a complex activity system and the outcomes of actions thus appear to be very limited and situation bound.

To overcome this limitation Engeström extended the analysis of individual actions to the analysis of actions within a broader context (Engeström 1987). In so doing he argued that actions are not fully predictable, rational, and machine-like. The most well-planned and streamlined actions involve failures, disruptions, and unexpected innovations. Since these are very difficult to explain if one stays at the level of actions, he suggested the analysis of the "activity system" which may highlight or bring to the fore the underlying contradictions that give rise to those failures and innovations as if "behind the backs" of the subjects (Engeström 2005, p. 32).

In CHAT an "activity" constitutes chains and networks of individual and cooperate actions and the actions are understood with reference to the broader activity system. The suggested model of an activity system also highlights the subject-community relations as an integral aspect of activity systems. Let us have a more detailed look on the concept of the activity system.

3.3. Activity systems

More than a decade ago Engeström called activity theory "the best kept secret of academia" (Engeström 1993, Roth and Lee 2007). This was because in its early stages activity theory was virtually unknown in the western world especially in the Anglo-Saxon literature. Today it is a well-known and well respected theoretical framework in educational research.

Activity systems analysis is a methodology that emerged from Cultural Historical Activity Theory methodology, which presented a way for researchers and practitioners to understand individual activity in relation to its context and how the individual's activities, and the context affect one another (Yamagata-Lynch 2010). Additionally, it can help document the historical relationships among multiple activities by identifying how the results from a past activity affect new activities. The main unit of analysis of activity theory is the activity system, defined as an "object oriented" collective and culturally mediated human activity (Engeström and Miettinen 1999b). Engeström represented the structure of an activity system by including six interacting components with an "activity triangle" as shown in Figure 5. Note also that the interacting components of an activity system are not a static model but it is dynamic and can be analysed at different scales (see section 5.2).

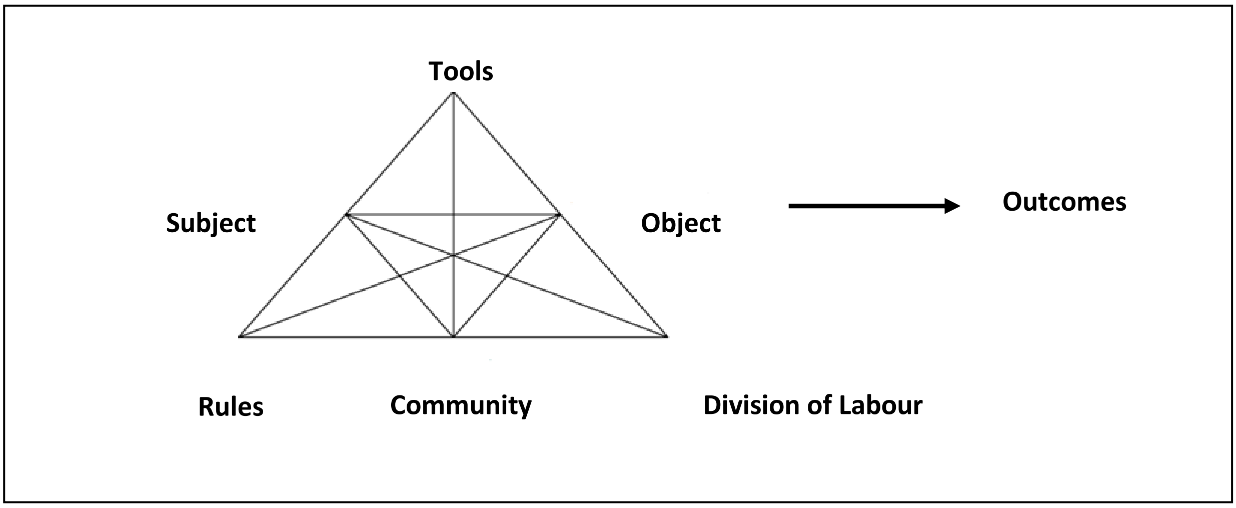


Figure 5. Engeström's representation of the structure of an activity system

According to Kuutti (1996), the components of an activity system include

- **Subjects**: in an activity system, the subjects are the individual or group of individuals involved in the activity. In a classroom system, this would typically involve the lecturers, students and tutors.
- **Object:** the object refers to the “raw” material or “problem space” towards which the activity is directed. The object is moulded or transformed with the help of physical and symbolic, external and internal tools. The object in the activity system is quite broad but it is usually referred to as the common goals that subjects in the activity system are working towards. For example, in a classroom, the object could be development of skills for understanding a particular course.
- **Tools:** the tools as a mediating agent for the object and consequently the outcome of the activity can be either external or internal. In my study examples of external tools used to mediate objects are textbooks, computers, journals etc., and internal tools would be language, mathematics and disciplinary ways of doing things, like solving problems. The available tools and how they are used transform objects to either an intended or unintended outcome.
- **Community:** refers to the participants of an activity system who share the same outcomes.
- **The division of labour**: refers to the division of tasks and roles among members of the community and the division of power and status
- **Rules:** refers are the formal and informal rules, norms and traditions that regulate actions and interactions within the system.

3.4. Principles of activity theory

Engeström (2001, p.136) formulated five principles of activity theory

- The first principle is that the main unit of analysis in activity theory is the *activity system*. Activity systems realize and reproduce themselves by generating actions and operations
- The second principle is the *multivoiceness* of the activity system. An activity system is always made up of a community of multiple points of view, traditions and interests. The division of labour in an activity creates different positions for the participants. The participants carry their own diverse histories and the activity system itself carries multiple layers and strands of history engraved in its artefacts, rules and conventions.

- The third principle of *historicity* points to the history of activity systems as an authentic way to help understand the participants problems as well as their potentials because "parts of older phases of activities often stay embedded in them as they develop" (Kuutti 1996, p.26). Historicity explains (where we are coming from) and how it impacts the system in study.
- The fourth principle of activity theory is the central role of *contradiction.* These are dilemmas, disturbances, and discoordinations internal to human activity that play a role in the activity system (Roth and Lee 2007). Since activities are open and dynamic systems, when an activity adopts a new element from outside, e.g. a new technology, a new rule in the classroom, or a new object, this often leads to tensions. While contradictions generate disturbances and conflicts they can also lead to innovative attempts to change the activity. Four types of contradictions in activity systems have been identified (see next section).
- The fifth principle is the possibility of *expansive transformations* in activity systems. This occurs through reconceptualization of the object and motive of an activity to embrace a radically wider horizon of possibilities than in the previous mode of the activity" (Murphy and Rodríguez-Manzanares 2008b, Engeström 2001). The principle proposes that through the resolution of contradictions in a system a system can develop and transform into better or higher positions than it started out with.

3.5. Central role of contradictions in activity system

Much of the power of activity theory as an explanatory framework rests in the concept of *contradictions* Engeström (1999c). Contradictions and their *tensions* are characteristics of an activity system. Activity systems are dynamic and constantly changing or disturbed by contradictions among constituents. The notion and character of contradictions have been extensively discussed in research studies that adopted activity theory (Barab, et al. 2002, Engeström 2000, Engeström 2001).

Tensions are depicted as double bind contradictory situations[2] where participants innovate, create, change or invent new instruments for their resolution through experimentation,

[2] Double bind situations generally refers to situations of conflict in which a person or group receives conflicting messages. For more discussion on double bind situations and effects see (Bateson 1987).

borrowing or conquering already existing artifacts for new uses (Engeström 1987) as cited in (McCafferty, Jacobs and Iddings 2006). In this ways tensions and contradictions within an activity system are mechanisms that help transform the overall system in unpredictable, restless, mutable way, including ways that may otherwise be suppressed or marginalized in institutional systems (Iddings and Rose 2012).

A basic idea suggested by Engeström, and adapted for Human Computer Interaction (HCI) (Kaptelinin and Nardi 2006), is that a new technology can induce instability and multilevel tensions within or between the systems in which it is applied, and an effort has then to be made so that these contradictions can be resolved for the system to reach a new temporary equilibrium (Kaptelinin and Nardi 2006) that is a seemingly stable condition (Lazarou 2011).

Kuutti (1996, p.34) explains the role of contradictions in activity theory in this way,

> *Because activities are not isolated units but are more like nodes in crossing hierarchies and networks, they are influenced by other activities and other changes in their environment. External influences change some elements of activities, causing imbalances between them. Activity theory uses the term contradiction to indicate a misfit within elements, between them, between different activities, or between different developmental phases of a single activity. Contradictions manifest themselves as problems, ruptures, breakdowns, and clashes. Activity theory sees contradiction as sources of development; activities are virtually always in the process of working through contradictions.*

Engeström (2001, p. 137) explains how contradictions can lead to innovation and transformation in an activity system:

> *As the contradictions of an activity system are aggravated, some individual participants begin to question and deviate from its established norms. In some cases, this escalates into collaborative envisioning and a deliberate collective change effort. An expansive transformation is accomplished when the object and motive of the activity are reconceptualised to embrace a radically wider horizon of possibilities than in the previous mode of the activity.*

Kirsten Foot (2001) provides an analogy of contradictions as resembling door hinges of a special kind known as “concealed hinge”. This hinge is affixed in such a way that on a closed door its two metal planes lie parallel to one another at first glance nearly indistinguishable from each other. When set in motion the planes of the concealed hinge move in divergent directions, revealing their distinction from one another. The space between them increases, exposing not only their inner surfaces, but also whatever lies beyond the hinge plane in the now-expanded frame of sight. He argued that similarly, a contradiction in an activity system consists of two figurative planes or forces which coexist, unnoticed most of the time, linked together as a single entity. Like hinges, the “planes” of a contradiction pressed into motion will move in diverging directions, exposing new facets and dynamics of the activity, and revealing possible directions for the future development and transformation of the activity.

Foot’s analogical description of contradictions has a second dynamics. He went on to argue that contradictions link the fixed” entity of an established activity system, with the mobile entities of its potential expansions and contractions.

By exposing new facets of an activity, and by linking the fixed historically formed activity systems with its mobile future structure, contradictions function as analogical hinges in the analyses of organisations. This analogy ties up well with this study as we would be linking students fixed historical experiences with a mobile present structure (NASSP) and analysing the contradictions that arise in the manner described.

A role of contradiction in learning practices is that it coerces subjects to develop a new orientation or approach towards the object, or goal, of learning and manifest in disturbances that can cause a shift in ideologies and practices by participants.

My impressions of contradictions on a personal level through observations of students during my research are that contradictions would result in positive development if they are “resolved” or managed. Due to the dynamic nature of activity systems, contradictions can be resolved unconsciously, other times a deliberate action needs to be effected in order to resolve the contradiction.

The resolution of contradictions however, cannot be achieved in a “once off manner” as Kirsten Foot noted, they are not “problems” to be “fixed,” and they cannot be quickly transcended through technical solutions. Thus, resolving tensions involves a series of stages in which the participants experiencing the tensions must consider, accept and adopt in order to bring the system to a new equilibrium.

As Nelson (2002, p. 34) describes:

> *Contradictions can either enable learning to progress, or they can actually "disable" it, depending on "whether or not they are acknowledged and resolved".*

However as Engeström (1994, p.22) has pointed out:

> *In order to become a source of substantial learning motivation, contradictions must be noticed, faced, and experienced by the learner as a personal challenge. Typically such an experience means that the learner is made to recognize conflict between his or her existing skill or knowledge and the demands of the new concrete task.*

According to Murphy and Rodríguez-Manzanares (2008b), contradictions may not readily lead to transformation because they may not be easily identifiable or they may not be easily acknowledged, visible, obvious or even openly discussed by those experiencing them (Capper and Williams 2004, Engeström 1993, Engeström 2001).

Capper and Williams (2004) conceive of invisible and undiscussible contradictions as the most difficult to use as spring boards for growth in the context of the work of teams. They see an invisible contradiction as one that is so much part of a team's everyday life that the members do not even recognize it as a difficulty. Invisible contradictions include anything that is taken for granted, and especially covers cultural assumptions about how things are done and how relationships are managed. On the other hand, undiscussible contradictions are those contradictions that nobody ever talks about because they are embarrassing, uncomfortable or culturally difficult to confront. Gender and racial issues in teams, or offensive personal habits powerful stakeholders, are all examples of undiscussible contradictions. While people may not be willing to talk about them openly, they may seriously impede progress towards a given goal. According to Capper and Williams, surfacing invisible or undiscussible contradictions, and stimulating a developmental dialogue around them is the most potentially valuable service that an activity theory based intervention can provide.

Engeström's (1987) four types of inner contradictions in activity systems are shown in the table below

Table 6. Engeström's categorisation of four types of contradictions in activity system

Primary Contradiction	Occurs within each constituent component of the central activity e.g. within the objects Of an activity system
Secondary Contradiction	Appears between the constituents of the central activity e.g. between the objects and the rules
Tertiary Contradiction	Occurs when activity participants face conflicting situations by adopting what is believed to be a newly advanced method for achieving the object
Quaternary Contradiction	When activity participants encounter changes to an activity that result in creating conflicts with adjacent activities

3.6. Examples of Using CHAT to identify contradictions

Activity theory and its use of contradictions for analysis have been used in diverse disciplines and for diverse purposes ranging from medical systems (Engeström 1993, Engeström 2000) to teaching environments (Murphy and Rodríguez-Manzanares 2008b, Berge and Fjuk 2006, Dippe 2006, Fåhræus 2004, Hardman 2005, Peruski 2003, Barab, et al. 2002). Since activity theory has not been used to do the kind of study that I completed in this thesis, I will describe how it has been used in related studies.

Basharina (2007) conducted a process-oriented study which focused on contradictions that emerged in WebCT bulletin board collaboration among English learners from Japan, Mexico and Russia, and explains them from the perspective of activity theory based on two research questions. The first question was: *what were the contradictions that emerged in the project under study, and what were the underlying reasons for those contradictions?*

The study identified a) two intra-cultural contradictions: to post or not to post on a bulletin board, to sound formal or informal; b) three inter-cultural contradictions: unequal contribution, genre clash/plagiarism, clash of topic choice; and c) three technology-related contradictions: message overload as hindering community formation, bulletin board as too "slow" when compared to chat, and names and gender confusion. It further highlighted the need to guide students and consider their expectations and beliefs related to technology use.

Dippe (2006) investigated a nationwide Swedish distance education programme. Data source for this study involved mainly quantitative analyses of students completed web-based and paper based questionnaire; with agree/disagree options and a comment field for each statement. The students were encouraged to use the comment fields to elaborate their answers. The research question was formulated thus: *what practices and contradictions for the students and the teachers emerge due to the design characteristics of the programme*?"
Such an analysis suggests that there was a contradiction between how the programme was presented and how it was carried out in a number of cases. There were also conflicts, not only between teachers and students, but also between senior university management and some of the course leaders and teachers which led to an interesting finding that the students perceived many teachers as being absent in the discussions online.

Barab et al. (2002) used activity theory as a theoretical and analytical framework for a study on how undergraduate students learn astronomy concepts while developing models of the solar system with a computer-based 3D virtual tool in a project-based course. Data sources included videotaped students group interactions, teacher interviews, field notes, student created, 3D models of the solar system, and other student produced materials. The analysis of data that identified contradictions in this study followed a process as described by Murphy and Rodríguez-Manzanares (2008b). The description points that analysing data with a focus on contradiction can involve a phase of analysis in which researchers "zoom in" on the analysis through a more specific or narrow lens. Barab et al. (2002) investigated "the relations of participants and object" in order to identify pervasive or overall tensions in the course.

The Barab et al. (2002) study also describes how groups of students came to understand both scientific and technological concepts from a series of activities that helped them build robust understanding of the course content. Additionally, they conducted an analysis of systemic contradictions related to undergraduate introductory astronomy courses. The authors went on to suggest that instructors should identify contradictions in their setting and consider how these influence classroom culture and how to balance them.

There is little work done in using CHAT and activity systems to study postgraduate learning environment particularly in the context that I have described in this thesis. In this way, this work contributes to the extension of research studies that have drawn on activity theory to investigate the role of contradictions in a system in order to inform pedagogy, didactical and curriculum development.

In order to utilize CHAT in understanding the nature of difficulties students face when making critical transitions the research question this study is:

From the perspective of Cultural Historical Activity Theory, what is the nature of the contradictions and tensions that South African students from Historically Disadvantaged Universities face in their transitional trajectories when entering the highly demanding National and Space Science Programme that is located at the University of Cape Town?

As a starting point, in order to use CHAT and its principle of contradictions, there are two main stages involved; the first is to *describe the system* and secondly use the description to *identify the contradictions* in the system.

4. Data gathering process

Before I describe the system under study, I present in this chapter the processes used in gathering data for this project.

As noted in Kvale (1996) familiarity with the content of an investigation is not obtained only through literature and theoretical studies. It is necessary to immerse oneself in the environment shared by the subjects under study. This will provide insights into the local language, the daily routines, and power structures.

My attempt to familiarize myself with the context of the study involved observing the selection of students for the winter school and for the EHP. In those programmes, I observed that attention is paid to capabilities in candidates and selection committee members are committed to obtaining the best candidates for both the winter school and EHP. Demonstration of interest in astronomy and good academic record is a general criterion for selecting students for both the winter school and the EHP. The increasing number of applications shows that the HBU's and its students are increasingly aware of astronomy and the NASSP in South Africa.

I also observed the winter school activities, including the social functions. I took notes and administered diagnostics tests in the winter school. In the first year of the research I taught the EHP students a section on Fourier Transforms for about 2 months. As I got more involved in the studies I documented my notes and began to build up on the preliminary work.

This research also borrowed from ethnographic research methods (Otero and Harlow 2009). Through extensive engagement of the researcher within a community, ethnographic research aims to build models based on both insider and outsider perspectives (Riemer 2008). As the researcher I had relatively free access to the broad range of activities of the EHP. As I mentioned earlier, I taught a group of the students for a while during pilot studies. After that year I became less involved in terms of teaching but participated in some lectures. In 2011 I and my supervisor sat through, observed and videotaped 35 lectures of the intermediate electromagnetism course (PHY2A)[3] which the EHP students were taking. During the observations we were careful to be unobtrusive.

In this research work I utilised a mixture of both qualitative and quantitative methods and used multiple methods of data collection. Observation was intense and was conducted over a relatively long period of time. I tried to gain an overall view of the issues and the context of study and then later purposefully sampled the group of students in order to collect data that represent the range of realities of participants in the context setting.

4.1. Surveys

Data sources included surveys used to probe epistemologies; in particular I used the Epistemological Belief assessment for Physical Sciences (EBAPS) (Elby n.d.). I used this survey extensively during the pilot studies to gain insight into whether students' difficulties were largely due to epistemological issues. I used it as one of the diagnostics tools during the winter school, as this gave us some perspective of the students' beliefs in regards to knowing and learning. I also administered the EBAPS instruments to other students with similar backgrounds. Upon analysis of our data, I had some concerns about whether the EBAPS statements were understood by the students the majority of whom were second or third language English speakers. I had evidence from students with similar backgrounds and second language English speakers that some of the statements were misunderstood when I asked the students to elaborate on their choices using a subset of the EBAPS survey. Other surveys administered were identity surveys (Li and Demaree n.d.) used to gain insight into how students situate themselves and feel about being in the physics/astrophysics community.

4.2. Interviews

Interviews were conducted throughout the three year period of the research. All interviews were semi-structured. At the start of the project most interview questions were open ended and broad as this allowed for issues to emerge in a natural, unbiased way. (This approach to interviewing is suggested by grounded theory (Strauss and Corbin 1990). Most of the issues that arose were then later probed objectively in a more structured way but still allowing for

[3] PHY2A is a second year intermediate level electromagnetism course, detail are in chapter 7

new ideas to emerge. Interviews generally lasted between 45-minuites and one hour. The last set of interviews conducted for the students and a few staff lasted for one hour.

In the interviews, I had usually structured an 'interview plan' but I was flexible with it and digressed when I thought it was necessary either to explore a new ground, or to allow the interviewee to express themselves in more depth when I observed something interesting, or just to put the interviewer at ease before continuing with the interview plan.

In order to recognize incidents of tensions I adopted process-oriented questioning usually at the start of the interview. Process-oriented questioning facilitates the investigation of key points of transition in the activity under study (Seaman 2008).
According to Charmaz (2003) such questions might include the following:

- When did you first notice your feeling of "X"?
- When is "X" most evident? What is going on when "X" is evident?
- How has your experience changed over the past day (week, month, year, etc)? When did you notice this change happening? What did you think it could be attributed to?
- What made you decide to do...?
- Is there one instance that jumps out as significant? What was going on when this happened?
- What led up to this experience? What was going on around this event? What happened afterward?

All interviews had elements of the questions above. However they were modified to suit the particular context being probed. As themes emerged from the gathered data, I also asked direct questions to gain more understanding on themes which we had previously identified as points of tension or change.

Interviewees included EHP students, Post-EHP students, some lecturers involved in teaching courses in which the EHP students were participants, and the coordinator of the EHP programme[4]. All interviews were very relaxed but a degree of formality was utilized in the sense that they took place either in my office, the physics seminar room, or a lecturer's office. The presence of a small video camera for recording in the individual interviews also added to

[4]The coordinator for the EHP programme is also the supervisor for this project.

the formality of the interviews. On some occasions I, my supervisor and an external evaluator had group interviews with the different cohorts of students that have enrolled in the EHP. On other occasions we had group meetings with current and previous EHP students to foster a mentoring scheme where the previous students can mentor and advice the incumbent EHP students.

During the individual interviews I played the role of an "emphatic listener" (Maxwell 2005) and did not express my own opinion on the issues raised. As the researcher, I endeavoured to play the insider-outsider role during the interview with the students. I was an insider in the sense that I could relate with some of the experiences shared by the students, however I was aware of the dangers of the insider perspective which has the potential to make untested assumptions about the participants' meanings (Glesne 2006, Minichiello, Aroni and Hays 2008). To avoid this potential problem, I assumed the position of an insider and that of a stranger, or cultural outsider. As an example, during interviews I adopted as best as I could the mind-set of a learner (Glesne 2006), suspending my assumptions and judgments and seeking detailed explanations of the information given by the participants in the interviews.

During the final set of interviews, students showed more enthusiasm in the interviews. Most students showed up for the interview on time and with a positive attitude. A debrief of one of the students after the interviews showed that they seemed to benefit from the interviews. This particular student spoke in depth about her experiences in the programme. At the end of the interview I asked how she felt about speaking on these issues she replied:

"*We should do this more often (laughs), the interviews helps me put things in perspective and talking about it helps a lot"*.

4.3. Student products

I perused tests, examinations and worksheets of the students in the electromagnetism (E&M) courses at the EHP level. For almost all the students, the course in which they had the most difficulty was with the E&M and the plasma physics course in the Masters level[5]. So after assessments I would request the scripts of the students and see how they performed, what

[5] E&M for the EHP students involved an E&M course in EHP year, and E&M course in the Honours year and a Plasma Physics course in the Masters year

they did well in, where the difficulties were, and what problems and concepts they struggled with. During the interview process, I asked some students questions about the examinations and worksheets to find out their perspectives on them. I also interviewed the lecturers on the students' performances in these assessments to get an overall and complete picture of student versus lecturer expectations.

4.4. Focus groups/Self reflection

I and my supervisor had focus group meetings with the EHP students in 2011 during the first semester. We used the focus group as an avenue to track emerging tensions and to note how they were being gradually resolved or regenerated. Focus group meetings usually involved asking students on how they felt about the different courses they were taking in the semester. In the focus groups we usually asked students to rate themselves using a numerical scale as to how well they were coping with the individual courses. It was interesting to observe their changing responses as they went through the semester. We also developed a self-reflection questionnaire at the beginning of the semester. The self-reflection also asked open questions about how students felt about the individual courses and how they felt generally about everything going on.

4.5. Personal Meaning Map (PMM)

Preceding the group interviews conducted by an external evaluator of the EHP programme, each student completed a Personal Meaning Map (PMM) (Falk and Adelman 2003, Falk, Moussouri and Coulson 1998). The personal meaning map involved a blank sheet of paper with the word "Astrophysics" typed in the middle. These sheets were given to the students and asked to write as many words, phrases or pictures that come to mind when they think about astrophysics.

4.6. Video and personal observations

My supervisor and I observed and videotaped the intermediate electromagnetism course based on the textbook by Griffiths (Griffiths 1999) consisting of 35 lectures. We also took extensive notes during the lectures. I also made notes during informal meetings such as lunch meetings with all the EHP students.

4.7. Overview of data analysis methods

I triangulated the data sources gathered by identifying key guiding research questions. I then gathered the analyzed data from the various sources, made observations and noted trends. Using these observed trends I made some hypotheses in relation to the guiding questions. I corroborated these hypotheses with my supervisor and one other colleague by allowing for independent assessment of the data and modifying them where necessary. I then summarized the findings and concluded from the data sources.

Analyses of the EBAPS survey provided insights into identifying and describing components of the activity system involved in the study. For example, recognising that some of the EBAPS statements were not well understood because they were long and wordy provided a clue as to what possible comprehension tensions students might be facing in other activities they might be involved in. The surveys also helped rule out some untested ‘anecdotal beliefs’. For example, the data from our surveys and observations made it quite clear that students’ difficulties were *not* due to laziness, lack of motivation or a lack of self-efficacy. The analysis of questionnaires on motivation and interest also provided a basis to gauge that students were genuinely interested in the course they were studying.

Different forms of analysis were performed on the videos. Initial interviews were analysed first. I used open coding as a way to sketch out the elements of the activity system (Seaman 2008). Open coding, which captures meanings of a small segment of data, enabled me to begin to ask process oriented questions in order to grasp subjects’ view of the elements. For the later interviews my supervisor, one other independent researcher and I watched the videos several times and identified excerpts that depicted the presence of tensions. In identifying contradictions we looked for tensions, choices, denial, contrast or opposition between two propositions (Murphy and Rodríguez-Manzanares 2008b).

Students’ products which were mainly from the electromagnetism courses were also analysed using established frameworks and findings are discussed in later chapters.

The PMMs were analysed by coding and categorising themes from PMM literatures and emerging themes from the particular data. Details are also presented in later chapters.

Table 7. Summary of data collected during project and description of analysis

DATA SOURCES	DESCRIPTION	ANALYSIS PROCEDURE
EBAPS survey	Administered at different phases to the different cohorts of EHP students. 23 students in total.	Analysed all EBAPS RESULTS grouped according to categories in the EBAPS survey
Individual Interviews	Conducted at different phases of the research and with the different cohorts of EHP students and the broader NASSP community including (non EHP students and staff). All interviews were semi-formal, used grounded theory as an analysis techniques, a total of 42 individual interviews each lasting about one and a half hours.	Looked for episodes indicating the presence of tensions, transcribed episodes and discussed the tension indicated.
Group interviews	3 Group interviews for each cohort of EHP students. Interviews lasted about 2 hours with each group. 2 Masters and 6 EHP students (others were away on a course) 7 Honours, and 6 EHP students	Analysed group interview field notes for contradictions in the different years of the NASSP programme
Identity survey	Administered a survey having about 22 statements probing confidence, learning attitudes, expectations and students' views on how they situate themselves in the community. 6 Masters, 7 Honours, and 6 EHP students.	Looked for tensions in written text, and insight into students' perceptions of astrophysics.
	Prior to the group interviews. Blank sheet - "Astrophysics" typed in the middle. Students	Coded for themes in previous PMM literatures,

Personal Meaning MAPS	were asked to write as many words and phrases or diagrams that comes to mind when they think of “astrophysics”	noted emergent unique emergent themes from the data
Video	Videotaped 35 lectures of intermediate electromagnetism. Each video lasted about 1 hour. Class consisted of three distinct groups including the EHP 2011 cohort	Used to analyse a sub activity system of an intermediate electromagnetism course
Student products	Student weekly problem set, hand –in exams and test from the electromagnetism class	Analysed using Bloom taxonomy, also reflected on during interviews
Focus groups	Six weekly focus group meetings with the students discussions about courses and general experiences	Used to also identified major tensions during focus groups
Winter School expectation and learning Questionnaires	Questionnaires probed students’ previous learning experiences and their expectations and motivation for the EHP programme and astrophysics in general	Analysed for students’ motivations and expectations and tools used in previous learning prior to postgraduate
Winter School E&M and general Physics questionnaires	Series of E&M and general physics questionnaire, including conceptual and mathematical questions.	Used as a gauge for students preparedness level for the EHP programme.
Personal Observations	Personal notes observations including formal and informal meetings.	Analysis of context of study.

5. Describing the activity system

5.1. Context of the study (a brief summary)

The EHP students in this research study are generally from HBU's. Most students from HBU's are second and third language English speakers. HBU's in South Africa were established by the apartheid government to serve black students who were prevented from attending Historically White Universities (HWUs).

HBU's were poorly funded and the poor funding affected their output adversely. Post 1994, with apartheid and segregation at universities abolished, the HBU's experienced other problems in addition to their inherited legacies from the apartheid years. According to Ilorah (2006) they remain poorly funded and their incoming students comprise mostly those from financially disadvantaged and rural backgrounds. Most students from HBU's can hardly afford to buy textbooks, software or other necessary materials needed to obtain a proper education. The fact that HBU's were under resourced also manifests in the universities having poor libraries, inadequate teaching staff and the scarcity of educational facilities and resources. In general, the high schools attended by these students also suffer a similar lack of facilities and resources.

From the interview data[6], I gathered that all the EHP students are either second or third language English speakers. The majority are the first university graduate in their nuclear families. The students enrolling for the EHP are usually 'good students' in the sense that they had previously obtained good results from their universities prior to coming to Cape Town.

As mentioned earlier, there has been a lack of successful participation of South African black students in the NASSP. Generally, the 1 or 2 South African black students who enrol for the programme usually have difficulties succeeding academically both at the NASSP Honours and the EHP level. These difficulties are usually reflected in the marks obtained in the individual courses and the total averaged final mark. A minimum of 50% average mark is

[6] I had series of semi-formal interviews with different cohorts of EHP students

generally required for students to be accepted into the NASSP Honours. While an average of 60% is required for enrolment into the NASSP Masters.

5.2. The NASSP activity system

Since I am considering students transiting from undergraduate studies at HBU's to postgraduate studies at UCT, I cannot study the subjects by themselves without considering the situation and context in which these transitions are made.

The unit of analysis then is the person in the situation, not the person as a separate entity. Activity theory with the unit of analysis being the activity system helps us to describe the system in a manageable way as long as its character of being dynamic is acknowledged. To give more insight of where contradictions or tensions might emerge from let us look at the undergraduate system and postgraduate system in the context of activity theory. In order to study an activity system it is important to ask the questions shown in Figure 6.

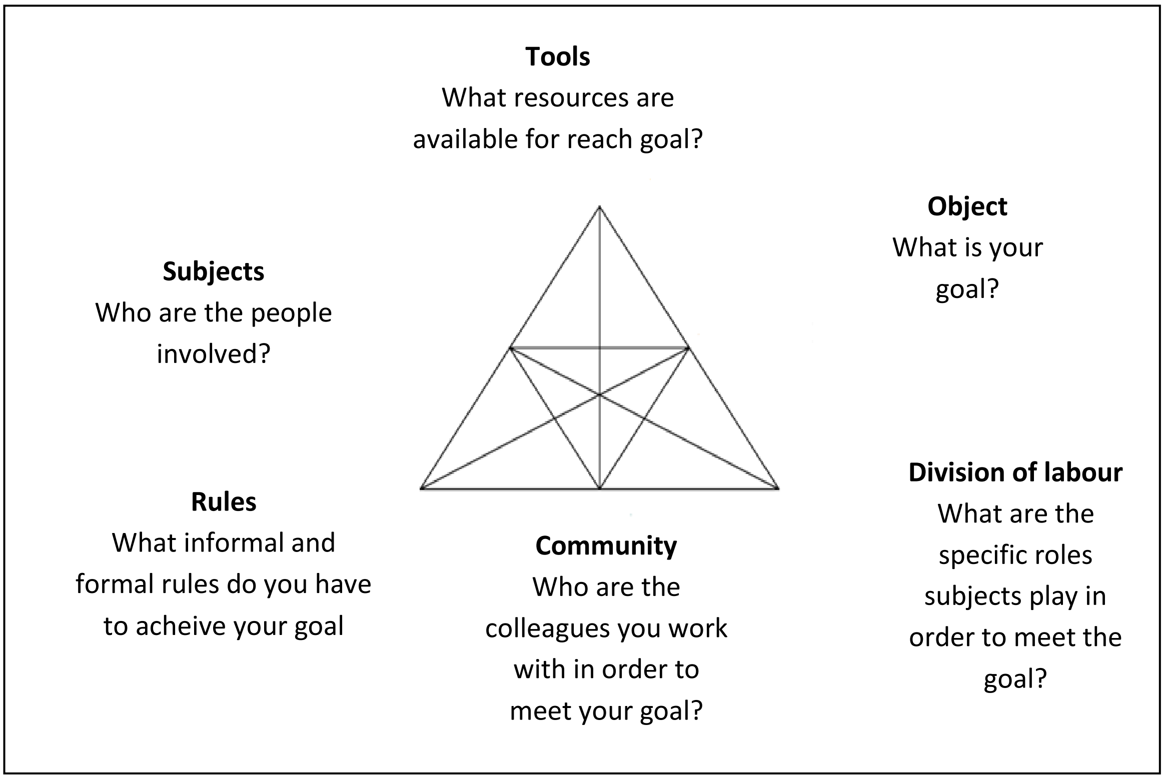


Figure 6. A basic activity system with its major components highlighted

The subjects being the EHP students, I used mainly two principles of CHAT: historicity and contradictions. It was necessary for us to understand "what used to be" and "what is now", as a result of students making a transition from undergraduate studies at HBU's to postgraduate study at UCT. Figure 7 shows an overall transition of subjects from one activity system to another. The structure of the activity system looks the same, the subjects represent the same individuals, but the other components vary in diverse ways. I will use the term (U,H) to represent the component of the activity system at HBU's and (P,C) to represent components of the activity system in postgraduate study involving the NASSP at UCT.

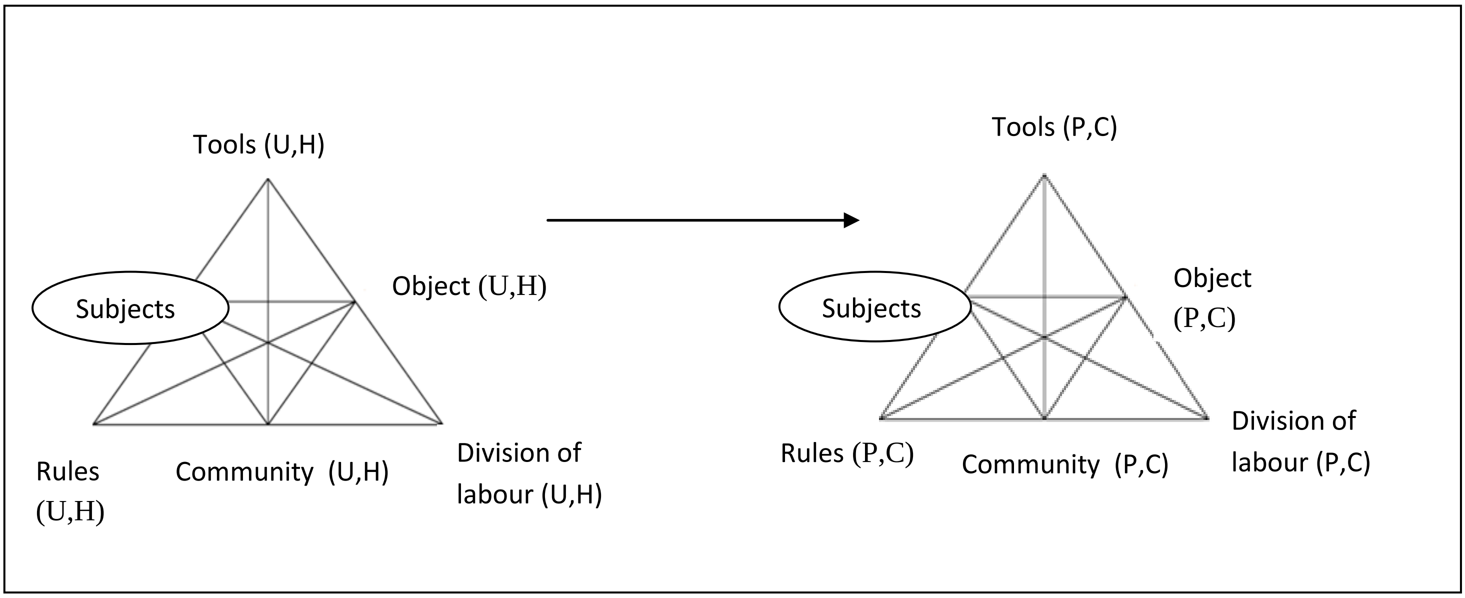


Figure 7. Transition from undergraduate to postgraduate activity system. Each system is influenced by social, cultural and historical factors

In order to avoid the diagram looking clumsy I have excluded the details of what each component consists of in representing the two activity systems.

As with most activity systems the NASSP activity system is complex due to its dynamicity. However I identified an activity system common to all the subjects shown in Figure 8.

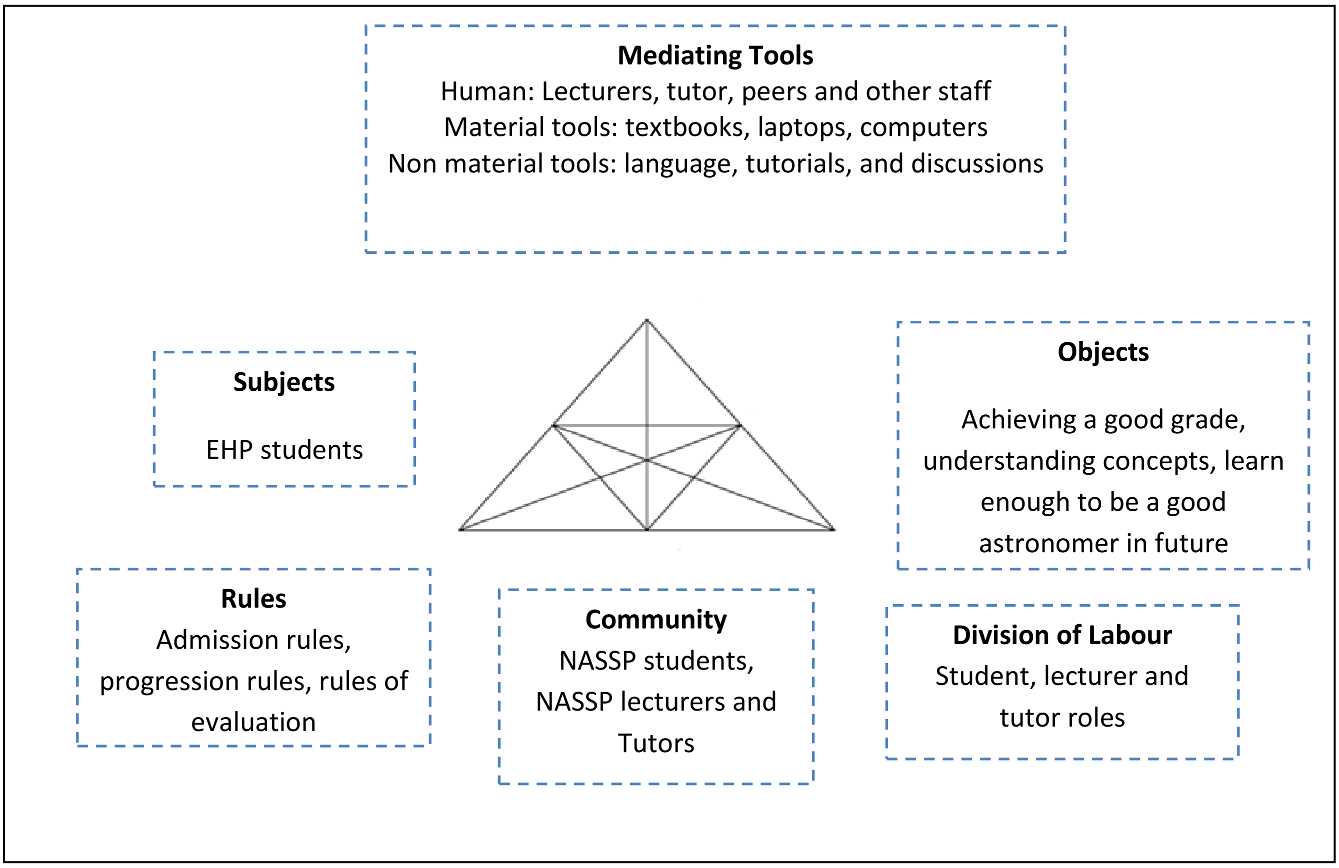


Figure 8. Structure of the studying (NASSP) activity system

It should be noted that the activity system as represented in the diagram above is not static. Rather when viewed from different vantage points and from different points in time, it may be construed and represented differently (Barab, et al. 2002). Activity systems can be understood and analysed at different levels. Barab, et al. 2002 explained how every macro level unit of analysis can be conceived as a collection of micro level units of analysis. Therefore there are many different scales of activity system, such as an activity system of a single course which is embedded in the larger scale of the activity system of the NASSP.

Rules controlling the NASSP system include the pass mark of 50% to continue from the EHP to the Honours, the 50% pass mark for the Honours but 60% mark to qualify for a NASSP Masters. There are a variety of tools (resources) available for the NASSP community. These include human tools, material tools and artefacts. Human tools consist of the lecturers and the staff, while material tools include textbooks, laptops, computers, and software. There are also 'non-artefact tools' needed to achieve the goal(s) and these include language, questioning and querying (Rambe 2010) . The community involves NASSP lecturers, tutors and administrators and NASSP students. For all the students *a shared object* will be to pass the courses and also to get some conceptual understanding of the material presented in the course. As mentioned above, it is important to emphasize that the activity system as represented in the diagram is not static but is *dynamic*. This means that the tools and objects of the broader system may change over time and may also depend on the particular point of view. For example, a tool such as language might be an object if the students were attending a language course. The desired outcome of the activity system would be for the subjects to acquire skills, including practical, theoretical and conceptual understanding of topics. In the next chapter, I highlight the nature and levels of contradictions in the overall system.

6. Identifying contradictions in the system

In order to identify the contradictions in the system two independent researchers watched the videos several times. We noted and marked the episodes that indicated that a contradiction was present. In this project we defined contradictions as tensions, choices, , contrast or opposition between two propositions (Murphy and Rodríguez-Manzanares 2008b). We used the suggestion made by Lofland, et al. (2006, p.108) where only deep, insightful, and detailed responses that were deemed valuable for analytic development were transcribed (see some examples of transcripts in appendix 1.3). According to Engeström (1987) and Yamagata-Lynch and Michael (2009), inner contradictions in a system can be grouped into four types as shown earlier in Table 6. I then grouped the contradictions according to these types. I observed all four types of contradictions in the overall system. For this thesis I show some illustrative examples of the contradictions in each type. In each section a student quote has been selected to represent the tension or contradiction. The quote is first provided and a commentary is given afterwards. The originality of the students' statements is preserved and given that English is the second or third language of all of the students interviewed, there may some grammatical errors in the quote. This applies for every quote throughout the thesis. In each quote the use of an ellipsis, "…", indicates a pause, an incomplete sentence or prolongation of word. A line space before "…" indicates that some sentences have been left out. Any words that are bracketed in the quote are not directly from the interviewee but included to clarify what I think the interviewee meant.

6.1. Primary Contradictions (P)

Primary contradictions, also referred to as double nature, are those which occur within the components of the activity system. For example, within "subjects". It can occur when subjects (students) encounter more than one value system attached to an element within an activity that brings about conflict. As Engeström noted the primary contradiction of all activities is that between the exchange value and the use value within each element of the activity system (Engeström 2001). Similarly one major primary tension we noted from observations, interviews and analysing students' products is that of a contradiction between studying for understanding and studying to get good grades or at least the required grades to be able to go further in the NASSP. The excerpt reflecting these conflicts is shown below.

6.1.1. P1. Tension between personal sense making and grades (Object vs Object)

Interviewer: *Do you see a connection between your understanding and getting a good grade?*

Student: *For some of the courses…yeah…for some of the courses I had to memorise the question papers... cos I couldn't like really understand....not that I couldn't understand…Not that I really didn't understand but more of there was too much work and I was getting confused, because you will find like...Gazilean (Galilean) formulas to do the same thing, but then you find they want specific formulas for specific thing. So it's more of they want you to you to memorise it and then you find that you are stuck between memorising and understanding and then the pressure and time…you can't understand now and then you have to memorise…you see that kind of thing...yeah so if that's what you were asking...I can say there is a connection between the two (laughs)*

Interviewer: *between which two now?*

Student: *between my grades and memorising... and now you are thinking ok the way you understand it, chuck it away and now you have to use their method...Cos another thing I had (coughing) ....another problem I had similar to that was with the CM...tell me what's his name (hitting head trying to remember) .... the lecturer that was teaching CM.*

Interviewer: *what is CM?*

Student: *Computational...*

Interviewer: *Methods?*

Student: *Yeah...like he had ways of solving a problem where we had to create bins and I didn't understand his method so I used my own method, it was a bit longer than his but then it worked (laughs)...you know....and like…like I could follow it step by step and understand what is going on, and then when he marked the paper, he said that…like.... its good but then....(Shaking head) not that it is good- he marked it correct but then he said that it's a poor method. So now you are stuck with the problem of ...ok I understand this, i don't understand his method and I am going to write the exam. So if he ask me the question, what is he going to mark like...is he gonna still give me mark or is he gonna reduce because he wanted it his way, so it's like very stressful sometimes...*

It might be interesting to mention that the student who is being quoted here has previously been interviewed and completed an EBAPS survey. The EBAPS survey score and analysis of the interviews with the student on general learning behaviours reveals that the student has a fairly sophisticated epistemological belief about learning. During the open coding I already noted that there could possibly be a complex tension of trying to understand concepts versus being strategic in obtaining good grades.

The excerpt above reveals a tension between personal sense making and her marks or grades. The personal sense making is also influenced by an authority figure[7]. A double bind situation exists here which confuses the student. The two messages here are that personal understanding leads to fulfilment but it might have a catastrophic effect if it also leads to a poor grade. Towards the end of discussion on the issue the student noted that:

"at the end of the day it is your grade that counts''

The NASSP community values personal ownership and understanding, but the "gate keeper" that allows one continuous access to the community is a mark or grade which more often than not, forces students to use other strategies such as strict rote learning which does not aid understanding and personal ownership.

6.2. Secondary contradictions (S)

Secondary contradictions exist between the components of an activity system e.g. between subjects and community or between rules and objects. A number of secondary contradictions in the NASSP activity system were observed, the EHP students being the primary subjects in the system.

6.2.1. Insider-Outsider tensions (Subject versus Community tension) S1-SC.

This first example was taken from an interview with a Post-EHP student now in the NASSP Masters year. The interviewer asked him to comment on the current EHP programme. He said he was happy with the fact that the EHPs now take some courses with the regular UCT students. According to him, this was relevant as he felt it is a big leap if the EHP students

[7] It is deduced that the student was influenced negatively by the "authority", yet the authority in all likelihood was trying to be encouraging by rewarding the sense making and pointing at another more standard method

were only taking EHP courses and all of a sudden moved from their rather small sheltered group, to the larger group of 19 people when they get to the NASSP Honours year.

Student: *...last year, that's why I was saying it was a…a whole new ball game...ummh...it was the time we were doing with UCT students...ummh....yeah and everything changed! I mean it was…it was…new faces...ummh, new ideas, new everything...so yeah…*

Interviewer: *when?*

Student*: last year*

Interviewer: *ok, when you got into the Honours?*

Student: *Exactly yeah.*

Interview*er: new faces, new everything…?*

Student: *it was not like the…the...a group of seven people I used to go in the class with all the time…all the time...it was 19 so...yeah...even yourself if you are a shy person like me...you will feel shy*

Interviewer*: ummmh (laughing)...why would you feel shy…*

Student: *I don't know...I am like...*

Interviewer: *so you feel shy…among 19 people?*

Student: *(nodding)...yeah… you…you... you…will be listening to them asking...asking…like relevant questions...relevant questions...because they have been to...I mean even when we were visiting, you go to SAAO, you find that people are known there...you re like... how are these people known here? You go to Joburg you find that people are still known there....*

Interviewer: *People in your class?*

Student: *yeah… and you are surprised I mean...you hear that they were doing ...ahnnn...ahnn...I think they...they went a step further than us because they have been doing ahnnnnn...they've been following astronomy from their childhood and when you go...I remember last year when we went to HARTRAO in Joburg. Ahnn…this other girl and this other guy…ahhnn they were two, one of them is from Pretoria, the other one is from Joburg, so this other girl they knew all...everyone there knew her...I think they even claim that they went overseas one time with her and this other guy everyone there knew...knew him because they...they…use to come there when there were in undergraduate doing...yeah. Even at HMO it was the same thing, HATRAO yeah and at SAA0. So I think they went a step further than us before…yeah the…they came to the programme. Most of them…yeah…most of the people who were doing well…so yeah...ummh...So it was easy for them to pass even things which…which…were not taught...(laughs) or something...yeah*

Interviewer: *and that makes you feel shy?*

Student: *that makes you feel shy? No...You…you…because they will be asking relevant questions...because if I did something before …its easier for me to ask good questions and all that…but if I am doing it for the first time, even a question… I will be having a question... that I feel like...annh...anhh...(Shaking head) I will just goggle it or do something, even if I could have got the answer at that time…yeah...you feel shy to ask that question, because the next person...he or she ask a very relevant question which...yeah…yeah (nodding)...*

The EHP students have all completed a Bachelor's degree from HBU's. Most of them only heard about the possibility of studying astronomy/astrophysics at postgraduate level just before attending the winter school. However in the Honours year, the class consists of different groups: the previous EHPs, some students from other African countries, some from other HWUs in South Africa and some who completed their undergraduate at UCT. To this effect, I observed from interview data that the EHP students in the Honours year do not feel like they are "true" members of the NASSP community. This is partly due to the presumed depth of knowledge that the other students in the class have. The tension was observed in the speech and behaviour of the EHP and the Post-EHP students in the Honours year. I first noticed this tension with the frequent mention of the phrase "other students" and "everyone else" in the class" by the EHP students. It seems there is a virtual division in the class according to these different categories.

The implication of these divisions for the EHP students is that it creates a barrier for actively engaging in class or in relating with peers for discussions on class work. It seems most students felt they did not know as much as other students in the class so they would rather not discuss with them so as not to reveal their presumed shallow depth of knowledge. It seems that they felt that one's depth of knowledge of astronomy is related to the amount of time since once first heard about the subject (as this would give one time to get used to the vocabulary and concepts involved). Since they had only recently heard about it, they concluded that they didn't know much. They considered themselves "insiders" in the sense that they were already enrolled for a course in astronomy (some have already completed the EHP), but "outsiders" in the sense that they are still trying to understand a lot of things required in studying astronomy, and most of these things they feel are already understood by the other students in the class.

Another effect of this is that the students don't want to ask questions to the lecturer or the other students who were supposed to be essential sources of help (i.e. essential "mediating tools") for them. They resort to other means such as internet which can sometimes provide misleading information.

For some of the students, tensions also exist between themselves and their lecturers as part of the NASSP community. Some students indicated that they had good relationships with their lecturers back in undergraduate days. Some reasons given for this was the fact that they spoke the same language with most of their lecturers, coupled with the fact that they were "good students". On coming to UCT, the feeling of not following the coursework made some of the EHP students feel like "outsiders"; they felt intimidated by some of the lecturers. Some excerpts that revealed this tension during interviews are presented below.

Interviewer*: How would you describe the relationship between teachers and students at undergraduate?*

Studen*t: at undergrad we were very close with our teachers, ok. I was very close with most of my lecturers because I used to ask a lot of questions, especially to my physics lecturers. So we had a very good working relationship yeah.*

Interviewer*: and here?*

Student*: I have never asked my lecturer questions (laughs) am serious*

Interviewer*: why is that the case?*

Student*: (Heads bowed) I don't know, I get intimidated I guess with the fact that like they expect us…me to know things from undergrad which I sometimes don't really understand. So mostly if I wanna ask a question, I get shy and I don't.*

The "insider-outsider" tension was prevalent in the Honours years also because there was an informal division in the class. The data indicates that the students could recognize four groups and it seems there were some groups for which the system worked well, while other groups struggled. I interviewed one student who did her undergraduate at an Eastern African university before coming into the NASSP Honours. This student succeeded in the Honours programme with over 70%. She recognized and described these different groups.

Interviewer: *it seems they were people with different backgrounds in the Honours class can you describe them*

Non EHP student*: I will mainly categorize it, according to undergraduate maybe…cos it seems there are people that before they came here, they probably had prior knowledge on some of these things or probably the did core physics like the stuff that is deep. Then they are those [UCT students], who had done astronomy in their undergrad then they are those who had not even don't physics in their undergrad that like the EHP people, they had done like mathematics and what… then they are those of us who had done like surface physics.*

…I think it's also the system one is used to because you find out that we are in class and some people seem to have better conceptualization when it comes to subject matter; I think it's the system since the system here is so interactive because where I come from there is not so much interaction. You are given subject matter and you go and teach yourself almost. So it's like there is a lot of interaction here, so you realize we are in class and there are people who are conceptualizing the subject matter there and then and there are giving feedback asking the lecturer questions which you haven't formulated in your mind yet because you are used to been given the notes and the textbooks so that you go back home and study. So for those it's not like they have a good background in astrophysics it's just they are use to a system of been fast…fast with stuff.

The student went further to describe the strategies she employed to succeed in the class. Considering the different academic background in the class, the student gave some insights on her opinion of the NASSP Honours and the EHP. The statement above corroborates the presence of a tension of feeling like an outsider in the presence of other groups which are perceived to be more knowledgeable than the group one falls into.

6.2.2. Subjects versus Community tension S2-SC (Lecturer status versus students learning)

Since the NASSP is a national programme its lecturers have to be drawn from the participating consortium. The lecturers are also chosen for their expertise. Most of the lecturers are well known professionals in the country. However for the EHP students in the Post-EHP year, this produces a tension for two reasons: one, because the students felt the lecturers are "too good" with what they do, so most of them just come to class and "do their job".

Student: *The main problem with the NASSP is that...I don't know… they were trying to take every ummmh...most of our lecturers, they were like…people with high positions…you know like (hands high in the air)…yeah. I mean you can be…you can be in those high positions, top astronomer, but it doesn't necessarily mean that you are...you are a good lecturer or something like that…yeah...*

This highlights a tension when considering teaching as an "object" in the activity system. UCT is a research led university and there is a strong feeling that teachers must be active researchers as this enhances the teaching. However students generally think it is best that teaching is done by those who enjoy teaching.

I also interviewed a non-EHP South African student who completed the NASSP Honours and I noted a different perspective (illustrated in the excerpt below). This also shows us that there are multiple points of view in the community regarding "teaching and learning" within the course.

Interviewer*: can you describe your experience in the Honours year?*

Non EHP student*: …here there was a lot of assistance (comparing with undergraduate), we had tut[orial] sessions with a different person other than the lecturer which is cool, because when we get stuck we could ask the lecturer as well. Here there was the lecturer as well as the tutors and stuff so…yeah I liked that about this programme there was always...they were always willing to help you and if you needed extra tut[orials] they were willing to make time to give you those extra tut[orials] and …yeah.*

6.2.3. Rule versus Object tensions S3-RO.

A second issue with the arrangement of lecturers being drawn from across the country is that lecturers come for a short time as they are usually simultaneously engaged with their home universities. A large amount of material is covered in only three weeks (see appendix for curriculum). From the interviews with the Post-EHP students, this is a major problem for them, especially because they have never been exposed to such a system. While they struggle to adjust to this new system, other students (typically from non HBU's) in the class respond well to the lecturing structure, having already been exposed to something similar before. At the same time the Post-EHP students struggle with revising previously learnt topics which they were supposed to have already covered but didn't really understand. They also have to keep up with the current material which is being presented at a fast pace by "top" lecturers who they feel shy to ask questions to. Below is excerpt of an interview with a Post-EHP student currently in the NASSP Masters.

Student: *…The main main challenge for me…in my...since I got to varsity, I think, the main main main challenges were last year…*

Interviewer: *last year in the Honours? And they were tied to what?*

Student: *They were tied to ummh…it was a completely new ball game for me, the three weeks thing, I never... I had never experienced the three weeks thing in my life...ummh...yeah, the three weeks thing and then you get people in your class who are like most of their lives that's...I mean most of their study they have been exposed to the three weeks thing.*

Interviewer*: which students are you talking about?*

Student: *I mean like students from [non-HBU]…they were doing almost the same thing...three weeks courses.*

The scheme of the lecturers coming in for three weeks and covering a substantial breadth of work (in which students are also tested after the three weeks) impacts on the goal of understanding the concepts and also getting a good grade. As mentioned earlier as a result of historical factors, the EHP students need more time to keep up with the work load. However, for them it seems they get less time to do the work since they have to revise previous work and still keep up with current work. It gets worse when it appears most other people in the class seem to be coping well. At the end of the discussion on this three weeks system, the student related it to its impact on the object of getting a good grade, as shown below:

Student: *You can't complain, even about the test, if you feel like the test was unfair or something, you can't complain if someone comes with a 90 and you got a 40, you can't complain, they will say how did he or she got a 90...yeah so...*

Interviewer: *that's interesting...so if you got 40 and someone else got a 90, where do you think that problem lies?*

Student: *like I said...ummh…one of the reasons was the three weeks thing-that you have to do everything in three weeks and you write a test about a scope this big (hands wide apart)...ummh yeah, it was mainly that, mainly that...because most of us we had never been exposed to such things...yeah.*

I interviewed a black South African female student who had completed her undergraduate degree at a non-HBU in South Africa and gained direct entry to NASSP. At the time of the interview she had completed the NASSP Honours. This contradictory experience also depicts the multivoiceness of the system.

Interviewer*: What's your opinion on the three weeks lectures you people were having?*

Non EHP student: *I honestly didn't mind because they were really good lecturers and I got so much from those three weeks than some other lectures which weren't so good. I mean I prefer having a really good lecturer for three weeks who knows what he is talking about than have having someone who doesn't really…not really a good lecturer explain stuff for a whole semester like the whole term I really enjoyed (mentions a specific lecturer) .*

6.2.4. Rule versus Object tension S4-RO. (Available time conflicting with grades and understanding)

Student: *Another thing I learnt here at UCT is that they don't give you time to think in the exam-its time to apply. So once you start thinking in the exam, chances of passing the exams are slim. The time won't allow you, so if you fail to plug everything that you know as quick as possible, you will fail the exam.*

UCT is noted for being the highest ranked university in South Africa and Africa at large, yet it has notably shorter semesters relative to the level, scope and workload students have to cope with. As explain above, for the Post-EHP Honours students it gets worse with the "3 weeks lectures" and for all other EHP students the timing tension is compounded by adjusting to a new environment, the fact that they are second language English speakers, historical tensions in terms of how things were done at their previous university, and other local tensions that demand extra time to adapt to or resolve.

A particular problem relating to the time is that of the actual time given to write exams. I observed during early investigations that there were scenarios when the EHP students would look back at their answer to a written examination paper in which they didn't perform well, and feel they could now do the questions and didn't understand why they had problems passing the examinations at first. Though the available time for the examinations is not the only factor influencing the grades but this definitely plays a role. With such a limited time (about 45 minutes for test and about 2 hours to answer the examinations) it is important that the students know what is expected of them during that time. Most students expressed concerns about not knowing what is expected and often answering question either too long or too short or not getting the main point of what is asked and therefore missing the marks.

As most of the students noted, “preparation” for the exams is vital to doing well in the exams. “Preparation” had slightly different interpretations for the different students, but however it was defined, it was clear that they needed more time to prepare, and due to the work load and requirements on the different courses most student did not find the time to prepare.

Student: *Sometimes you don’t fail because you don’t know... I remember we were laughing with... (mentions a fellow EHP student), he was saying that…if you...one thing he has learnt at UCT is that if you start to think then you start to fail...it’s real…because…when I...mean previously... I would like…back at my old university, you go up first year, second year...you try and adjust, third year, you know what is going on, you can manage, you know that if i don’t do something this time, I will be able to handle the next time and I will be able to understand what is going on.*

But here you leave stuff...you leave stuff...for... at bay and then you try...and then you try and do it…say...a day before the test and then you don’t understand it…so it basically…it’s a build-up process, here you have to understand it...

Interviewer*: “so if you start thinking you start failing” how does that comment apply?*

Student*: .... when a problem is given-a similar problem is given, you can under...you can work out your way out of the problem and try and get a solution. Now say he twists everything and gives you a problem- a real problem where you need to apply everything that you’ve learnt into that problem...then you start thinking about the problem, time is going on-the time is going off, then you try to…you don’t solve the problem that you are faced with, not necessarily because you don’t know how to solve it, it’s just that you don’t know how to apply the knowledge that you have learnt in order for you to understand everything….you end up wasting time and you end up not even solving the problem you were trying to solve, you end up doing one problem out of the whole test, or do two problems out of the whole test so...*

It was clear that there was a complex conflict of the time pressure during the exams and thinking critically about the problem to be solved. The strategies used at their previous universities were well understood by them. Most of the students said they could predict questions that the lecturer would ask in the exams. In fact some students said that lecturers would ask students to read the notes given in class and if they could stick to and be able to solve problems in those notes then they are guaranteed to pass the exams. So if thinking about "new" problems or unfamiliar problems was new to them, it then takes more time to be able to adopt this new method. Hence the limited time given to think becomes a hindrance to the students performing well even if they could solve the problem if they had more time.

Student*: …Most of the time I tried to study to understand because I know I have a short memory, most of the times I can't memorize things, I can't. I tried to understand but you find that the time is just…is never enough to do that. Like I said that the preparation time for last year it was one week and most of the exams it was a day difference. So when it's like that you have to memorize things. I even started using past papers in my life last year. Seriously, I had never, I had never, I had never used past papers before. I didn't sleep I started using the past papers for [course x], it felt like gamble because it's something you have never done before to use past questions to study. The question I kept asking myself is what if these questions they don't come-but I didn't have the time. A friend of mine was advising me don't worry they are going to come.*

Interviewer*: and did they come?*

Student*: yeah I think they came because I got and E or so (laughs).*

6.2.5. Tools versus Object tension S5-TO. (Language versus understanding)

Student*: ummh… the test I think the questions were not understandable, but maybe is that we are far from England.*

Interviewer: *interesting…ok, so you think that the language thing was an issue?*

Student: ummh yeah...I think...I think because when you look at the memorandum you see that...ahh I should have done this, but when you check alone when you were there sitting and writing you realize that ahnnn...maybe it's because we are far from England the English is not good

Interviewer: *so...ummh but back at your undergraduate your test and exams were written in English right (student nods yes) and it's also written in English here?*

Student: *yes and then there I used to understand them cos some of the questions were repeated maybe that's the reason (laughing). Because there they don't…they didn't use to hide the words, of what they really want-they will tell you what they want. Here they will play around with the words and then you end up not knowing exactly what you will be solving...*

Tensions emerge when the EHP students are not familiar with the common discourse of a course. This impacts the object of understanding. However I noted that the tension manifested as a hybrid between understanding the linguistic representation and understanding the concept, coupled with the limited time given to achieve the object of understanding.

Toward the end of the discussion of how the student's understanding of English is impacting the outcome of the test and exams in a physics course, the student acknowledged the discourse and semantic issues.

Student: *...actually it's not basically the English itself but how we understand the English of physics.*

6.3. Tertiary contradictions (T)

Tertiary contradictions arise when participants in an activity system face conflicting situations by adopting what is believed to be a newly advanced method of achieving the object on the basis of expectations. The subjects in this study transit from undergraduate at HBU's to postgraduate at UCT and go through the different levels of EHP, Honours, and Masters. The changing system produces primary and secondary tensions which give rise to other tensions some of which are tertiary in nature. The different courses and different levels have different "lives" and adopt new methods or strategies for achieving the object. Therefore adjusting or recognizing what tool to use for what scenario, when to use one tool or another, and when to use one strategy or another, turns out to be a tension for the students (Hewson 1985).

6.3.1. T1. Adopting new attitudes and beliefs about learning ("epistemological tensions")

Interviewer:*... so if you were doing well in a particular course back at undergrad and you come here and you were struggling what will you attribute that to?*
Student: *I think maybe it's just that when we came from...when I came, I thought maybe the system might be different or maybe the things that...the way they do things here is different from our university, but now, since I have already seen how they do their things...I can...when I check the difference I can see that they are the same, it's just that when you start you just think maybe they do…the other way.*

Interviewer: *What other way? How where you thinking it will be different?*

Student: *ok…ummh when I came here like...it's like in my mind I thought maybe we are only going to do research, I thought we are not going to attend classes, something like that you see…that is why maybe when we are taught always wanted to understand everything, I wanted to like, if they are teaching something, I just want to go in...in depth...like I don't know.. I thought maybe is...is going to be something different so on that part I was left behind, so maybe that is why I have struggled sometimes because I thought maybe we are going to do research and if you are taught something you have to go maybe and search on that thing and then maybe to understand it very well, that where maybe I missed the point...*

Tensions were created from adopting new methods and styles of learning and teaching. Most of the EHP students had similar ways of learning at the undergraduate phase, especially with the more mathematical and physics-based courses. For the few EHP students who had done any computational course before arriving at UCT, it was mainly taught theoretically with little or no practice. The students usually knew what the instructor wanted and could follow a set path to achieve the object and get a good grade (Perry 1981). However at EHP, part of the goal was to train students to be more epistemologically sophisticated in order to promote creativity with research in the future (Elby and Hammer 2001).

6.4. Quaternary contradictions (Q): between what is now and how it used to be

A major tension facing students going through the EHP is "historical" in nature. As mentioned earlier these tensions are interlinked and not independent of each other. For purposes of outlining the tensions, I classified historical tensions as those directly emerging from an "outside" activity system which are influencing the current system under study.

Student: *Am not used to getting these marks nobody will take your result seriously if you submit 50 %, especially when other people get 70, 80 what will you then say? I don't know why, sometime I go to (student x non–HBU) room to study and she is watching movie, they don't even work as hard as us, but then they pass, I don't understand, I don't know why.*

Students are usually disturbed by the fact that their outstanding undergraduate results does not always help with learning in the present institution (UCT). Generally though, HBU's may not provide conceptual tools for learning maths and physics in a robust way, students will generally possess some skills in solving algorithms in mathematics and physics. The problem here is that after recognising the new way and style of learning at UCT, it is sometimes the case that students are not aware of how to fill in the missing gaps in the learning and still take advantage of previous skills. Some students feel all they have learnt before is not useful or helpful and so do not use previously acquired skills productively.

Another disturbance is the fact that students selected for the programme were the top students from their classes at undergraduate. Usually most students generally average a 70-80% pass with most courses. The fact that they now usually strive to get through a pass of about 50% for most courses is most depressing for most of the EHP students. Furthermore, most of them don't understand why this is the case[8]. This emotional disturbance and adapting to the new standard and rating are tensions most of the students have to grapple with. The conflict for most students is the importance such grades will have when they have to present their CVs in the market place for jobs.

Disturbances due to economic or financial issues from family and friends cannot be overlooked for this group of students. Most students are the first graduate from their respective families and the expectation after obtaining a degree is to get a job and work in order to provide some financial assistance to the family. Most of the students indicated that the availability of the NASSP fund/bursaries goes a long way to ease this tension in the sense that they don't expect financial assistance from home, but on the other hand the bursaries are only enough to take care of themselves and not their families. Sometimes considering their positions in the family, some students have to extend part of their bursaries to their families to ease the pressure from home so they can focus on their studies. I should mention that not all of them are even able to successfully resolve that tension by doing this, and when the tension could not be resolved in some way it could lead to students dropping out or not being able to focus on the work as noted below.

***Student**: It's quite a pressure because some...sometimes you just wanna close yourself off the family for a while and then you come back and say ok I am...cos every time...like I graduated and I told them ok I am gonna go and study, and one thing they actually told me was that they had their hands full and they won't...they won't be able to fund me...my studies and then I told them it's fine I will be able to fund myself, but they are still stuff I still need from home, so it becomes a problem...like like asking for finances...and then saying...hearing them saying they are struggling its quite difficult knowing*

[8] I gathered this from interviews.

that you have a degree and you could do something to help them but you can't because you know that in order...if you go out, you still need to come back and study again in order for you to get a promotion or... stuff at work. So it becomes a …when you are dealing with family it becomes difficult...

Another aspect of historical tension is from the fact that astronomy and Astrophysics appears not to have been fully embraced by some HBU's[9]. One of the students actually commented that a Head of Department at her former university said to her

Why are you doing astrophysics? It's not for people from here.

Expectations of family and friends for most of these students are to get a job and help the family financially after the first degree[10]. When these students decided instead to pursue degrees in astronomy it creates a *quaternary tension* with family pressures. This tension is increased with lack of awareness by the community on the importance of such pursuit to the community and the country at large.

6.5. Other tensions

Some other tensions which I could not categorize as any of the types described above existed in form of denials, contrasts and blame. These tensions were salient because I believe they also influenced the "object". During interviews it was clear that some of the students did not understand that the tensions outlined above existed and rather than working through them to resolve these issues, they just blamed themselves for the failures and were in denial regarding some of the issues on ground. As an example, it was interesting that an EHP student whom the convener and the E&M lecturer have both observed putting in a lot of time and effort, spending long hours in the physics library and actually engaging with reading materials, felt he did not work hard enough. During an interview with this particular student, when asked what he thinks was the reason for him not getting good marks and passing the courses well, he replied by saying that he felt the basic problem was his being "lazy". Such occurrences of denial and self-blame also came up with other students. When asked what the problem was with the programme, they would say that they "were not able to manage their time well" or simply that they didn't do their best.

[9] One reason is that students cannot easily return to their physics departments for MSc or PhD degrees as there are no supervisors

[10] Most students expressed this tension during interviews

Interviewer*: describe your experiences in the EHP year*

Student: *oh my experiences…, I will be honest for me I did not work hard…I did not work hard this year (visibly shaking head), I will be honest I am not going to lie I did not work hard. I didn't... I, First semester when I started I was working fine at some point but I…at some point I lost my…even second semester the same thing happened even this semester the same thing happened I will be honest so…but the lecturers they were very patient with us they worked with us. Mr A, very thankful to him, and you know…also Mr B, Mr C all of them, they were very patient with us they worked with us…yeah I got no complains it was ok.*

Interviewer: *you said you didn't work hard (student shakes head to indicate no) so didn't read? What's your definition of "work hard"?*

Student*: For instance, I will compare myself for instance…you know if…if you look at, working hard for me is been consistent in the sense that you know that every day you allocate a time for this work, every day you allocate a time for this work and I...I slipped out of that and started off slacking…you know having a day where I didn't do large sums of work and there will pile up to the next day and the next day. You know the usual…and then it will get to when you have to do a rush rush job. Hence I said I didn't… like my peers…worked.*

Table 8. Summary of contradiction types, description and possible sources

Type/Type contradiction	**Description**	**Manifestation of the contradictions**	**Possible Contradiction Source**
Primary contradictions	"Double-nature" in elements of the system (within elements of the system)	Contradictions between getting the required grades and deeper understanding of subjects as object of programme	NASSP system, Gaps in previous academic background, Learning new skills and new environment
Secondary contradictions	Between elements of the activity system	Between NASSP EHP students and the community (Lecturers, tutors and other students) Between the rules of delivering a large scope of work in a short time and the object of understanding the same content Between the rules of assignments deadlines, tutorials, weekly problem sets which are supposed to aid learning but due to time constraint may hinder learning Between different tools needed to achieve object, mainly language and use of textbooks in passing exams.	The Historicity of the NASSP system, The UCT system, individual course rules Social Background, academic histories
Tertiary Contradictions	Adopting new attitudes and beliefs about learning	Tension caused by transitioning from binary stage to constructive stage (Edward, Jeffery and Richard 1998), while still having to keep some	Previous learning styles. Inconsistencies in

	("epistemological tensions")	"binary" methods. Tension is created from inconsistency in the system and constant framing and reframing of activities without a stable mode of operation	the systems. Variation from course to course
Historical Disturbance	Between what is now and what used to be	Used to be top in their classes and now struggling with same content and barely making good grades. Economic and financial challenges for family and self	Academic background, adjusting to new rules, new tools, social economic status
Other Tensions	Denials and contrasts	Not confronting the real issues, blaming self for failures, comparing performance and grades with peers, the feeling of not been good enough Working harder than others and yet not getting even an equivalent reward That other students in the NASSP Honours class are usually over prepared than there are, yet the students think they have an advantage for having done the EHP year	Not understanding what is "going on" why these challenges are present

6.6. Identifying dominant systemic contradictions in the EHP and Post-EHP years.

In section 6.1-6.5 I have discussed tensions which the students who attended the EHP face while at UCT. During this study I also noted that they were specific tensions which were dominant in each year of the NASSP. In order to gain insight into this, interviews were conducted during September of 2011. The first group of students interviewed were the Post-EHP Honours students, who had completed the extended Honours year. This group consisted of 7 students: 5 males and 2 females. The second group were the current EHP students. At the time of the interview they were in the second semester/second half of the year. 6 students in this group were in attendance: 5 males and 1 female. The last group interviewed was a mix of 2 first year Masters students (males) and 1 second year Masters student (male). One of the first year Masters student and two second year Masters students were away at other participating institutions in South Africa.

At the start of the interviews, students completed a personal meaning map (PMM). During the interviews, students were asked to highlight and elaborate on one or two things they had written in the PMM which they felt was most important.

The interviews were carried out in groups as opposed to individual interviews. This allowed for lively interpersonal dynamics and social interactions which lead to novel interview statements. (Kvale 1996). The PMM facilitated the interviews. Interview duration for each group lasted about 1hour 30 minutes on average. The interviewer took notes of responses, comments and behaviours of the students during the interview. At the end of each interview, each student completed an identity survey (Li and Demaree n.d.). Students were asked to rate themselves on a scale of 0-10 about their agreement to statements in the survey. Further explanations on choice of ranking were required for some statements. This provided more insight into the declared reasoning behind the choice of the ranking.

The analysis for identifying contradictions was aided by coding techniques. I first coded interview transcripts according to emerging themes for each group. The units of text on each theme were then coded to identify if contradictions were or were not present. The rules for identifying whether a contradiction was or was not present followed Murphy and Rodríguez-Manzanares, 2008b. I identified major tensions in each group and categorized them according to the Engeström categorization of types of contradictions in an activity system.

6.6.1. Dominant tension in the EHP year: contradictions between activity systems resulting in tensions between the components of the activity system

For the EHP students the dominant tension appeared to be between neighbouring activity systems i.e. between *what used to be* and *what is now*.

Interviewer: *Tell me something you like and something you dislike about the year (EHP year)*

Students in group: *a lot of work…demanding but understand why…sometimes discouraging…nothing wrong about courses but depends on background and how you adjust to the system …it's not about what you know or don't know but about adjusting to the system …really a problem first semester*

The students were currently in their second semester about 8 months into the year, but they could recount that, especially in the earlier months in Cape Town, they had had a hard time adjusting to the system. This appeared to be the dominant tension and all other tensions seemed to hinge on the fact that they had yet to adjust to the system.

6.6.2. Dominant tension in the Post-EHP (Honours): contradictions within and between activity systems

For the Post-EHP Honours students the dominant tension identified was within and between the components of the activity system. The NASSP Honours year is particularly intensive even for traditional UCT students who are familiar with the system. Courses in the year consist of a blend of theoretical and practical topics covering all major areas of modern astro- and space-physics, and are designed for students to acquire a breadth as well as depth. The year is fast paced with invited lecturers from the NASSP consortium visiting for three weeks addressing broad topics in this condensed time. This has been identified as a tension in the overall system. The year is assessment driven, and its core value is a percentage mark which determines if a student will pass the year or not.

Interviewer: *How do you feel about the Honours year?*

Student x in group: *Comparing results with other students…made me feel like I'm less than an astrophysicist… incapable of getting 80-90's… [Knows he is capable], but comparing with peers it doesn't feel good …maybe I don't fit [group members nodded and agreed] but your passion… makes you think twice about that .*

One interesting thing about the NASSP Honours year is that while the pace is fast, and assessment and grades form part of the rules of the system, its object is also for students to be able to have a deep understanding of the courses, and to develop skills. The system itself faces a tension between its object and its rules. This tension between grades and passion was apparent in the student interviews.

Interviewer*: Any other questions before we do the survey?*

Student*: Have to think about their future, Masters and PhD God willing…how do the 'guys upstairs' what do they really expect from us …do they want us to just pass, to do well or exceptionally well … and how does that reflect… my experience in EHP… was struggling a lot with EM, just no I failed even though didn't see result… still find it difficult to get through what I didn't understand …find it hard to ask, hard to relate to peers even, E&M is so important so if it takes time to grasp now, then what is really expected? Want to do it …but barely making it. Eventually reach a point where you have to teach others… how is that going to be possible?*

6.7. Dominant tension in the Post-EHP Masters year: contradiction within objects

The dominant tension observed in the Post-EHP Masters students was also within the components of the activity system. Students are motivated to study astronomy but also feel an obligation to help their community. It seems students have not yet reconciled how to successfully achieve these two objectives.

Interviewer*: what motivates you about studying astrophysics?*

Student: *initially all about knowing more, the pictures on the internet – but as time goes by and start seeing, start asking questions like 'how does this help the other person – someone from where I come from - I don't know how to explain. (I ask how does what he's studying help someone from where he is from) – he explains – he questions this aspect because now this is becoming important to him and he doesn't know the answer – he has the satisfaction of knowing but doesn't know how it helps*

This tension was seen in all three group interviews, but was highly pronounced with the Masters students. A reason for this could be that they had completed their course work and were starting to become integrated into the astronomy research community which has different values. One of the students, a second year Masters student, appears to have found a means to resolve that tension within himself.

Student: *I don't know how...how…how…how...how astronomy would help my community or…or how my studying astronomy would help my community. I would be lying. May be I could help them with ideas or …That's one other thing I was thinking to do someday, like to go to schools and give presentations. Just…basic ...go to schools spend an hour there may be give a presentation about the stars and all those things. Maybe one can encourage them to continue with their studies yeah because most of them is just the matric and those who dream higher its junior degree that's its yeah. I know people from my township…(shrugs).*

6.8. Result of Personal Meaning Maps

Primarily, the personal meaning maps were used to generate interview questions and help students brainstorm ideas before the discussion. The PMMs were analysed using codes from PMMs literature and supplemented with emergent codes specific to these students (astronomy, nature of science and general interest see Table 9. The different themes were counted for the number of times they appeared for each group of students (EHP and Post-EHP). For example from Table 9, 62% of what the EHP students noted in their PMM was coded as astronomy, 12% as nature of science and 8% as general science and interest.

One of the more interesting findings from the PMMs was that significant number of terms indicating stereotypes and judgments were only from the Post-EHP Honours students. This enforces the findings from the interviews that students during different years face different tensions as they progress through the programme.

Figure 9. Example of an EHP student's PMM

Table 9. PMM analysis for group interviews

	Top 3 ideas from PMMs	
EHP	Post-EHP Honours	Post-EHP Masters
Astronomy (62%)	Astronomy (65%)	Astronomy (62%)
Nature of Science (12%)	Nature of Science (11%)	Nature of Science (30%)
General Science & Interest (8%)	Interest (6%)	Nature of learning (9%)
	Honours only codes (10%) Religion, Affect, Stereotype Threats, NASSP	

7. A sub activity system (Electromagnetism)

The electromagnetic theory course is a foundational part of the EHP curriculum as students have to pass it in the Honours year. E&M forms a crucial part of astronomy and astrophysics. This includes the intermediate level electromagnetism taught in the second year which the EHP students participate in. However, many of the EHP students have found this course very challenging. Although they have been exposed to much of the material in question they still find themselves struggling to cope with the course. As part of the broader project to identify students' challenges in the EHP programme, we audited and videotaped the 35 lecture E&M course in 2011. I also interviewed the EHP students and the lecturer on issues about the course. Thus, I studied the activity system at a different scale: at the level of an individual course. I used the same methodology for this individual course that I used for studying contradictions in the system as a whole. This intermediate E&M course has been referred to as the hardest undergraduate physics course. The E&M course, in which the EHP students were involved, consisted of a 35 lecture course after which they had a 5 week tutorial with Dr G to prepare them for the examinations and then a 12 week course which Dr G designed to prepare them for the NASSP Honours E&M course.

CHAT is applied in this chapter and illustrates how historical and systemic tensions impact student learning and understanding. This perspective was useful for understanding the relationship between a learner's previous experience and their current experience and how this intersection might give rise to other tensions in the learning process.

7.1. Course description

In 2011 the class consisted of UCT 2nd year physics majors and 6 EHP students.
Lectures: 35 x 45 minutes each: Monday to Friday: for 7 weeks.

Syllabus: Vector calculus (div, grad and curl), dirac delta functions; electrostatics; laplace equation; electric fields in matter; magnetostatics, magnetic fields in matter; Ohm's law, currents, circuits; electromagnetic induction; Maxwell's equations, Poynting's theorem. electromagnetic waves.

The required pass mark for the course is 50%. The breakdown of the course evaluation is given in Table 10 below.

Table 10. Assessment mode in PHY2A (activity and number of marks allocated)

Two class tests	180
Essay	20
Twelve weekly problem sets	100
Laboratory reports	200
Final examination	500
Total	1000

The CHAT model of the studying activity system (E&M course) is given in Figure 10 below.

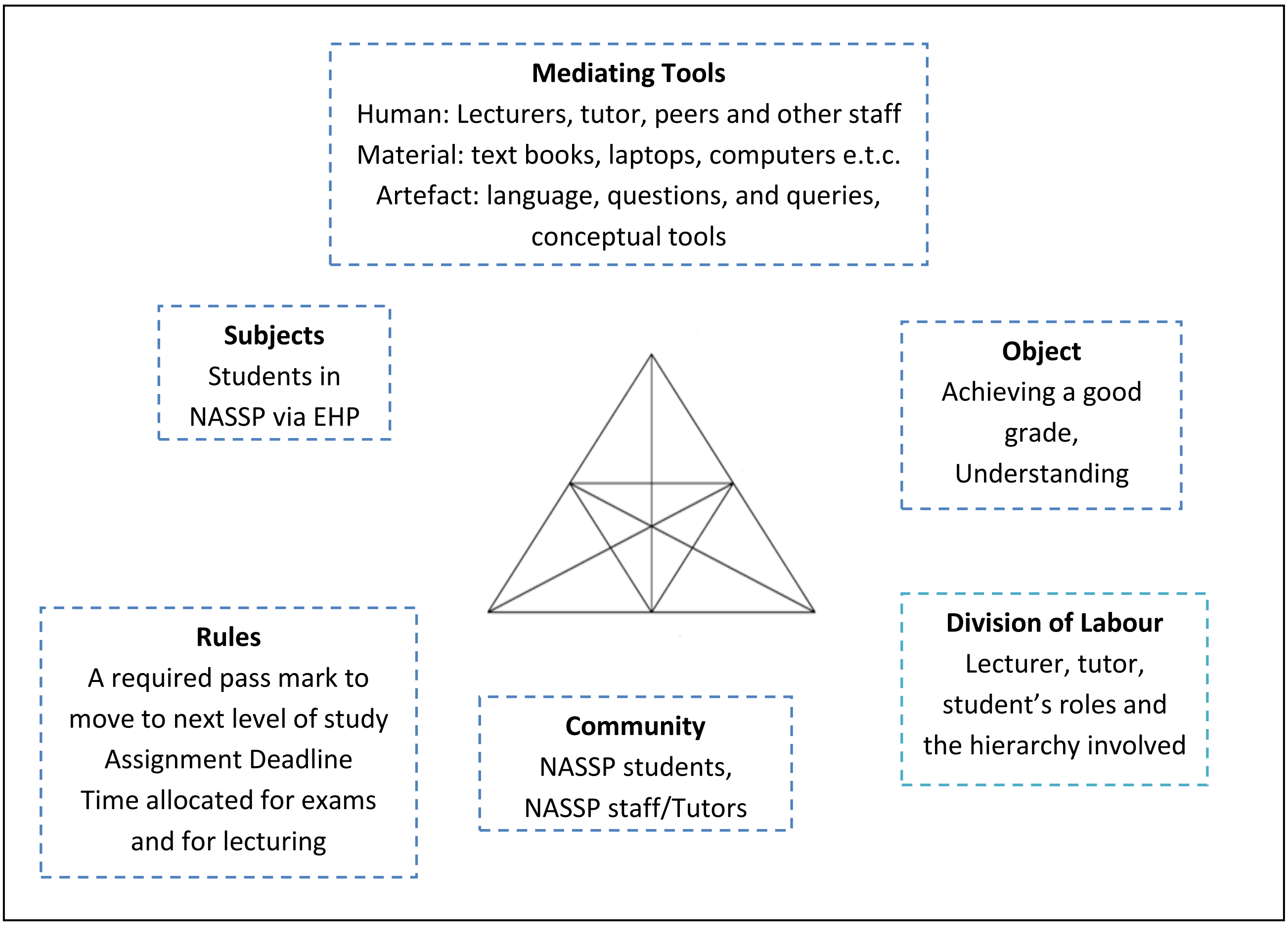


Figure 10. The studying activity system (E&M course) activity system

The prescribed textbook is: D.J. Griffiths, Introduction to Electrodynamics (3rd ed Addison Wesley). The course essentially covers chapters 1 – 6 and chapter 8.

7.2. Aims of the Course

The aims of the UCT PHY2A course on electromagnetism, as outlined on the course website, are to:

a) Provide a solid understanding of electromagnetism at the intermediate level.
   - an introductory course is based on a first-year text book such as Chabay and Sherwood 3rd ed. (2007), Halliday and Resnick (1999) or Young, Freedman and Ford (2004) and treats the electric and magnetic fields as vector quantities
   - an intermediate course (such as PHY2A) is given at the senior undergraduate level, is based on a text like Griffiths (1999) and uses vector calculus (div, grad and curl) to show how the physics of electromagnetism is expressed in terms of Maxwell's equations, and goes on to examine some solutions of these equations, such as electromagnetic radiation

7.3. Interview with Instructor

I interviewed the lecturer on his expectations and views about the course.

***Interviewer:** What are your expectations for the course?*

***PHY2A lecturer**: …from the students learning point of view, the most important thing that I would like to see them achieve is the realization that they have to work on their own. It's no longer the case where you can come to the university and sit down and wait and see what is told to you: Come to the lecture and listen, go to the tutorial…listen, get the problem sets look at it, it's difficult-put up your hand and somebody will help you. This is the time they have to make the transition to working on their own. They are the only ones who can help themselves. If they can identify their difficulty, and then help will be given but they have to get past the assumption that all I have got to do is sit there and somehow it will be taught to me…No…the students have to learn the stuff for themselves with guidance, with help…so those are my expectations.*

Apart from the general aims of the course it was apparent that one of the lecturer's expectations is for the students to be able to transit from being "told what to do", to owning the learning for themselves while being guided. I infer from the interview that the lecturer wanted the students to transit from binary stage to a constructive stage of learning electromagnetism (Edward, Jeffery and Richard 1998).

The interview with the lecturer also provided insight as to the reasons why the course may have been challenging to the students. This intermediate level electromagnetism course was regarded as the hardest undergraduate physics course at UCT. The statement came out of end of term evaluations by the students. I asked the lecturer why he felt that the course is described as “hard”.

Lecturer:*…and the reason it’s hard, is because not only is it mathematically sophisticated but that it involves trying to describe a physical situation which you have to…is probably presented to you in words which you then have to imagine how it looks in real space, and then describe it by mathematics, solve the mathematics and then interpret the mathematics to tell you what is going on in the real world. So in that sense it’s more a than a simple mathematics questions.*

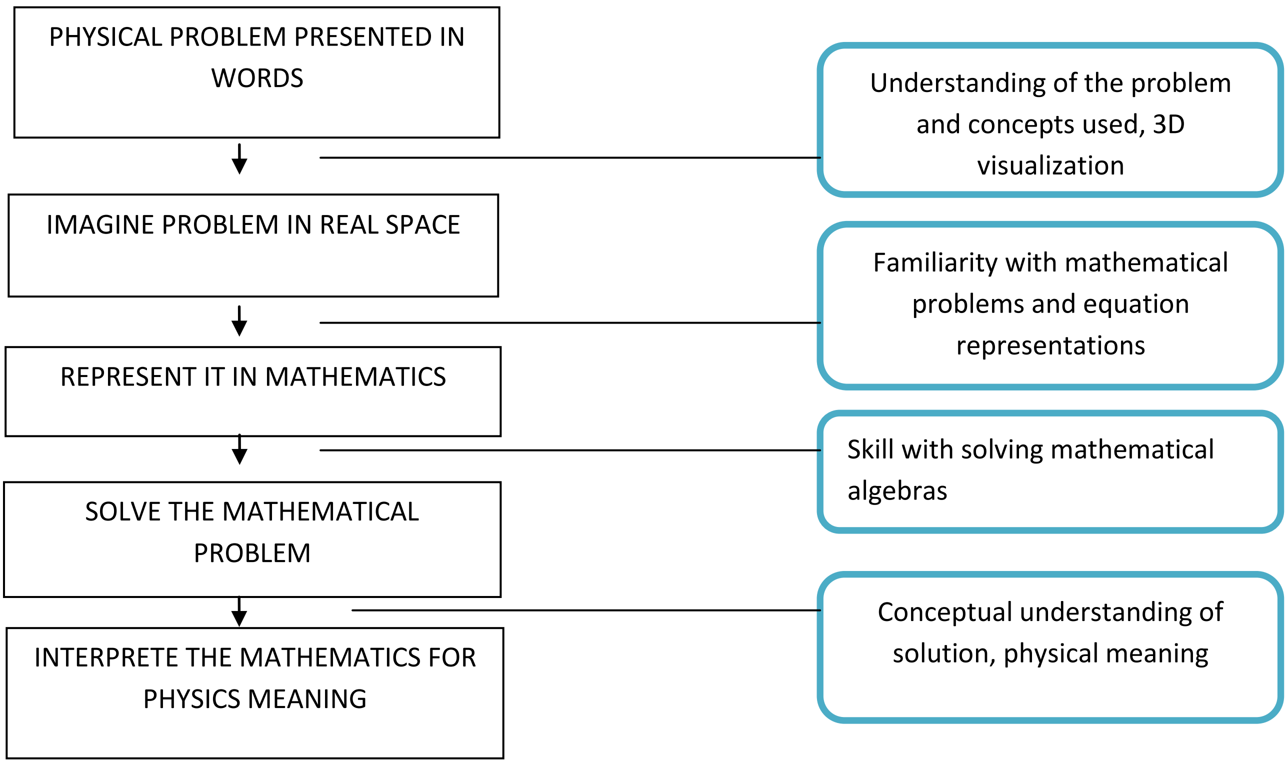


Figure 11. Diagram depicting skills needed to successfully engage with PHY2A (E&M)

7.4. Student Interviews

I interviewed the EHP students on their views and expectations of the PHY2A E&M course.

***Interviewer**: how did you learn EM at undergraduate?*

***Student: ...**the way the lecturers taught was easy to follow, He would come to class give you notes and tell you to concentrate and focus on the notes so you knew what to expect, the lecturer would ask us to try and figure out questions that could be asked from the notes and then that's what you would meet.*

Below are two other quotes to describe how students had previously learnt E&M

***Student:...**it was more of a method based thing-like…this is the way you do Gauss's law, this is the way you do…but you never understood where does Gauss's law come from, what do you look for in order for you to be able to use it to solve a problem, it was only now when I learnt the vector calculus…and the physics that I could apply the vector calculus into the EM 2A.*

***Student:…**Annh...you know our "nation" they always teach you what they gonna ask you in the exam, that's why we thought that we were the kings of it, because you will only be taught what will be in the exam if they feel that they will never ask you this they skip it in the textbook, then you know anh...the lecturer skipped this, then you don't bother reading it then you will pass it.*

These statements from the students reveal the presence of quaternary tensions in this subsystem. There is a constant struggle between how they have studied before and the new way of learning this E&M course. During the interviews with the EHP and Post-EHP students all but one of the students mentioned E&M as the hardest or most challenging course they are facing at UCT. Analysis of all the students' interviews reveals that the major tension in the course is "historical" in nature - the contradiction between how they had previously learnt the course and how they are learning it now at UCT. This quaternary tension produces further tensions within the studying activity system and between it and other systems. Interviews with students revealed tensions between the tools (e.g. textbook) currently used and previous textbooks they had used to study similar material, between the object of the course and the expectations of the course, secondary tensions between the rules and the objects (e.g. the time given for the course and the expectation to understand the concepts), and between the community (lecturer/ tutor and student perceptions of what constitutes a meaningful engagement during "walk in assistance" (consultation time with the lecturer or tutor). Other challenges with the course that came out of the interviews concerned understanding what the lecturer wanted, and misreading the questions. The pop quiz, weekly problem sets, tutorials at second year were also formalities that were new to the EHP students.

A common trend to emerge was the description provided by all the students as to the method by which they had learnt the E&M course at their previous universities: the lecturer comes to the class, lectures and gives them notes and practice questions, if students are able to read the notes, solve the questions give and reproduce them in test and examinations then the students are guaranteed to pass the examinations.

During the interviews most of the students acknowledged that this method was easy for them to follow and it provided good grades but it wasn't helpful for understanding the concepts which they now have to grapple with again. For most of the EHP students, their initial expectation of the 2nd year E&M course at UCT was that it was going to be a "walk through" of the material presented in their previous E&M courses which they had done during their undergraduate degree.

A number of historical contradictions therefore emerged as they went through the course, and considering the fact that the course content was delivered in a very short time in comparison with the amount of content covered I believe that most of the tensions were not resolved, hence the outcome was not optimal.

Episodes from interviews depicting different categories of contradictions experienced in the course are transcribed and analysed.

The three excerpts above show some characteristics of the lecturing styles used during their undergraduate studies at HBU's these are patently different to the lecturing styles employed at UCT. As mentioned earlier, tensions also existed between the subjects (EHP students) and the community (lecturer and tutor) with regards to the nature of the assistance given during walk-in tutorials. The students were obviously struggling with the course, and the tutor and lecturer had told students to feel free to come in and ask questions if they had difficulty. However, the students neither went to the lecturer or tutor to seek assistance. Upon interviewing the different parties I found out that the tension was with the nature of the mediation offered during the tutorial walk-in sessions. The students felt that when they went for help, the tutor just gave hints on how to solve the problem while they perceived their difficulty to be at a much deeper level of understanding than the problem itself. Since they felt the engagement was not helpful for them they stopped going to the tutor. Through informal communication I learnt that the tutor was frustrated that students were not coming and attributed it to a lack of interest.

7.5. Analysis of students' products in Phy2A

I analysed a final examination in the PHY2A course in 2011. Historically examinations have been used as the main mechanism for assessment (Buick 2010). Tests and examinations usually cover the material in the course description and test the level of knowledge and understanding, which a student requires to pass the examination or test.

7.6. The PHY2A examinations

The EHP students took the examination with the rest of the PHY2A[11]. The examination was two hours long.

I analysed the examination with Buicks taxonomy for physics (Buick 2010). Buicks taxonomy for physics develops on the limitations of Biggs SOLO taxonomy and Blooms taxonomy when applied to physics assessments (Biggs and Collis 1982, Biggs 2003, Bloom, et al. 1956). A summary of the levels of understanding proposed by Buicks is shown below.

[11] EHP students had 5 weekly tutorials with Dr G before the examinations

Table 11. Summary of Buick's (2010) taxonomy for Physics. (Explanation of the different levels of understanding and knowledge)

Levels of knowledge/understanding	Explanation
Factual knowledge	Statement of facts
Bookwork	Answers can be found in any standard textbook and will presumably be covered in class, requires comprehension
I. Application – previously solved II. Application – routine procedure III. Application - novel	I. A question that is identical or virtually identical to a question that the student has already been exposed to or has already solved II. A question that is broadly similar to a question already encountered III. A question that is significantly different (in terms of the application of the law or the method of mathematical solution)
Relation within topic	Relating answer given in previous part of question to knowledge obtained elsewhere in the unit and determining the consequence of the comparison (provided this comparison had not been provided in lectures or an assignment in which case it would be application previously solved)
Relation without topic	Bringing together knowledge and understanding from other topics or units and relating them to solve the problem

For the PHY2A final examinations most of the questions involved the use of more than one of the levels described above. However I used the level which was most needed to successfully answer the questions applying the descriptions outlined by Buicks.

Table 12. Nature of questions for PHY2A final examinations and Buick's taxonomy category for each question

Questions	**Topic**	**Nature of questions**	**Buicks physics taxonomy category**
1a	Electrostatics and Magnetostatics	Application of coulombs law, the curl of the electric field, recall of stokes theorem, principle of superposition and use of potentials	Application novel
1b	Electrostatics	Recognition or identification of electrostatic fields, curl and divergence of electric fields	Application Routine
1c	Electrostatics: electric potential, electric fields	3 D visualizations,	Application novel
2a	Displacement current and Amperes law	Interpretation of mathematical representation, explanation of conceptual physics phenomena	Application novel
2b	Magnetostatics, magnetic fields	Recognition or identification of magnetic, divergence of magnetic fields	Application routine
2c	Magnetostatics-Ampere’s law	Application of Amperes law, integrals	Application previously solved (if

			student attempted the tutorial and problem sets questions or sought help) or Application Novel if student did not solve it as a tutorial question
3a	Electrodynamics, Maxwell's equations, Amperes law	Interpretation and derivation	Bookwork
3b	Maxwell's equation propagation of energy in free space	Derivation	Book work
3c	Capacitors	Application of concepts: Period, time and energy	Application routine

Though standard bookwork questions often require comprehension to successfully follow through they can also be memorized. During an interview with one student who got 72% in the bookwork question, he admitted to not understanding the question. The standard bookwork question for (3a) was

(5a) Explain why Amperes law needed modification. Describe how Maxwell did this, and what important scientific understanding this led to (15 marks)

As part of the plan for students' interviews on their performance I asked the student about particular questions I wanted to probe further.

Interviewer*: (looking at student's script) tell me about Amperes law and why it needed modification or why Maxwell modified it?*

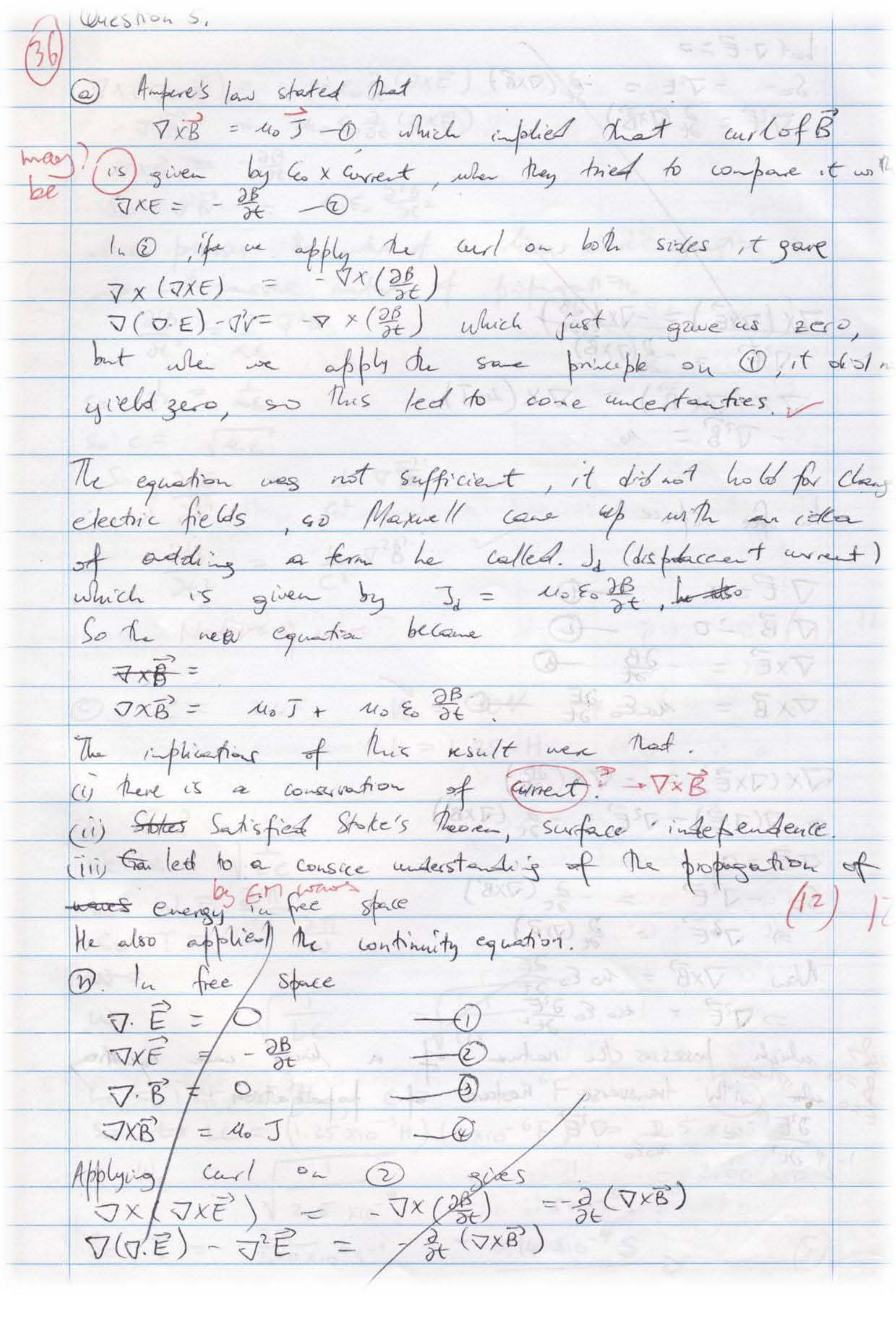
Student: oh, I don't know about Ampere's law don't understand it.

Interviewer*: but you wrote it down and did well in the question.*

Student*: really? Let me have a look…oh…*

Interviewer*: so how did you do it here?*

Student: *you know sometimes when (lecturer) G says some things it just sticks, he treated that problem and I have also seen it somewhere else so I just remembered it and wrote it down not that I understand it.*



Question 5.

(36)

(a) Ampere's law stated that

$\nabla \times \vec{B} = \mu_0 \vec{J}$ — ① which implied that curl of $\vec{B}$

may be (is) given by μ_0 x current, when they tried to compare it with

$\nabla \times E = -\frac{\partial B}{\partial t}$ — ②

In ② , if we apply the curl on both sides, it gave

$\nabla \times (\nabla \times E) = -\nabla \times (\frac{\partial B}{\partial t})$

$\nabla(\nabla \cdot E) - \nabla^2 V = -\nabla \times (\frac{\partial B}{\partial t})$ which just gave us zero,

but when we apply the same principle on ①, it didn't yield zero, so this led to some uncertainties. ✓

The equation was not sufficient, it did not hold for changing electric fields, so Maxwell came up with an idea of adding a term he called J_d (displacement current) which is given by $J_d = \mu_0 \varepsilon_0 \frac{\partial B}{\partial t}$, ~~he also~~

So the new equation became

~~$\nabla \times \vec{B} =$~~

$\nabla \times \vec{B} = \mu_0 J + \mu_0 \varepsilon_0 \frac{\partial B}{\partial t}$.

The implications of this result were that.

(i) there is a conservation of current ? → $\nabla \times \vec{B}$

(ii) ~~Stokes~~ Satisfied Stoke's theorem, surface independence.

(iii) ~~Gau~~ led to a concise understanding of the propagation of ~~waves~~ energy by EM waves in free space (12)

He also applied the continuity equation.

(b). In free space

$\nabla \cdot \vec{E} = 0$ — ①

$\nabla \times \vec{E} = -\frac{\partial B}{\partial t}$ — ②

$\nabla \cdot \vec{B} = 0$ — ③

$\nabla \times \vec{B} = \mu_0 J$ — ④

Applying curl on ② gives

$\nabla \times (\nabla \times \vec{E}) = -\nabla \times (\frac{\partial \vec{B}}{\partial t}) = -\frac{\partial}{\partial t}(\nabla \times \vec{B})$

$\nabla(\nabla \cdot \vec{E}) - \nabla^2 \vec{E} = -\frac{\partial}{\partial t}(\nabla \times \vec{B})$

Figure 12. A student's solution to a book work question

From the student's answer shown above we can see a contradiction between the lecturer's expectation as stated in his interview and the marks obtained by the student. The student recalled formulas and procedure but did not really understand the concept behind the question. However, during the interview with the lecturer, it was apparent that the lecturer was aware that for this particular question students could get marks without understanding. He pointed out question five as the "bookwork" question where he felt students could get by just memorising or comprehending the standard work in the Griffiths textbook.

The lecturer said he designed questions in such a way that deep conceptual understanding was rewarded. However during the interview with the student who scored the most marks amongst the EHP students I asked him what strategies he used in learning the course that made his mark significantly better than other EHP students, considering that they all had similar difficulties. The student's response was that he did not deviate from the learning strategies he had used at undergraduate; he said he just stuck to the notes, tutorials and problem sets. He said he didn't go seeking for new things but rather worked with what he had, as he had always done back in undergraduate. This was interesting because some other EHP students who tried reading other textbooks and materials to broaden their understanding and concepts performed worse than this student.

Another tension I found during the analysis of students' products in this examination was the effect of the pace of the course on students' learning. The course covered the first six chapters of Griffiths' text book in 35 lectures: one lecture every work day – Monday to Friday. The lectures were usually followed by weekly problems sets and tutorial questions which were handed in for assessment. As a result of the pace, it was not surprising that by the middle of the course some students were already "lost". Most of the EHP students in the class complained about being left behind and while they were still struggling with grasping the concepts in chapter 2 of the textbook, the lecturer was already lecturing from chapter four. I also interviewed 3 students from the other groups in the class and some of them seemed to have the same issue with the pace. During interviews with the EHP students at the end of the course most of them said they did not really understand Magnetostatics as they did Electrostatics. From the interviews I infer that this was caused by the teaching time of these two topics. Magnetostatics is in chapter five of the textbook and was delivered at a time when students were already side-tracked with large volume of work from other courses and from the other demands of the course itself. This reflected in students' performance on questions relating to Magnetostatics. This is also reflected in question four of the final examination shown below.

Table 13.Students marks in each question for PHY2A E&M and final mark for the course

Students	Q2 (%)	Q4 (%)	Q5 (%)	Exam mark (%)	Final E&M 2014 MARK
S1	26	2	54	27	35
S2	20	24	32	25	29
S3	34	12	22	23	24
S4	30	12	72	38	46
S5	60	52	64	59	56
S6	6	16	16	13	18
S7	40	22	54	39	42

As can be seen from the marks obtained, students' performance in the course was very poor, considering that the students had already covered most of the content during their undergraduate degree. Only one student got above 50% in the final examination and the cumulative mark for the course. We can also see from Table 13 that students did best in question five in which 60% of the marks were allocated to book work questions (Wood, et al. 2002).

7.7. The Second E&M course (PHY2B)

7.7.1. Course description

From a formal assessment point of view, the performance of the EHP students in the PHY2A course was very poor. As part of the goal to prepare the students for the NASSP Honours course, a follow up course was put in place to continue the bridging between the E&M learnt during their undergraduate degrees and the one which they would meet at postgraduate level with the main NASSP programme. The first part of the course ran for 5 weeks where the instructor Dr G acted as a tutor to prepare the students for the PHY2A examinations. Then in the second semester the instructor did a 12 week course which he designed, the topics covered were the 2nd half of Griffiths. The lecturer, Dr G, said he told students that they could walk into his office and ask him questions outside of 'classroom hours'. However during an interview with him, he also expressed surprise that none of the students came to him to ask any questions. This problem of not responding to walk-in sessions or meeting the lecturer or tutor for help when it was obvious that students were struggling with the course was common for the electromagnetism course. The form of lectures for this course was more interactive in the sense that there were only six students in the course. The style of pedagogy for the course was quite different from the regular UCT physics courses. The lecturer encouraged the students to develop their own notes from class lectures and didn't give them notes because he felt if he gave the students notes they would just go memorising what he had put down and not begin developing their own ideas. However they had the standard textbook which was also the later chapters of Griffiths (1999).

There were weekly problem sets to hand in at the end of the week. Weekly problem sets were then solved in class after students had handed their solutions in. The lecturer treated later chapters of Griffiths but did not follow the chapters consecutively. The lecturer was teaching this course for the third year at the time of the research so he was quite experienced with issues which students from HBU's are likely to face with the course. This bridging course is given the code PHY2B. (It is useful to mention that at the time of this research the lecturer was also involved with the NASSP Honours electromagnetism component).

7.8. Analyses of students products from PHY2B

The questions for the examination were given as follows:

1) Suppose the x-y plane is filled by an infinitesimally thin insulating sheet carrying a surface charge-density σ_f outside which is vacuum; the sheet is in uniform motion along the positive y-axis at a speed of v.
   a) Sketch the electric and magnetic fields on the axis below: (4)

b) Determine the electric everywhere. (4)

c) Symmetry considerations imply that $B_y = B_z = 0$. Hence determine the magnetic field everywhere. (5)

d) Determine the energy density u_{em}.

e) Determine the Poynting vector $\vec{S}$. (2)

f) What is the flow velocity of the electromagnetic energy density? Be sure to express your answer in terms of v and c only. (3)

2) Consider a linear medium in which the permittivity ε, permeability μ, and the conductivity σ are frequency independent real constants and $\rho_f = 0$.
   a) Using the in-medium Maxwell equations together with Ohm's law, derive the differential equation that the electric field must satisfy. (10)

In the rest of this question assume the solutions:

$$\vec{E}(z,t) = \tfrac{1}{\sqrt{2}} E_0 exp(-\kappa z)\left(\cos(kz - \omega t), \pm\sin(kz - \omega t), 0\right),$$

$$k = \omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\sqrt{1+\left(\frac{\sigma}{\varepsilon\omega}\right)^2}+1} \quad , \quad \kappa = \omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\sqrt{1+\left(\frac{\sigma}{\varepsilon\omega}\right)^2}-1}.$$

b) What is the physical meaning of the exponential factor? (2)

c) How would one characterise the limiting case $\omega \gg \sigma/\varepsilon$? What are κ and k in this limit? By how much is the wave attenuated over a wavelength at optical frequency in pure water? Describe the solution in words (both at fixed $z = 0$, and fixed $t = 0$; don't forget there are two values $\pm$). Approximately find the corresponding magnetic field. (12)

d) How would one characterise the opposite limiting case $\omega \ll \sigma/\varepsilon$? What are κ and k in this case? (2)

e) Sea water has a rather low resistivity ($\approx 0.2\Omega\, m$) due to dissolved ions. Where does σ/ε fall in the spectrum? In order to effectively communicate via radio with nuclear submarines cruising at a depth of $20\, m$, what frequency should be employed? (4)

The lecturer expressed dissatisfaction with the students' performance in this examination because he felt he had kept the level "down. The key to succeeding in this examination was in being able to understand the key ideas of a problem in a robust way; to be able to take ideas from worksheets or class materials and apply them in similar problems but not the exact same problems.

Interviews with the 2 other lecturers involved with the EHP reveals that this was a major tension in the EHP year. The source of this tension was from the EHP students' previous studying experience, as the students admitted that it was difficult for them to transfer ideas from one problem into another since this is not the way they were used to learning physics and E&M in particular. They could understand and follow the worksheet's questions but not in a sufficiently robust way such that they could expand the idea into a similar question.

The lecturer for this course stated that this was a problem he had noticed with the EHP students, the second year UCT physics majors students and the mainstream NASSP Honours students, but from his experience the mainstream NASSP Honours students were usually better in handling this physics problem development.

I analysed the questions based on topic, nature of question (to what extent they are familiar with the question) and lecturer's comments on performance on the question as shown in Table 14.

Table 14. Analysis of PHY2B final Examinations

questions	Topic	Nature of questions	Lecturer comments
1a	Electrostatics- Electric field, symmetry, magnetostatics- magnetic fields – sketching field lines	Application routine (Same routine as Q1 in work sheet 1) with small changes	Poorly answered: most students struggled with E-field of moving charge distribution, and B-field of same
1b	Gauss's law,	Application routine (Same routine as Q1 in work sheet 1) with small changes	Typical error: not accounting for E-field on both sides (mistreated as conducting plate)
1c	Application and use of amperes law, understanding symmetry, understanding sketch require visualization	Application routine (Similar routine to Q2 in work sheet 1) with small changes	Typical response: confusion with line charge, misapplication of memorized formula
1d	Concept of energy density or simply recalling formula, Requires correct answer from 1b and 1c	Application routine (Same routine as Q3 in work sheet 1) with small changes	Partial credit for correct formula
1e	Understanding what the Poynting vector is Requires correct answer and understanding of 1b and 1c	Application routine (Same routine as Q4 in work sheet 1) with small changes	Partial credit for correct formula or direction
1	Understanding application and use of concepts in 1e and1 d	Application routine (Same routine as Q5 in work sheet 1) with small changes	Partial credit for correct definition of velocity vector & direction

2a	Relation and use of Gauss's law, ampere-Maxwell modification, Maxwell's laws in matter Electromagnetic waves in medium	Derivation of in-medium wave equation in text book, and was given in lecture.	Only one student got the derivation correct. Several tried to set conductivity to vanish
2b	Analysis of the solution and meanings attached	Conceptual/physical understanding	Surprisingly poorly answered; no physical understanding of attenuation of wave
2c	Implication of special cases, Analysis and prediction, conceptual understanding of limit attached to solution of wave equation given	Combines ideas from work sheets 3 and 4	Most misidentified limit as good conductor, leading to systematic errors in answering subparts
2d	Implications and deductions of special cases attached to given	Combines ideas from work sheets 3 and 4	Many misidentified limit as good insulator

As shown in the third column of Table 14 most of the questions combined ideas from the worksheet and/or the textbook. However using the ideas in a different but similar problem posed a challenge.

7.8.1. Electric and magnetic field of a moving charge distribution

The first question in the examination required students to sketch the electric and magnetic field in the context provided in question 1a. A similar question had been given in worksheet 1. The question for the worksheet had to do with calculating the electric field, magnetic field, Poynting vector and energy densities, of a moving line charge, while the examination question had to do with calculating the same quantities for a moving sheet of charge.

Work Sheet 1.

A line charge λ lies along the z-axis, and is in motion with velocity $\boldsymbol{v} = vz$ "

1. *Determine the electric field*
2. *Determine the magnetic field*
3. *Determine the energy-density u_{em}. Write your answer in terms of v/c*
4. *Determine the poynting vector*
5. *With what velocity does the energy-density move? [Warning: think before you answer!]ˆ*

The standard solution from an understanding perspective requires, first recognizing that the electric field can be written as

$$\vec{E} = E_S(S)\hat{S}$$

Where $E_S(s)$the magnitude of the electric is field and $\hat{s}$ is the direction.

Then the total electric field of the line charge is given by

$$\int \vec{E}.d\vec{a} = \int |E|\, da$$

Applying Gauss's law with cylindrical symmetry (Fleisch 2008), we have that the flux through the surface is

$$\int \vec{E}.d\vec{a} = 2\pi SLE_S(S)$$

Where S is the radius of the cylinder and L is its length

From Gauss's law also $\int \vec{E}.d\vec{a} = \frac{q_{enc}}{\varepsilon_0} = \frac{L\lambda}{\varepsilon_0}$, and therefore $\frac{L\lambda}{\varepsilon_0} = 2\pi SLE_S(S)$

And this gives the magnitude of the electric field which is uniform at every point of the cylinder as $E_S(S) = \frac{\lambda}{2\pi S\varepsilon_0}$. The electric field is then $\vec{E} = E_S(S)\hat{S} = \frac{\lambda}{2\pi S\varepsilon_0}\hat{S}$

For the worksheet problems it was expected that students would either give a standard answer or explain in words how they arrived at a given expression. However, because there was no outside classroom interaction with the students, the lecturer assumed that the students were happy with his classroom explanations. A major tension which I identified in the system is that lecturers who evaluate from an "understanding" perspective assume that the right answer must come from a process which requires understanding; whereas the students know that most of the time one can get the right answers without understanding the concepts.

7.8.2. Instructor's comments on determining the E-field of a moving charge distribution

***Lecturer**: ….once the worksheets were done it came across in the exam question 1. Which was essentially like the first work sheet, but the context of it was slightly different, because the first worksheet was based around a line of charge moving and the exam question was based around a sheet of charge moving. The expectations overall were the same. So if you knew how to do the line…in some cases what you see which kind of slipped it the use of a symbol λ which you would use for a line charge versus k which you would use for the surface current density or σ . There was still that sort of mismatch that they were looking too much at a pattern of a particular example and trying to transfer that rather than looking at the overall context.*

I was sort of very surprised-disappointed that they got off with a bad start with the question. I can't think of anybody who drew it exactly like it was the problem out of the tut[orial] in terms of drawing the field lines. But typically what would happen is that: if you have this moving sheet of charge just like a moving line charge. You are still going to have an electric field this way and an electric field this way (pointing above the surface of the sheet and below in the z-direction). Here is some hypothetical capacitor plate and here is some other hypothetical capacitor place (somewhere below and above the surface of the sheet) which were not referred to anywhere in the problem, you just have the surface charge in the x-y plane and then they draw electric filed lines in between, so invariably they recognize it's not exactly like the worksheet question but I have some idea that they got the feeling that the electric filed lines must be in the z direction and the place where they have seen that the most is in capacitors, so they try and draw it like a capacitor problem and then they were variations to that beam (lecturer describes S3 examination representation of the field, which seems like a capacitor problem but still the electric field came in skewed, describes two other representations) nobody came anywhere close to the magnetic field, they just drew things like it was a bar magnet.

7.8.3. The electric field of the line charge and sheet of charge

Looking at question 1a in the examination and question 1 in the worksheet, the lecturer expressed disappointment in students' performance in the examinations because he felt that they should be able to transfer the idea of the calculating the electric field of a line of charge into that of a sheet of charge. I first looked at students' responses to the questions in the worksheet and that of the examination and analysed what went wrong. Different students' responses to question 1 in the WPS on determining the electric field are shown below.

Student 1 (S1) work sheet 1 response

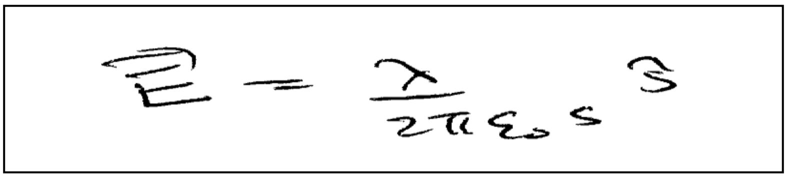


Figure 13. S1 response for calculating the electric field of a moving line charge

Here we see that S1 only wrote down the standard expression for the electric field of a line charge. Since this was a worksheet problem, there was no time constraint. The lecturer assumes students understand where the correct answer is from and marks it correct.

S1 examination response

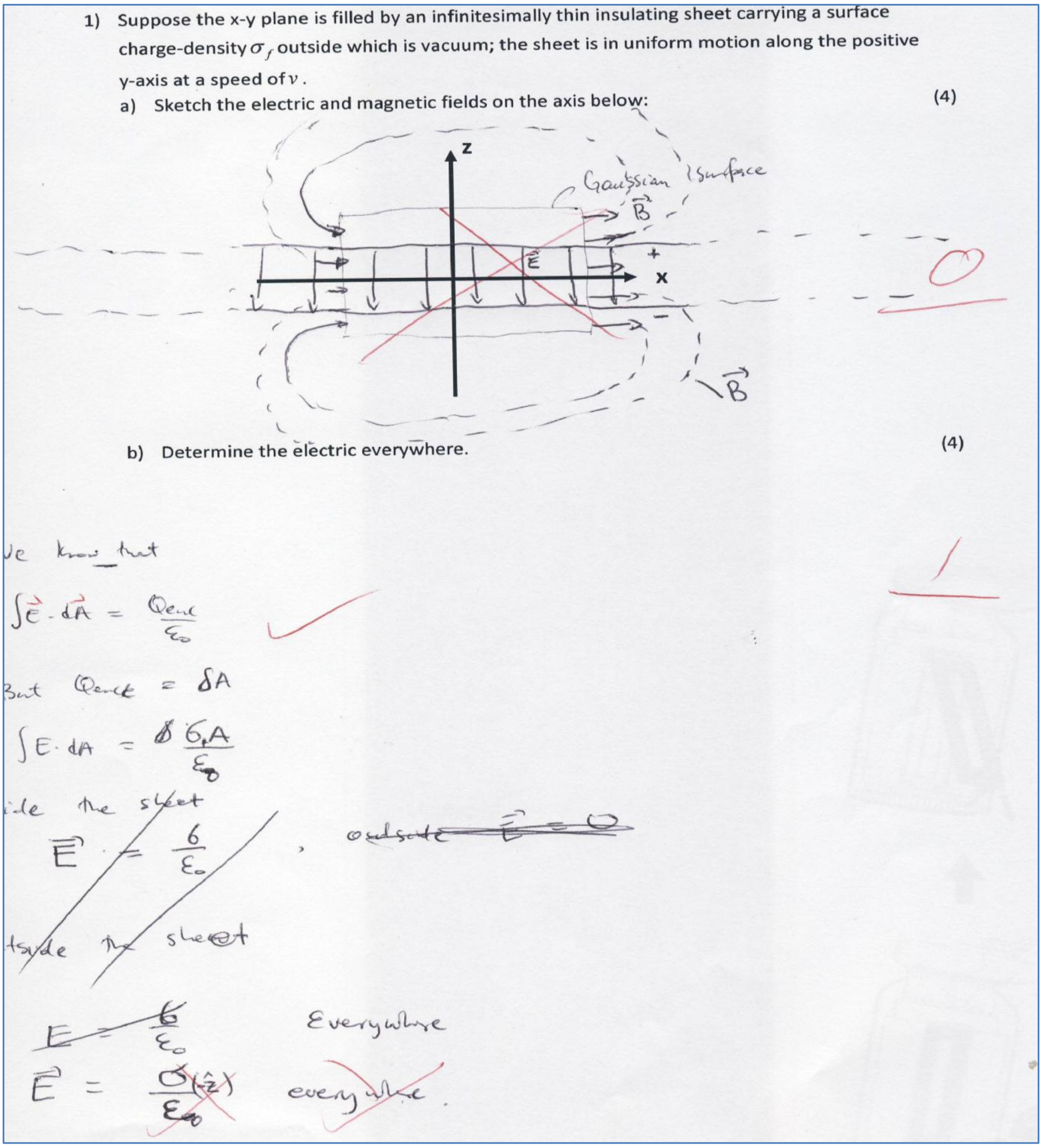
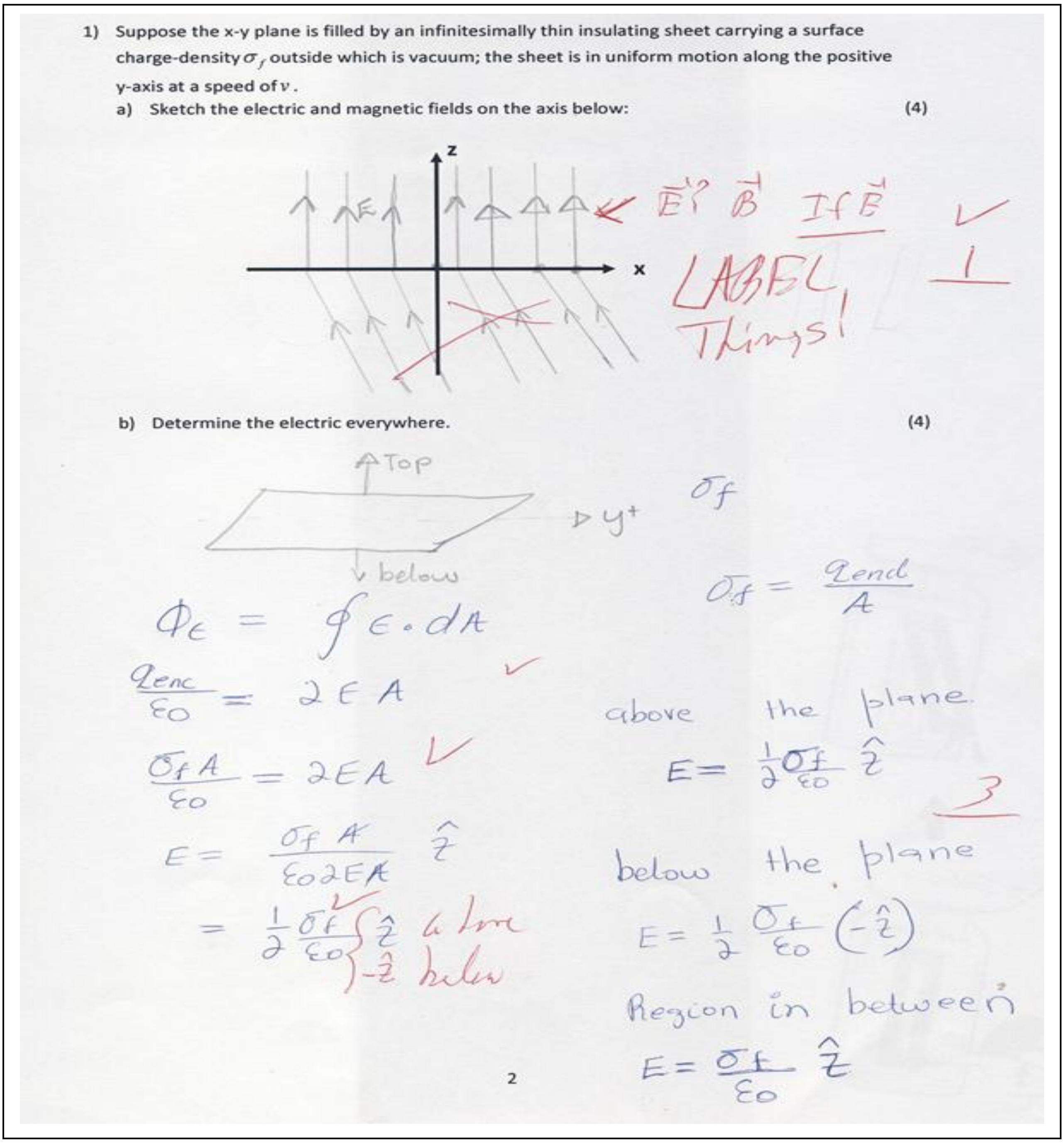


Figure 14. S1 response to calculating the electric field of a moving sheet of charge

Here we see student S1 drawing the magnetic field of a sheet of charge as if it were a bar magnet. However, the student wrote down the correct formula for the flux through a Gaussian surface.

S2 examination response



1) Suppose the x-y plane is filled by an infinitesimally thin insulating sheet carrying a surface charge-density σ_f outside which is vacuum; the sheet is in uniform motion along the positive y-axis at a speed of v.

a) Sketch the electric and magnetic fields on the axis below: (4)

b) Determine the electric everywhere. (4)

2

Figure 15. S2 Examination response on calculating the electing field of a moving sheet of charge

The student correctly draws the direction of the electric field at the top of the sheet but then draws skewed skewed electric field below. However in question 1B the student correctly represents the problem diagrammatically.

S3 examination response

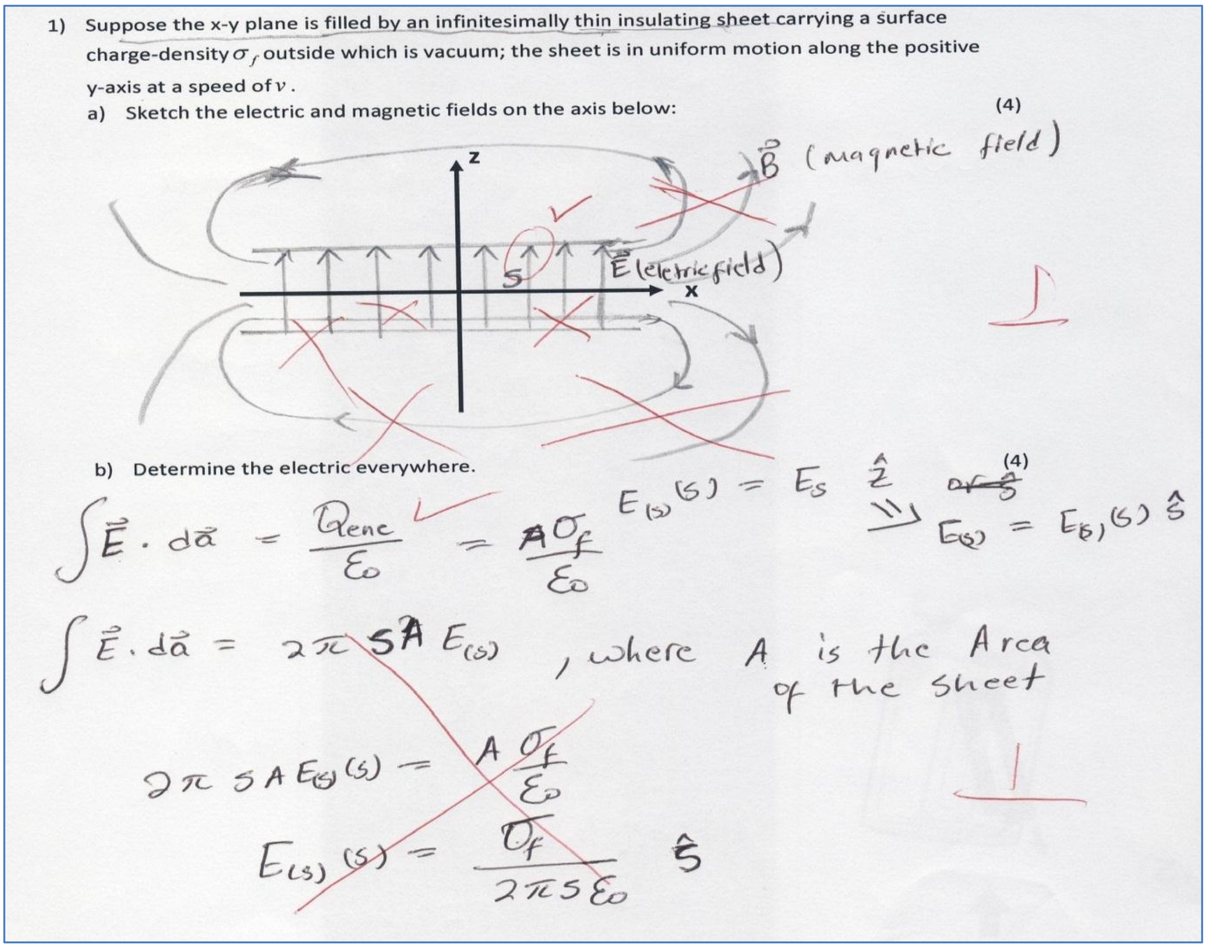


Figure 16. S3 response to calculating the electric field of a sheet of charge

This student thought the problem was a capacitor problem. The student also complained of having issues with the meaning of the question. The only correct aspect of the answer was the recalling of the formula for the flux through a Gaussian surface.

7.8.4. Students' comments on determining the E- field of a moving charge distribution

For some students there was a total misunderstanding and consequently wrong interpretation of the problem. For example during interviews with student 6 (S6) who had frustrations with what he called the "English of Physics" used at UCT he commented on question 1 of the examination versus the question given in Work Sheet 1.

Student*: ….here they play around with the words and you end up not knowing what you will be solving. For example like the one we wrote of Dr G... question 1, it came like we use to work on a plate been stationary and the charge moving and we know that the electric field is in the direction of the charge, then now is the other way round it's the plate moving and the charge is stationary and you ask yourself ok what am I supposed to do now? Because it's the plate moving and you think and you are like…ok I will come back to this. You see, so here they play around with the motion-which one is moving. That side you only knew that it would always be the charge moving*

Interviewer*: so for that particular example now is the issue with the "words" in terms of English or do you think it's with the Physics?*

Student*: I think the issue is with how we understand it, maybe if umh we upgrade our understanding of the physics, cos if we understood it very well, you wouldn't mind either of them moving, but we got used to that it must be the charge moving…so…actually it's not basically the English itself basically, it's how we understand the English of physics.*

Contrasting the lecturer's and student's views we see that there were several contradictions or tensions which resulted in poor performance in answering the question[12]. According to Tuminaro (2004), qualitative sense-making is important for students to be able to correctly sketch the electric field lines. The inability to make accurate qualitative sense of the problem led to other pitfalls such as constructing the correct expression for the total electric field using Gauss's law (Singh 2006).

7.9. Micro Tensions observed in the electromagnetism course

I analysed the scripts of the students in the PHY2B course to see how the contradictions manifested in what the students actually did.

7.9.1. Charged parallel plate capacitor versus sheet of charge

Most students sketched the electric field for the sheet of charge as if it were a charged parallel plate capacitor problem.

[12] Note that time is a boundary condition that can cause epistemological tension but if understanding or comprehension is lacking one can spend the whole time solving the wrong problem

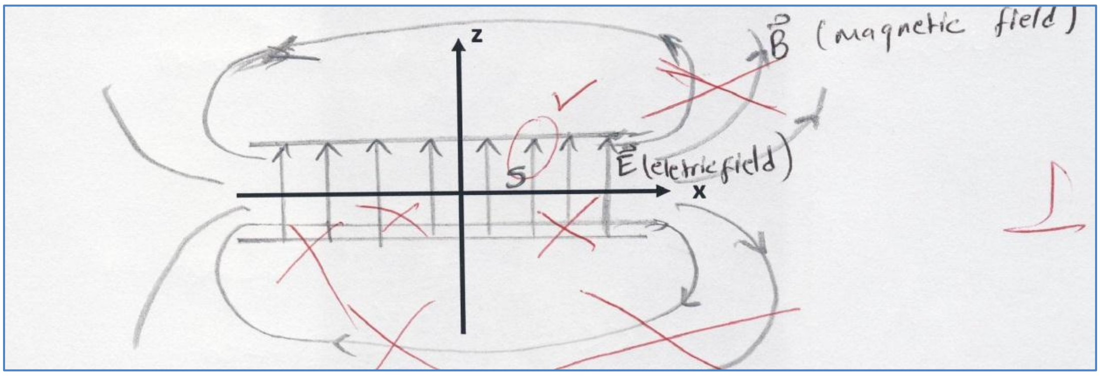


Figure 17. Example of students' sketch of the E-field of a sheet of charge as a capacitor problem

Only one student figured out that for a charged sheet in the x-y plane the E- field would have components in the positive and negative z axis pointing away from the charge. Most students did not realize that the sheet of charge has no thickness.

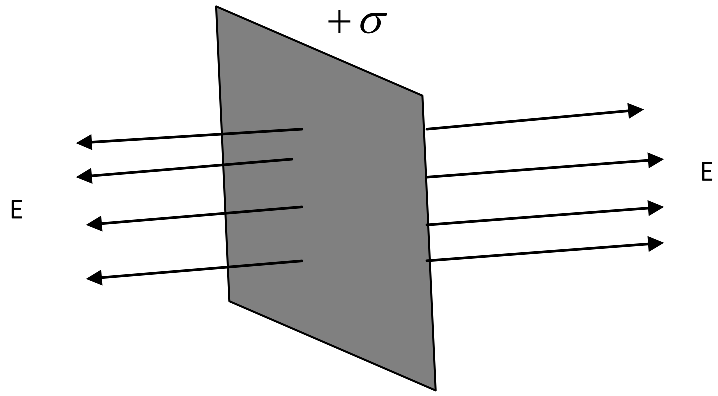


Figure 18. Perspective view of the sheet of charge

The first tension we observed here was that the students framed the question differently from what the lecturer expected them to do. There was a mismatch in the lecturer's and students; expectations.

7.9.2. Visualization of 3D on a 2D surface

Another problem the students had was with representing the electric field on the "2D" axis provided. As seen from the S2 and S3 solutions there was contradiction in how students represented the electric field. For example S2 wrote down the statement. *"The electric field above any point in the x-y plane is …."* However, the student did not show those points on the diagram. Also we observed a misunderstanding in the representation of the electric field when the student wrote down:

$$\vec{E} = \frac{\sigma_f}{\varepsilon} y\hat{y}$$

It is also puzzling how student S3 could visualize the sheet correctly as sketched just below the provided axis on the question paper but then wrongly represent the direction of the electric field on the axis provided. Evidence of difficulties with the visualization of problems was also seen in the mathematics course[13] which had to do with line and surface integrals. We think that if the perspective view of the sheet was provided then the students would have done better with the representation of both the electric and magnetic fields. We later confirmed this with interviews where I drew the sheet as in Figure 18 and students' responses improved.

7.9.3. Poor conceptualization of a physical problem

A salient problem which students tend to have when solving physics problems is with understanding significant aspects of physical situations and relating this understanding to the mathematical formalism (Albe, Venturini and Lascours 2001). This was evident also with the PHY2B examination, particularly with question 2a.

- *Consider a linear medium in which the permittivity ε, permeability μ and conductivity σ are frequency independent real constants and $\rho_f = 0$.*

a) *Using the in-medium Maxwell's equation together with Ohm's law, derive the differential equation that the electric field must satisfy.* *(10)*

[13] The mathematics Lecturer Mr A was also interviewed and he confirmed that student were struggling with 3D visualizations

There was evidence that most students did not fully understand this problem even though it had been treated in class. Only one student got the correct derivation. The major pitfall with the question was that the students set the conductivity to zero while deriving the required differential equation. It is clear that students were not incorporating all the information provided in the problem since it was clearly stated that the medium had a conductivity, σ , hence the current density should not vanish. Typical responses from students are shown below:

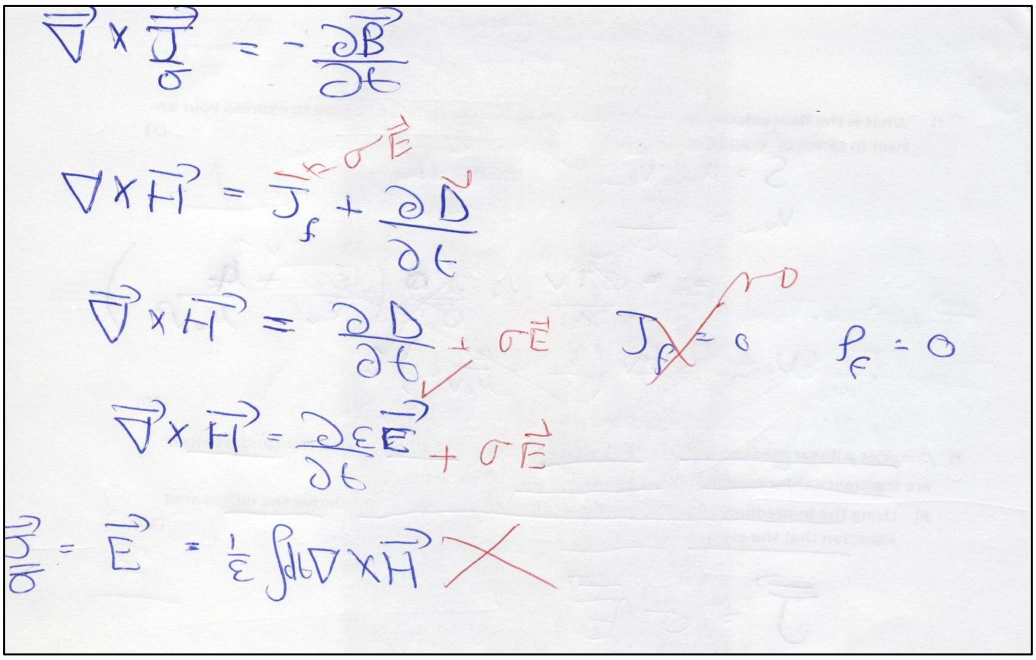


Figure 19. Typical response to conductivity problem: students set conductivity to zero

This form of reasoning has been identified as functional reduction. Guisasola, et al. (2008) define this as the tendency to reason in such a way that one does not consider all the variables which influence a problem. With functional reduction students try to find a simple solution to a complex problem.

Other problems which were noted with the question were the consistent inappropriate use of the permittivity symbol. Most students used the permittivity of free space for the question involving a medium and used the permittivity of the medium for the question involving free space.

Another issue which was of great concern (especially to the lecturer) was the fact that most students were unable to explain the physical meaning of the exponential factor.

In the rest of this question, assume the solution

$$\vec{E}(z,t) = \frac{1}{\sqrt{2}} E_0 \exp(-\kappa z)(\cos(kz - \omega t), \pm \sin(kz - \omega t), 0),$$

$$k = \omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\sqrt{1+\left\{\frac{\sigma}{\varepsilon\omega}\right\}^2}+1} \quad ,\kappa = \omega\sqrt{\frac{\mu\varepsilon}{2}}\sqrt{\sqrt{1+\left\{\frac{\sigma}{\varepsilon\omega}\right\}^2}-1}.$$

b) *What is the physical meaning of the exponential factor?* *(2)*

The expected answer from the lecturer was:

Expected answer: As the wave penetrates energy stored decreases as energy is lost to Ohmic heating.

This means that the lecturer was expecting a conceptual and physical understanding of the exponential factor in the context of the wave solution. However, typical student responses either did not provide the explanation in context, only interpreted the consequences of the mathematical solution or completed misinterpreted the expression. It seems there was a mismatch in lecturer and students reasoning about what an explanation of "physical meaning" require (Dolmert, et al. 2007). We infer that this error also stems from historical contradictions since students have previously stated that most questions of that nature in which they were familiar, had to do with interpreting the mathematical expression without relating it to a specific context. Typical responses provided were:

What is the physical meaning of the exponential factor?

- *S1: It describes the depth. Lecturer's comment: what depth? Means? Not responsive.*
- *S2: The exponential factor is the damping factor; it is responsible for damping effect of the e.m wave as time passes. It also shows that the wave number is frequency dependent.*
- *S3: The exponential factor specifies that this is circular polarized wave. That moves in circle forming a Helix in the* $\hat{z}$ *direction.*
- *S4:* e^{-kz} *is a weight function.*

- *S5: The amplitude of the wave is decreasing exponentially. Lecturer comment: why?*
- *S6:* $e^{(-kz)}$ *, exponential increase or decrease due to change of k or z keeping any of the two fixed. Lecturers comment: physical reason?*

We also interviewed students on this and there was evidence that students did not fully understand what was required and so rather did what they have been used to doing before.

***Student**: yeah we didn't understand what he meant by "physical meaning" because we usually use to do the interpretation of what it meant. We never did the exact meaning of what really it means we usually did the interpretation of what it means.*

***Interviewer:** what do mean usually? You mean back at undergraduate?*

***Student:** yeah, so when he said physical meaning I thought he just wanted the interpretation*

***Interviewer:** oh, ok. But when he said "physical meaning" what came to your mind?*

***Student:** … I ask myself when I put value here what happens to the term. When I put initial values to it what happens to it.*

In summary: the aim of this course has been to bridge between the PHY2A E&M and the NASSP Honours E&M. Even for this course, where there were only six people in the class which creates a forum for student and lecturer to work closely together the performance for the course results were poor. Though the final marks were better that the PHY2A course, the final examination performance was also poor. I interviewed Dr G, retrieved the students' products and interviewed students on the course in a bid to gain insight into the problem. The products and interviews were analysed for contradictions and disturbances in the system which could be impeding success. It is important to note that I have also been following these courses for up to four years, and trends remain similar from year to year.

7.10. Macro contradictions with the E&M courses

Over the years, the EHP and Post-EHP students have generally obtained low marks with their courses at UCT. This is especially brought to the fore when they attend the classes with other students who are from non-HBU's. I "zoomed in" specifically to the E&M courses which can be described as the backbone of physics and astrophysics in particular and which students have found most challenging. For most of the students, including the EHP-Honours students, the challenge in understanding and passing the E&M course is of major concern, considering its importance in astronomy. In order to identify the contradictions we looked for those disturbances manifesting in the course. According to Turner and Turner (2001) and Engeström (1999) contradictions are the underlying causes of disturbances in the free running of a work place and in this case a ‘learning work place’. In other words disturbances are the visible manifestations of underlying contradictions in a system as many disturbances can be mapped into one contradiction. Turner and Turner (2001) therefore maintain that understanding the dynamics of an activity and making visible its nuances and identifying any disturbances therein are the necessary precursors to identifying contradictions.

In that light we made observations, interviewed students and staff about the E&M courses, and analysed students scripts and question papers from the courses.

We found many disturbances (most notably, the EHP students’ difficulties in passing the E&M course), and attributed these to underlying contradictions in the E&M course activity system.

For the PHY2A course the rule versus objects tensions were quite severe and I think students did not resolve them by the end of course. The rules of having lectures every day of the week, weekly problem sets which needed to hand in every week, pop quizzes, test and examinations did not allow time for conceptual understanding of the content covered in 35 lectures. For students who already have the adequate background to the topics treated they may be able to follow at the pace of the course without getting lost, but where the student still had gaps to fill in, it was most likely that they would not cope with the pace.

Even though the EHPs had covered most of the content of the course, they were only covering it in a deep conceptual way for the first time. The fact that they had covered most of the content was to some extent a disadvantage in the sense that there was contradiction of: “though I have heard about a concept I really don’t know about it in the way I should”. The other problem of having covered the content was the expectation of the community. There was a mismatch between the expectations of the community (other students, lecturers, and tutor) and that of the EHPs students. This fundamental problem was a key to other tensions such as a mismatch in the expectations for walk-in tutorials, misunderstanding of examination and test questions etc.

8. Discussion and conclusion

The purpose of this work is to understand the nature of difficulties faced by students transitioning from HBU's to the NASSP UCT programme. We started this work by first looking at students' epistemologies with the aid of instruments such as the Epistemological Assessment for Physical Sciences (EBAPS). However I noted that a focus on epistemology alone could not account for the difficulties students face in a system with conflicting values such as the NASSP Honours. Furthermore, as already noted by some researchers (Hofer 2004, Gregory and Gale 2004) the complexities of epistemological beliefs cannot be fully gauged from Likert-scale instruments or experimental manipulation alone. Since epistemologies can be linked to their sociocultural origins there is a need to investigate students' epistemological beliefs and approaches to learning from a qualitative perspective and to situate students' epistemological beliefs and their learning approaches in a sociocultural framework (Phan 2008). This resulted in the need for a broader framework that accounts for tensions and conflicts. We adopted the CHAT perspective to discuss contradictions and tensions experienced in the system involving postgraduate students in an astrophysics bridging year.

In order to identify tensions we had to describe the NASSP activity system with the aid of different data sources. We gathered data via surveys, interviews, focus group meetings, observations, Personal Meaning Maps, questionnaires, and classroom video recordings. With the different data sources, I was able to identify and categorise the tensions in the system. The object of training and producing more South African black astronomers is influenced by contradictions whose manifestations can also be nested within the broader socio-political context of South Africa (Lim and Hang 2003, Núñez 2009). See Figure 20.

The society is faced with the challenges from its history which caused segregation and consequently the style and nature of learning at different institutions (e.g HBU's and liberal Universities such as UCT). These striking differences in institutional practices and learning further develops disturbances for students transiting from HBU's to UCT for the NASSP programme. These tensions are even reflected on the micro scale for core courses such as electromagnetism which is required to succeed in the NASSP. One might ask what the benefits of the contradictions are if they generate these disturbances. According to Engeström, contradictions acts as sources of change and development, and could be productive if they are identified and measures are taken to "resolve" them. There are no quick fixes to contradictions in a system; in order to benefit from them, measures have to be put in place so that they don't lead to a collapse of the system.

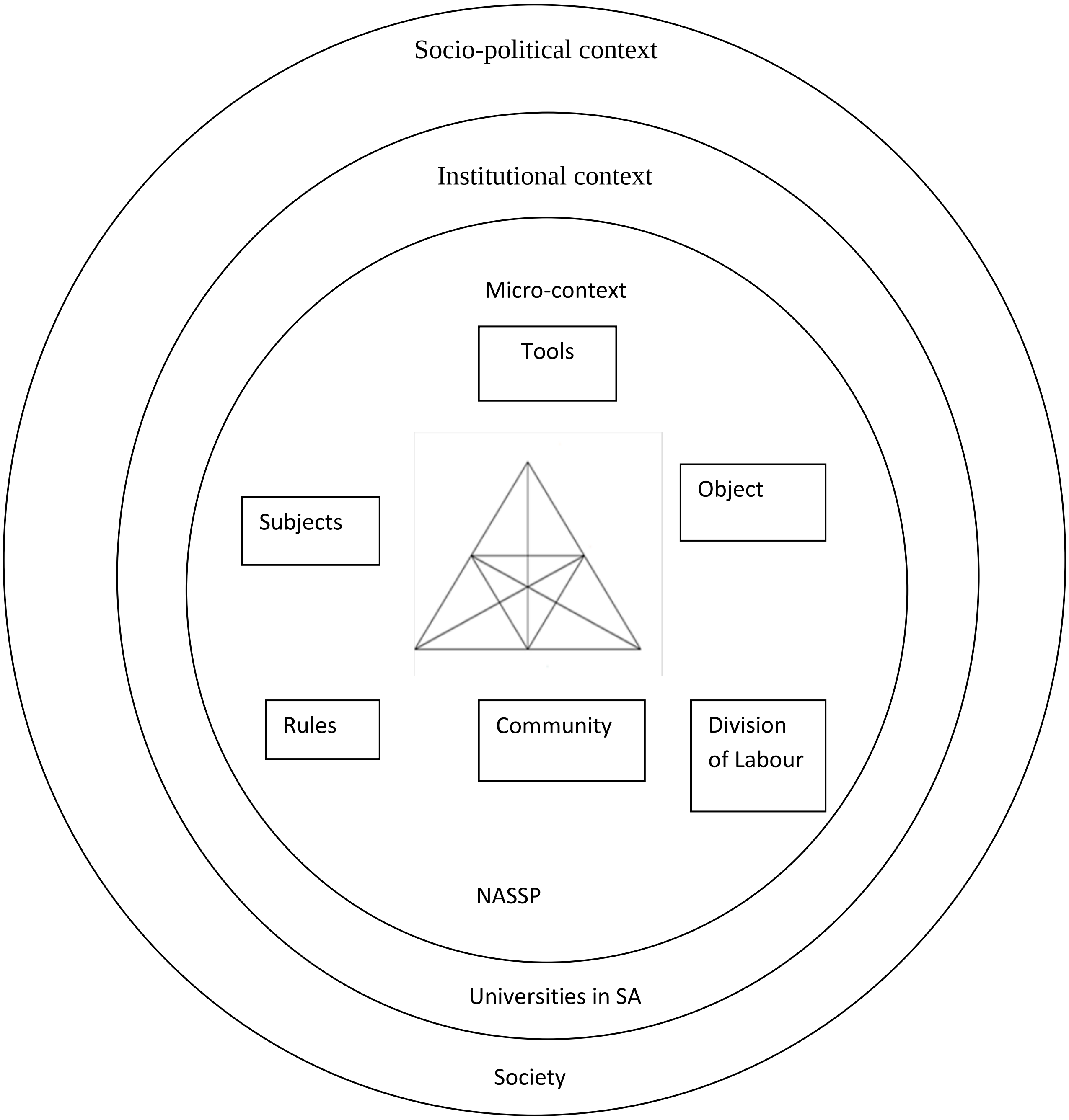


Figure 20. Nested activity systems from the socio-political context to the classroom context.

I described the nature of the tensions in the activity system involving students transiting from HBU's at undergraduate to postgraduate study at UCT, South Africa using CHAT. The tensions identified were categorised using Engeström categorization of types of contradictions. All four types of contradictions were identified in the system.

Primary contradictions involving contradictions within the components of the activity system, commonly known as "double nature", were salient in the system. This type of contradiction adversely affected the NASSP Honours students, who were torn between studying to pass exams and get good grades and studying for personal sense making and understanding. My supervisor and I noted that in the Honours year the system simultaneously utilized what we described as a *mass based system* and *apprentice learning system*. Broadly speaking, a mass based system involves summative outcomes, tests, and examinations while the apprentice model, which is commonly used in MSc and PhD programmes, values performance, processes, and understanding. The effect of the simultaneous use of both models, was that students were getting mixed messages from the system. The NASSP community apply the tools of the mass based system, especially in granting access to, and measuring success in, the community. The mass based system acts as the 'gatekeeper'. And yet, the same community claims to promote other values such as process and understanding, which contradict the values of the mass based education system.

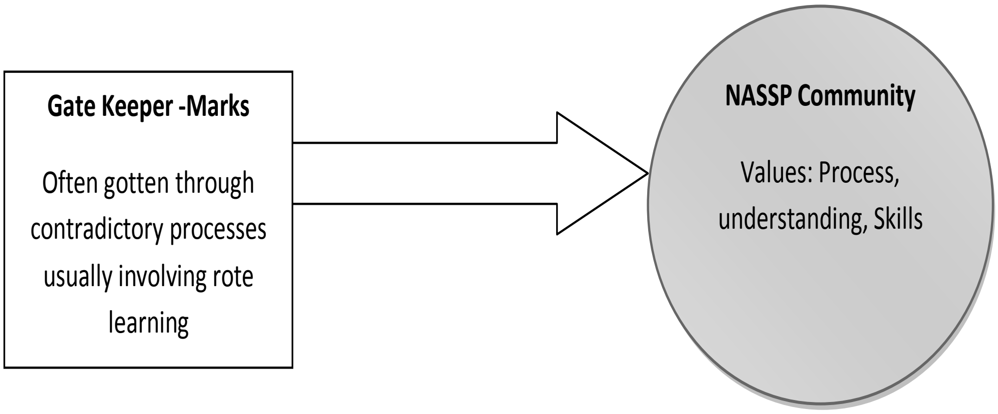


Figure 21. Diagram illustrating double nature of the NASSP Honours Programme

The contradictory actions and values often lead students to constantly reframe their situation. This leads to an almost constant 'monitoring' of the situation, which in turn reduces the capacity to meaningfully engage with on-going activities. A similar effect of monitoring is observed in studies on stereotype threat (Steele 1997).

There were several secondary tensions identified in the system. Most of them were systemic. For example, tensions between the rules and the objects. The EHP attempts to foster a transition from a binary stage (where students just know the right answer, or can derive the right answer, memorize formulas etc.) to a constructive stage where student takes charge of building his or her own knowledge. Consciously constructivist students carry out their own evaluation of an approach, equation, or result, and understand both the conditions of validity and the relation to fundamental physical principles (Edward, Jeffery and Richard 1998). According to Edward et al. (1998), students who want to become creative scientists will have to make this transition from binary to constructive.

The complexity of this tension is that when considering these new methods of developing a robust understanding of physical and mathematical concepts, students are not always clear how productive these methods are in achieving their short term goals. Productivity is usually understood in terms of coping with the pressure of large scope of work, meeting deadlines of submissions, and ultimately getting a good grade to be able to continue in the programme. For those who have been in a similar system during their undergraduate studies, it seems easier for them to be strategic and to know which particular strategy to use in a specific context. When the EHP students participate in the Honours year is gets more complicated with the fact that the Honours year utilizes a mix of binary and constructive modes of learning. The degree of the methods used therefore varies from level to level and from course to course. The inconsistency causes a tension and some students only finally resolve these when they manage to get to the Masters level. This conclusion is supported by my interview data. The excerpt presented above in section 6.3 indicating this tension, was from an interview with a student who had just completed the NASSP Honours Programme.

Data from other students who had completed the Honours programme also revealed this particular tension; where the process of adopting what is believed to be an advanced method of achieving the object of success, creates a conflict as the students cannot see the immediate benefit of adopting this ‘advanced method’, and furthermore, they do not know *when* to apply this new method.

There is a major tension in the Honours year between students succeeding in understanding the courses and the time given to teaching the courses and learning the material therein. This is exacerbated by the politically motivated (and perhaps politically appropriate) scheme of inviting lecturers from participating Universities to teach a course in the programme. Because of the visiting lecturers' time constraints, they usually only have three weeks to deliver a large amount of content. Students then get overloaded with so much information and have very little time to process it. This usually causes them to resort to seemingly easier and more familiar study methods, such as memorisation and rote learning, which do not help achieve the purported goal of the NASSP programme. There were also contradictions between the EHP students and the community. Productive interaction between the EHP students and the NASSP community (which consists of other students, tutors and lecturers) were sometimes disturbed by differences in expectations and false assumptions or ideas.

From our observations and our data, we found that most of the students who came into NASSP via the EHP route did not discuss or learn with the other students in the class. This was because they felt that doing this was not helpful, since most of the students are not on the same "level of preparedness" as them. Most of the students complained that whenever they asked for an explanation from the community, it is usually assumed that they knew some things which they did not know and they felt too shy to say that they did not know about these things. The feeling that other students in the class are more prepared or knowledgeable about the NASSP also led to feelings of inferiority and alienation, and the EHP students therefore readily experienced the 'outsider syndrome' (Mukherjee 2001). Participation in learning was consequently reduced.

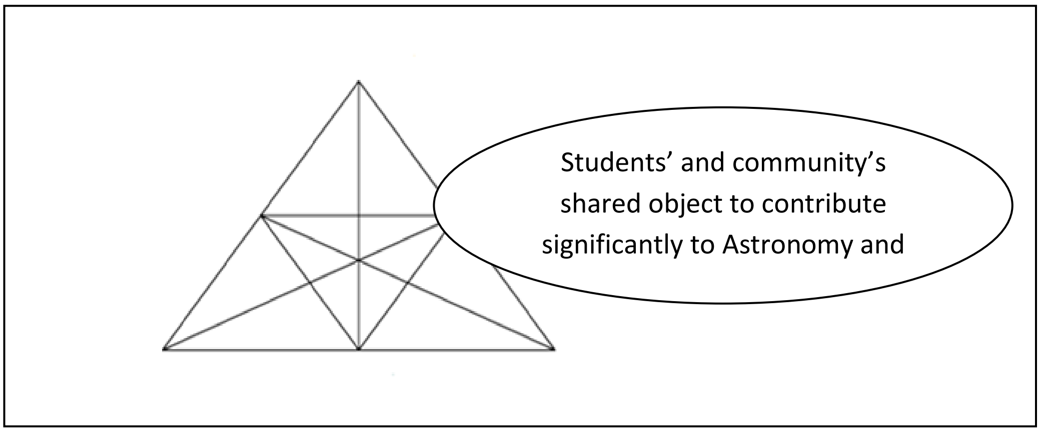


Figure 17. EHP students' and NASSP community's shared object

I have also discussed tertiary contradictions: contradictions stemming from the implementation of what seem to be new and more productive ways of doing things. For example, most students encountered tertiary contradictions when attempting to implement more epistemological sophisticated stances in learning. The statement by the EHP students: *"when you begin to think you begin to fail"*, is evidence of both primary and tertiary contradictions. Primary in the sense of 'double nature' and tertiary in the sense of adopting a new attitude which contradicts the object of passing. I also observed this tension during interviews and during the analysis of the students' products in the electromagnetism course. Though the EHP students did not do well in general, I found that some students performed worse off when they made attempts to think more deeply about the questions; they got things mixed up and ended up performing worse that students who just wrote down what they felt the questions requires. However, from the lecturer's perspective it is difficult to see this problem if you are just marking and not probing with interviews why students took certain actions when solving the problems.

For example during interviews with two students who scored no marks and one mark on question 1a and 1b in the PHY2B examination, I asked the students to sketch the electric field of the charged sheet provided from a 'perspective view'. Both students were able to draw the electric field lines reasonable well. When I probed further to find out where the mismatches were and at what point students got confused, I found out that the words in the question confused the students who were thinking a lot about the meaning and implication of those words.

***Student**: for the direction of the electric field I always knew it would point outwards and downwards from the plane but that was for static charge. There was something different about the questions it says the sheet is moving. I thought of this problem as a dielectric problem its says "outside is vacuum" so I thought outside would be above the plane and inside you would have a medium.*

***Interviewer**: does that mean you were thinking the plane or sheet has some relevant thickness*

***Student**: yes*

***Interviewer:** why did you draw the problem like it was for two conducting plate when it was a sheet of charge*

***Student:** because I couldn't imagine the other way round. Cos I was thinking…as I told you I thought of it as a sheet. Earlier on I drew in only this part and have them moving up and down in a piece of paper, not here where I was calculating it. but then I looked at the question-motion and what? Uniform motion- I lost everything with that statement.*

It seems that the students who did not think too much about the question but just guessed what sort of problem it was and solved for the electric field Gauss's law got more marks that these students who tried to think more about what the question required.

I also identified quaternary contradictions in the system. Unresolved quaternary contradictions were responsible for few students leaving the EHP before completion in order attend to financial issue in their families. These tensions existed when neighbouring activities such as family or other communities, outside of the NASSP community, interfered with the on-going activity under study. Financial pressures definitely played a role for some students: Because all the students entering the EHP programme are science graduate students who have done remarkably well in their respective degrees, their families usually expect them to get a job so as to support the family financially. However, as a result of pursuing a career in astronomy they are not able to meet that expectation and these causes tension. The other type of quaternary tension is trying to align a passion for astronomy with a genuine desire to positively impact the communities from which they come. Most of the students tried to resolve this by aiming to create an impact in the community by sharing their knowledge of astronomy, which they felt would make people live better lives as it might give them some motivation to study further or seek further education on scientific concepts.

I also identified major tensions which students going into the NASSP via the EHP route encounter in the EHP year, Honours year and Masters year. A major tension in the EHP year was found to be that of adjusting to the new system. In the Honours year the major tension was in the double nature of the programme; a primary tension between understanding and passing the exams to gain further access into the programme. In the Masters year the major tension was with how to align their lives to this real career without totally disconnecting from their local communities.

Other contradictions which I could not place in categories suggested by CHAT were also identified. A summary of these contradictions can be found in Table 6. There is also what I call a *self-judgement or self-blame tension* which the students develop when comparing themselves with their perceptions of other EHP students and non-EHP students in the class. Some students did not think anything was wrong with the system and blamed themselves for their shortcomings. If the students thought that something was wrong in the system but they felt that other students were still getting by, then they resorted to putting the blame on themselves since they could not understand why other students still do well despite the issues at hand. I believe that the tension of blame is especially prevalent in the Honours year when the EHP students work much harder than the other students in the class and get lower grades. Most of them expressed frustration with this tension.

The underlying causes of these contradictions were also discussed throughout the work. The major causes were Historical and Systemic: Historical Tensions caused as a result of prolonged practices which have been productive for the EHP students and are now no longer rewarding; Systemic tensions resulting from the rules of the university, such as time limitations in writing examinations, or the speed at which the expert teachers teach the courses; Mismatches in students' and lecturers' expectations also constituted a major problem in the overall system.

8.1. Historical tensions in learning E&M

A major contradiction which I found evident in all the E&M courses was a historical tension. This particular tension also manifested as disturbances in other courses such as the Mathematics course and the Computational course. This was evident from the interviews I gathered with the respective lecturers. The way the students have previously learnt E&M in their undergraduate studies and the way they are learning now conflicts with each other and so the students get confused with having to constantly reframe activities in other to figure out what is really expected.

These tensions plays out in the way the students frame the activities in the E&M courses: What they do during the lectures, how they approach the questions in tests, exams and problem sets, what they pay attention to, and other related activities. In other words their epistemic framing and consequently the epistemic game (Collins and Ferguson 1993, Shaffer 2006) played in these courses are impacted by their previous learning. A scenario which illustrates this historical tension was observed while we attended the E&M lectures. When the lecturer explained various concepts in electrostatics, we found it surprising that none of the students took notes of the diagrams and explanations being made. However, as soon as the lecturer wrote down the contents of the course which he intended to cover in the semester, all the students starting writing the contents down. I infer that this attitude stem from what the students described as "just following the material the lecturer hands out" which is sufficient for you to pass the examinations. I cue from Bing and Redish's (2009) definition of framing, which suggests that an individual's framing of a situation tells them what is necessary to pay careful attention to in a situation and what can be considered irrelevant and ignored. Admittedly, this scenario took place at the start of the year when the students were still new to the UCT system. However, as with any complex game, understanding all the subtleties of a new epistemic game requires a long period of learning (Collins and Ferguson 1993).

The issue with selective attention in answering questions and employing unproductive methods and approaches to solving problems were also evident in other courses such as the computational courses, the mathematical courses and even the language and communication courses.

Historical tensions are underlying sources of contradictions in the system and are defined as the tension between what is now and what used to be. These historical tensions cause students to frame physics lectures in a certain way. Even when the mode of activity has been changed the students still think of the physics class as place in which they ought to follow the 'rules' and methods which they had used during their undergraduate studies. The framing they have of the activity leads them to particular epistemic games which may or may not be productive. Unproductive epistemic games which do not assist students in succeeding in the programme, such as not paying attention at appropriate times during the lecture or memorizing formulas without any underlying understanding, are defined as disturbances in the course.

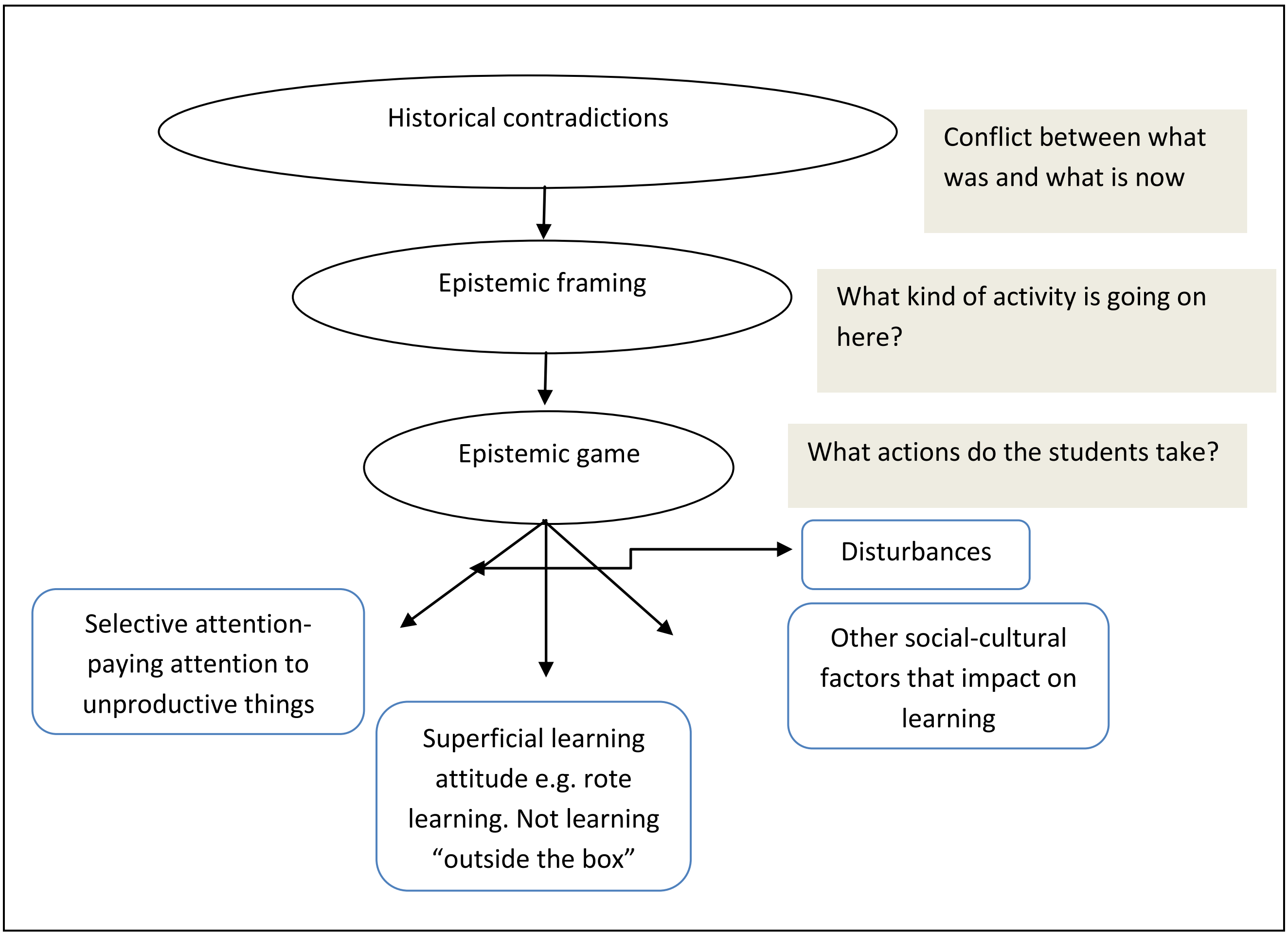


Figure 22 . Contradictions as the underlying source of disturbances

In the process of development and change it is sometimes difficult to see the effect of contradictions due to the presence and effects of the disturbances which these contradictions yield. However over longer periods of time (as was evident with the NASSP Masters students who got in via the EHP route) one can the see the expansive learning completing its cycle as illustrated in the Developmental Work Research using CHAT methodology (Mukute 2009, Engeström 1999a). Expansive learning has the following stages.

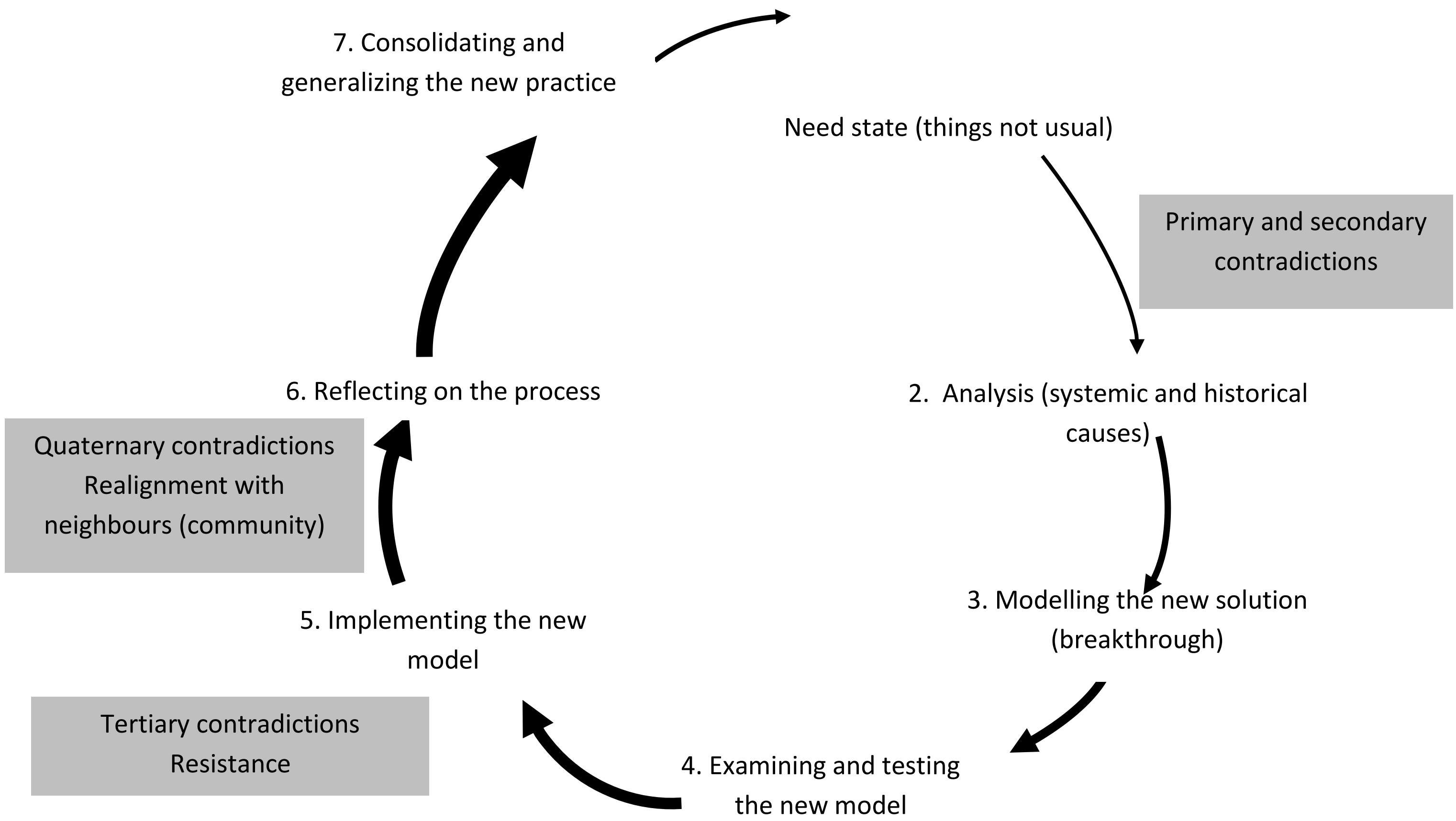


Figure 23. Expansive learning cycle from a CHAT perspective

8.2. Future directions

There is very little research work done using the CHAT framework to describe physics educational settings and identifying contradictions in the system with a view to finding ways to resolve these contradictions. Using CHAT to understand contradictions which might be present in an educational system will help in understanding students' and teachers' experiences and more importantly will highlight areas where improvements might be necessary. It brings to the fore seemingly "invisible" practices which could be hindering progress in such a system since it targets specific components in the system such as the tools, rules, community, roles, subjects, objects and the outcomes. Using CHAT as a theoretical perspective helps to eliminate false diagnosis of causes of disturbances in systems as it employs a robust method that also looks at both social and historical factors.

In this dissertation my main goal was to highlight the contradictions in the system with a view to highlighting areas where improvements might be necessary. Future work could focus on investigating how these tensions are resolved as students go through the expansive cycle and to track at what point and in what way some students overcome the tensions faced in the programme.

Some suggestions came from interviews with students and staffs about the EHP. There is a suggestion that instructors should attempt to create a safe space where students are free to ask questions and express their views during the learning process. For some of the lecturers, this was the most difficult challenge. Lecturers should be aware that students would naturally tend to be reserved and non-participatory due to a number of reason including the cultural shock of being in a different environment, not knowing what to expect and just wanting to be safe. It will require extra effort to get students to open up and be active participators in the class. One of the lecturers who managed to create a safe space for the EHP students before the end of the year commented on its importance.

Lecturer: *At the start I didn't know what was going on in their heads. If I asked them to something, whether they are just saying ummh I will just memorize the formula as I have usually done back in undergraduate. If we can get them to talk more and open up I think that would help a lot. …I don't accept second best in the sense that you know the formula but you don't know where it comes from, then think, we must understand where it come from and you don't want to put them off and be judgmental but you want to say you haven't yet thought about it. But how do get them to open up and try and discuss it that takes a bit of time. By the second semester things were much easier because most of them had opened up as I was always emphasizing that I was here to help and had them do blackboard stuff where I would be a learner and ask them questions…*

It was also suggested that students should receive training on examination preparation. Both students and staff involved with the EHP programme noted that the EHP students were slow at writing during examinations. Most of the EHP students felt that the time allocated to attempt questions at UCT was too little compared with what was being asked. Students felt they had more time to answer questions at their undergraduate institutions and that the little time given them to answer questions just makes them panic and not do as well as they ought to. Some lecturers felt it was a question of confidence on the part of the students; that students lacked confidence and because of that they were slow in writing. Whatever the case it was apparent that the students needed to practice how to write UCT examinations at a faster pace and with better accuracy. In this context, examination preparation means not only getting to grips with the given material, but also getting past question papers with their memorandum and learning what is expected from the questions.

PhD student (previous Direct entry NASSP Honours student*): Any student, any clever student, should know that there is a difference between an examination and the general knowledge that one must have. And I feel that for someone to be successful in an examination they need to go through past papers and should be able to sit and write those past papers in the set time allocated. If it's a 2 hour paper they should be able to do it within the two hours. If they can't do it in two hours then it's a problem that's the basic idea, so they should try to practice…its called examination preparation.*

…for you to pass in an examination it goes beyond understanding you have to actually practice and get the feel of the exam. …Students need to have speed and accuracy.

One of the non-EHP students who just completed the NASSP Honours Programme also commented on the need for examination preparation, especially for the EHP students. This is the same student from Eastern Africa which I described earlier on. She worked closely with some of the EHP students on some academic work. She remarked that, even taking into account the other problems (such as lack of background knowledge) EHP students faced, she believed that they did not know how to write UCT examinations because she had access to their tutorial and homework marks which were usually reasonably good. She suggested that apart from content preparation for the Honours programme, the EHP should also be prepared for examinations in the Honours Programme.

Non-EHP Student: …*for example the EM exam it needed…it wasn't something you would pass just because you have been studying, cos when I looked at that exam. It need you to get off the level of "I have read the stuff" and go like "what I this lecturer trying to say". For me they use to also set us tricky questions in undergrad, so when I see the questions I couldn't try to manoeuvre around certain questions. You find out you read with people on a topic but when the lecturer set tricky question they (the EHP students) took it literally.*

…ok me if you ask me, I think they should change the way they set the questions at the EHP and train people not just to give them how the moon looks, different phases and all. I know life is not all about exams and what, but these exams they determine our lives. You sit for three hours and it determines whether you go this side or the other side so I think they should also have that training.

Having identified the nature of the tensions faced by the EHP students in an intermediate electromagnetism course, future work will then tend towards developing instructional practices that would assist in resolving these problems and relieve the mismatches in student-lecturer expectations, thereby significantly improving instruction and learning in core physics courses.

For this work I considered the NASSP programme and the major contradictions were highlighted in the NASSP Honours years. However, on the surface, physics courses at first year, second year and third year level, appear to suffer from similar contradictions. In order to resolve these contradictions one would require 'buy-in' from all participants in the system. The CHAT framework and its principle of contradictions can also be extended for use in larger populations of students in other undergraduate bridging programme such as the Academic Development General Entry to Programmes in Science (GEPS).

The tea room discourse often tries to attribute a single cause to a perceived failure. Even a sophisticated single cause like epistemology only offers a limited perspective.

CHAT has provided a descriptive language to describe a complex system and to bring to the fore the multi-causal and interwoven aspects that lead to failure.

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APPENDIX

1.1 Sample of the interview protocol questions

Part 1 Ethics

We are conducting a research on the EHP, with a view to making recommendations for the future.

- Are you happy to be interviewed?
- Excluding the coordinator and me, is it ok to share information with other people in the field who might be able to help us.
- To what extent are you happy to be identified? Would you mind if your video is shown to this group?
- Information will not be related back to the lecturer or tutors as direct quotes from you.
- There is no right or wrong answer; we just want your opinion and experiences.

Part two general experiences

- What is your main purpose of doing the Masters programme?
- Describe your experiences.
- Has your learning experiences changed from EHP to Honours, what are the changes?
- What can you attribute it to?
- Where there unexpected things encountered during the Masters programme?
- What were the courses you did in the Honours?
- How do feel about them, what were the major difficulties?

Probing grades tension

I will like to ask a rather difficult question can you think back and remember the first time at university when you ever had a grade, can you tell me what happened around it?

- How did it speak to you or made you feel, comparing with peers?
- The fact that you were being graded, did that influence the way you learned?

NASSP Honours experience

- Did you feel that he effort that you put in led to a result that matched the effort in terms of grades?
- What can you attribute this to?

- Was it clear to you what the lecturer wanted/expectations for you to do well in the courses?
- Did you make effort to understand things and did it lead you get good grade?
- Do you see any connection between your grades and understanding?
- Have you experienced a conflict between what you wanted to read (study) and what you had to read to obtain a good grade?
- The fact that you were being graded, did that any influence on the way you learned?
- What majors strategy or attitudes do you think leads to a good grade in the honours/EHP?

Specific EM questions

- When did you first take a course in electromagnetism? How did you learn the course?
- Did you find it difficult? What were the difficulties, did you do well?
- What about Mr G's course? Did you find it difficult, did you perform as well? Where did the difficulties lie?
- What are the differences in the way you learnt at undergraduate, Dr G's course and the Honours first semester course in Honours?
- Did you think the E&M tutor in Honours was helpful? What role did he play, what role did the lecturer play, what role did the textbook play?
- Did you make effort to understand the course and did that lead you get a good mark?
- Did the E&M you learnt in Honours help with the main stream, do you think you would have passed the Honours without the EHP E&M?

EHP Year

- How do you feel about the EHP year?
- Have you observed any influence of the EHP on the Honours year? What are these influences?
- Are there particular learning experiences or general experience that were particular to the EHP and not Honours, what can you attribute those challenges to?
- what were the major challenges of the EHP year and how did you overcome them?

Tensions between adjacent Activity systems

- How do you feel about doing astronomy in the community where you come from, what are the views of the community?

Undergraduate stream

- What was the main purpose why you went for the course you did at undergraduate?
- What resources did you use to learn at undergraduate? How did you use these resources? How does that differ from here?
- What rules affect the way the subjects (students) achieve their objective and how?
- How does the division of labour influence the way the subjects satisfy their Objective? How would you describe the relationship between teacher and students? What other roles existed? How did this affect the goal of learning?

Closing

- Are there any more things you would like to say before we end the interview?
- Thank you very much for our cooperation.

Lecturer interview protocol guide on PHY2A at start of year

- What do you expect the students to learn at the end of the course?
- Why is 2014 regarded as the hardest undergraduate physics course?
- What are the necessary skills needed in order to be successful in the course
- Do you think students who don't come through the main stream will struggle?
- How much preparation should students do before coming to the course?
- Since they are students with different academic background in this class will you do anything differently?
- Thank you very much for your cooperation

Lecturer interview protocol guide PHY2B at the end of 3 year

- Can you describe your experiences of teaching the students so far?
- What are your expectations or goals when you begin teaching the students?
- How do you communicate that? Are you usually explicit about what you want students to do?
- Are they mismatches in your expectations and that of the students?

- What are common trends that you observe since teaching these students? What are the specific struggles, what are their strengths? Do you notice this trend with other groups of students e.g. Honours students?
- How do you feel about the examination performance?
- Are you aware of student's previous mode or style of learning E&M?
- Did that influence the way you taught the students?
- Do you have recommendations suggestions or ideas that can help other students with similar background entering the course?

1.2 Themes emerging from data analysis

Table 15. Coding themes for identifying tension

Themes	**Description** **This category was coded as present when students expressed the following:**	**Sample statement**
Conflicting situations	Feelings of frustration, arising as a result of having to choose between two between two unfavourable strategies to achieve objective	*…So now you are stuck with the problem of ...ok I understand this, I don't understand his method and I am going to write the exam. So if he ask me the question, what is he going to mark like...is he gonna still give me mark or is he gonna reduce because he wanted it his way, so it's like very stressful sometimes...*
Insider-outsider	(a) Feelings of not being part of the "team". (multiple use of the word "the other students") (b) Perception that the non HBU students are more acquainted with the experts in the field, more advanced in knowledge, experience and skill.	*…they went a step further than us because they have been doing ahnnnnn...they've been following astronomy from their childhood…*
Expectation violation of participants	(a) Expectations not being met, (b) disappointment	*I thought maybe is...is going to be something different so on that part I was left behind, so maybe that is why I have struggled sometimes because I thought maybe we are going to do research and if you are taught something you have to*

		go maybe and search on that thing and then maybe to understand it very well, that where maybe I missed the point...
Mismatches in expectation between members of the community	Lecturers, tutors and peers, inaccurate assessment of their background knowledge.	*I mean you can be…you can be in those high positions, top astronomer, but it doesn't necessarily mean that you are...you are a good lecturer or something like that…*
Unproductive rules and regulations in the NASSP	Standard policies in the NASSP which the students felt were not productive for their learning e.g, status of lecturers, "three weeks lecture style" , having too many assignments and tutorials etc.	*like I said...ummh…one of the reasons was the three weeks thing- that you have to do everything in three weeks and you write a test about a scope this big (hands wide apart)...ummh yeah, it was mainly that, mainly that...because most of us we had never been exposed to such things...yeah.*
Feeling cheated	Feelings of having to compete with peers who have more advantage, have to work more hours yet reward (grades) not encouraging	*don't know why, sometime I go to (student x non–HBU) room to study and she is watching movie, they don't even work as hard as us, but then they pass, I don't understand, I don't know why.*
Self-Blame	Blaming self for not succeeding, feelings of not doing something right, not getting it right, not working hard enough.	*oh my experiences…, I will be honest for me I did not work hard…I did not work hard this year (visibly shaking head), I will be honest I am not going to lie I did not work hard. I didn't...*

Comparison with peers	Negative feelings when comparing performance and grades of the Non-HBU students	*You can't complain, even about the test, if you feel like the test was unfair or something, you can't complain if someone comes with a 90 and you got a 40, you can't complain, they will say how did he or she got a 90...yeah so...*
Uncertain of the relevance of study to family/ home community	Not sure about how their studying astronomy would help their immediate families and friends	*I don't know how...how…how…how astronomy would help my community or…or how my studying astronomy would help my community*
Struggle between the new situation and the old	(a) Struggle reconciling previous academic ratings, with current ones (b) Adjusting to new methods and strategies of learning	*it's not about what you know or don't know but about adjusting to the system …really a problem first semester*
Language difficulties	Difficulty with comprehending concepts during exam considering the time constraint.	*Hmmn… the test I think the questions were not understandable, but maybe is that we are far from England*
Economic, social and financial difficulties influencing learning	(a) Economic and financial struggles, (b) Inadequate support structure	*…and then saying...hearing them saying they are struggling its quite difficult knowing that you have a degree and you could do something to help them but you can't…*

1.3 Sections of interview transcript

Transcript of interview with a Post-EHP Honours student at the end of the NASSP Honours year (about 15 minutes leading up to a critical moment)

Interviewer: We are conducting a research on the EHP, with a view to making recommendations for the future. Are you happy to be interviewed?

Student: yes.

Interviewer: Excluding the coordinator and I is it ok with you to share information from this session with other colleagues in the field who might be able to help us?

Student: yeah.

Interviewer: if we have to share something you said, would you like to be anonymous or to be identified?

Student: I don't mind being identified.

Interviewer: ok. So tell me why did you go into the Honours programme?

Students: umh…let's think…

Interviewer: its ok, take your time (laughs).

Student: basically it's in the matter of interest, because Dr T. came to our vasity in third year and I didn't really want to go work, so I figured it's a nice thing to go into so I came just basically because of interest

Interviewer: so after the EHP, you moved on for the Honours why did you that?

Student: because what we did in the EHP was very interesting to I wanted to see what the Honours would be like.

Interviewer: where there particular interesting things you would like to share?

Student: the things that particularly interested me would have to be…I think everything, everything relating to astronomy. Cos, this is all new to me, like, I didn't know anything about astronomy before 2010, and here is all these things about stars and there are like so many parsecs away and am like ok… (laughs). It's a different view from what you see on

TV, they just tell you that is a star and that's the sun and that it is, but now you find out it's a star, it's so far away, so many reactions happen chemically…you know, it's very nice, it's very interesting (laughs).

Interviewer: Can you describe your experiences in the Honour programme?

Student: umh…truthfully?

Interviewer: yes truthfully?

Student: (laughs) Ok. The first six months were terrible. Because the work load was hectic for the first six months, but then I manage to pull through, so I guess it was ok. Then the past six months, the work load was also much but not as much as the first six months but it was bearable, if I can put it that way (laughs). Cos they were times in the beginning when I was like "yo!" I just wanna finish and go home.

Interviewer: What did you think made the first six months more hectic?

Student: I think it was because we had a lot of work, we had to summit tutorials during the week, and we had to attend lectures and you find that we go home late and then we still had to find time to study…it was just a lot of work compare to the amount I had the previous year.

Interviewer: which was the extended Honours year?

Student: which was the extended Honours year; it was more…a bit better compare to the Honours year. I personally think that it's better to put the level of work almost the same, so that when you go into Honours, you don't feel like "what's going on" you know? But then I just think it was just a lot of work for me, personally for me it was just a lot of work I think.

Interviewer: ok. Can you remember the last time you has a grade in undergraduate?

Student: yes, modern physics was my last paper in undergrad

Interviewer: And you got a grade? How did you feel about the grade you got?

Student: I actually felt cheated to be honest…because I was so confident when I was writing the paper, but then you can't really change anything after exams, so I just left it.

Interviewer: why did you feel cheated?

Student: because I had a good class mark (the mark that you go into the exam with) and like I really really studied hard for that exam, also when I was writing it, there weren't so many questions I felt I couldn't answer so I was expecting a B, but I think I got a C…but it was ok.

Interviewer: Can you remember any course which you did well in?

Student: I did well in my JAVA.

Interviewer: what did you think you did that made you to do well?

Student: what did I think I did…? I have always been very good with JAVA because I understood JAVA a lot more than I understood all my other courses (laughs).

Interviewer: interesting, so the modern physics one, did you think that you understood the course?

Student: Not everything, there were some things that I didn't understand. But then with our university they didn't have good tutors in physics, so most of the work I had to do myself. So the reason why I am saying I am ok with it is because I figured even if I wasn't ok with it there isn't really much I could have done because the background from my university is not good…yeah, which is one of the reasons why I wanted to come to UCT so bad so I could upgrade on my undergrad. Because it's difficult to get a job with a degree from my university for some reason. I know a lot of people in physics who went into academia cos they couldn't find a job cos they couldn't find jobs because they got their degree from University of [x] you know…especially in the science fields.

Interviewer: you mean like an industrial Job?

Student: yeah

Interviewer: but in academics they will be fine?

Student: I dont know (laughs). But then I know very few people who have actually remained in academia. Most people go and study something else or they do something they didn't study for.

Interviewer: interesting. For the Honours programme do you feel that the effort you have put in matches the grade that you are getting now?

Student: it depends…am not quite sure.

Interviewer: ok. Let’s talk about EM in the first semester.

Student: EM first semester- I worked very very hard and I was attending tutorials, I didn’t really understand most of the EM stuff because I didn’t understand (lecturer x). In first semester we had (lecturer x). But then besides (lecturer x) there was the other guy and he also spoke very fast and he went through the material so fast so I had to like get a lot of help from that guy that was tutoring us (tutor x) and also from the other extended honour guys because we use to study together. So I never rated myself as being very good at EM so I can safely say I think the results I got basically matched how much I knew about EM.

Interviewer: so it matched how much you knew…

Students: how much I knew or how much effort I put in it basically.

Interviewer: Apart from the EM course in general, about other courses, did you make effort to understand what the course was about and did that lead you to get a good grade?

Student: yeah for some of the courses…yes I tried to understand cos I knew it’s now or never if I don’t pass then it’s like the end. So I did put a lot of effort into my studies especially now in the second semester cos I figured you know, this is like make it or break it. If I don’t make it now then I won’t do masters. But I was like …yo! So stressed…and stuff. My grades, I don’t know what I got for the exams now, but there were two exams which I felt were really difficult but then for the other exams I think I did pretty well…

Interviewer: Do you see a connection between your understanding and getting a good grade?

Student: For some of the courses…yeah…for some of the courses I had to memorise the question papers... cos I couldn’t like really understand....not that I couldn’t understand…Not that I really didn’t understand but more of there was too much work and I was getting confused, because you will find like...Gazilean formulas to do the same thing, but then you find they want specific formulas for specific thing. So it’s more of they want you to you to memorise it and then you find that you are stuck between memorising and understanding and then the pressure and time…you can’t understand now and then you have to memorise…you see that kind of thing...yeah so if that’s what you were asking...I can say there is a connection between the two (laughs)

Interviewer: between which two now?

Student: between my grades and memorising... and now you are thinking ok the way you understand it, chuck it away and now you have to use their method...Cos another thing I had (coughing) ....another problem I had similar to that was with the CM...tell me what's his name (hitting head trying to remember) .... the lecturer that was teaching CM.

Interviewer: what is CM?

Student: Computational...

Interviewer: Methods?

Student: Yeah...like he had ways of solving a problem where we had to create bins and I didn't understand his method so I used my own method, it was a bit longer than his but then it worked (laughs)...you know....and like…like I could follow it step by step and understand what is going on, and then when he marked the paper, he said that…like.... its good but then....(Shaking head) not that it is good- he marked it correct but then he said that it's a poor method. So now you are stuck with the problem of ...ok I understand this, i don't understand his method and I am going to write the exam. So if he ask me the question, what is he going to mark like...is he gonna still give me mark or is he gonna reduce because he wanted it his way, so it's like very stressful sometimes...because sometimes you might find out that they explain it a different way and I understand it a different way, It might be longer but at the end of the day I understand exactly what I am doing. So it becomes a problem especially in exams where you don't have the time to be thinking whether you understand it his way or your way and you have to put it on paper then I end up writing things that don't makes sense because I am trying to mix the two, yeah it's very confusing sometimes.

Transcript of interview with a Post-EHP student in the NASSP Master year, about 15 minutes leading up to a critical moment

Interviewer: ok. Just tell me about the EHP year. What were the main challenges for you and how did you overcome them?

Student: course wise or anything?

Interviewer: anything

Student: (thinking), I don't remember. The main main challenge for me…in my...since I got to varsity, I think, the main main main challenges were last year…

Interviewer: last year in the Honours? And they were tied to what?

Student: They were tied to ummh…it was a completely new ball game for me, the three weeks thing, I never... I had never experienced the three weeks thing in my life...ummh...yeah, the three weeks thing and then you get people in your class who are like most of their lives that's...I mean most of their study they have been exposed to the three weeks thing.

Interviewer: which students are you talking about?

Student: I mean like students from [non-HBU]…they were doing almost the same thing...three weeks courses.

Interviewer: which other groups do you have in your class?

Student: I think there was one guy from France, then Africa and South African universities. It's mainly Africa.

Interviewer: so do you think that the other groups knew what was going on?

Student: those who come from those top universities. I mean you could see it was completely divided. It would be university[x] up there and then university [y], university [z] and the others (using hands to show ranking or levels). You can't complain, even about the test, if you feel like the test was unfair or something, you can't complain if someone comes with a 90 and you got a 40, you can't complain, they will say how did he or she got a 90...yeah so...

Interviewer: that's interesting...so if you got 40 and someone else got a 90, where do you think that problem lies?

Student: like I said...ummh…one of the reasons was the three weeks thing-that you have to do everything in three weeks and you write a test about a scope this big (hands wide apart)...ummh yeah, it was mainly that, mainly that...because most of us we had never been exposed to such things...yeah.

Interviewer: what do you intend to do after your masters?

Student: there is a 70-75 percent chance of continuing for a PhD. I will say 75 percent. ok maybe 80.

Interviewer: I like the facts it's increasing.

Student: (laughs).

Interviewer: ok so what's motivating you to continue?

Student: you know some of us we come from the townships …and all those things so I will say what's motivating me is sometimes looking at my peers and what they do out there. I wouldn't say it's because I wanted to be a doctor (PhD), I never wanted to be a doctor in my life.

Interviewer: "looking at your peers and what they do out there" what do they do out there?

Student: different things men…I sometimes ask myself…you know some of my peers, after junior degree they go and find a job or something. So I always ask myself if I was like them, would I have liked the job or what will happen after seven years or eight years in the job. I don't know if you understand what I am trying to say…you know you will be employed and then you work for someone for maybe eight years. The question would be…I know my mind, I always want to know "why is that so?", "why is this so" it's almost as if I will be doing the same thing every day for many many years yeah so that's why I would like to continue further to avoid doing almost the same thing for many many years going to work sorting out files or doing whatever…so in astronomy I can switch fields I can decide to study this for two years, then decide to study this for another two years. If I feel like bored here I move here. That's the thing with me, actually the word is "bored". Feeling bored of doing the same thing or finding something more challenging.

Interviewer: ok. You are already in the career path of being an astronomer, do you think of how this is going to affect your community where you come from?

Student: (silent for a while).

Interviewer: do you think about it?

Student: I don't know how...how…how… astronomy would help my community or…or how my studying astronomy would help my community. I don't know, I will be lying. One other thing I was thinking to do someday is maybe go to schools spend an hour there giving them presentations about the stars and all those things. Maybe one can encourage them to continue with their studies yeah. Because most of them it's just the matric, those who dream higher it's to junior degree, that's it. I know them, people in my township, it is the case.

Interviewer: and why would you want to motivate them?

Student: perhaps for a better life. I was looking at the news the other day. You could see that politicians they take advantage of people who never went to school, so yeah for them to see things differently I would say so.

Interviewer: What was the student-teachers relationship like in your undergraduate?

Student: I come from a university where most of the people speak my language so, it was easy to talk to some lecturer, it was so easy. It was not a challenging thing. I would also say, from what I have observed, it's more of what you are interested in. if you are more interested in what [x] is doing, it easier for you to be close to [x]. The questions would just come naturally about the concepts or the field of what [x] is doing. Unlike if [x] is doing something which I am not interested in, then it's not easy to ask questions since I am not interested in what he/she is doing.

Interviewer: is there anything you would like us to know about the EHP, do you have recommendations?

Student: ok. I would say I am happy with the way things are being done this year…this year I think the standard is above ours. Because there are always working, always under pressure, they never get the time to …; it's just work, work, and work. I am also happy with the fact that they are doing many modules with the UCT students and that helps as well. I remember for us when… last year, that's why I was saying it was a…a whole new ball game...ummh...it was the time we were doing with UCT students...ummh....yeah and everything changed! I mean it was…it was…new faces...ummh, new ideas, new everything...so yeah…

Interviewer: when?

Student: last year.

Interviewer: ok, when you got into the Honours?

Student: Exactly yeah.

Interviewer: new faces, new everything…?

Student: it was not like the…the...a group of seven people I used to go in the class with all the time…all the time...it was 19 so...yeah...even yourself if you are a shy person like me...you will feel shy.

Interviewer: ummmh (laughing)...why would you feel shy…

Student: I don't know...I am like...

Interviewer: so you feel shy…among 19 people?

Student: (nodding)...yeah… you…you... you…will be listening to them asking...asking…like relevant questions...relevant questions...because they have been to...I mean even when we were visiting, you go to SAAO, you find that people are known there...you re like... how are these people known here? You go to Joburg you find that people are still known there....

Interviewer: People in your class?

Student: yeah…and you are surprised I mean...you hear that they were doing ...ahnnn...ahnn...I think they...they went a step further than us because they have been doing ahnnnnn...they've been following astronomy from their childhood and when you go...I remember last year when we went to HARTRAO in Joburg. Ahnn…this other girl and this other guy…ahhnn they were two, one of them is from Pretoria, the other one is from Joburg, so this other girl they knew all...everyone there knew her...I think they even claim that they went overseas one time with her and this other guy everyone there knew...knew him because they...they…use to come there when there were in undergraduate doing...yeah. Even at HMO it was the same thing, HATRAO yeah and at SAA0. So I think they went a step further than us before…yeah the…they came to the programme. Most of them…yeah…most of the people who were doing well…so yeah...ummh...So it was easy for them to pass even things which…which…were not taught...(laughs) or something...yeah

Interviewer: and that makes you feel shy?

Student: that makes you feel shy? No...You…you…because they will be asking relevant questions...because if I did something before …its easier for me to ask good questions and all that…but if I am doing it for the first time, even a question… I will be having a question... that I feel like...annh...anhh...(Shaking head) I will just goggle it or do something, even if I could have got the answer at that time…yeah...you feel shy to ask that question, because the next person...he or she ask a very relevant question which...yeah…yeah (noding)...

Interviewer: so what's your idea of a relevant question?

Student: my idea of a relevant question? You know there are those questions which are like "the true or false questions", something like, "is this a camera" you reply "yes". If you are a lecturer I ask you "is this a camera" you reply with a "yes" or "no". A relevant question I will say is if someone comes and start talking about the shutters, the filters, and what what you know it's like he is getting deep. So that "is this a camera thing… (shaking head)".

Transcript of interview with a Post-EHP Honours student at the end of the NASSP Honours year (about 15 minutes leading up to a critical moment)

Interviewer: can you recount if there are striking differences between the way you studied at undergraduate and the way you have learning here at UCT.

Student: I think the difference is in the way things are done here. It's like we take courses, maybe one course we can take it 5 hours a week. But in my university, we usually take one course 2 hours a week. That's the only difference that we have.

Interviewer: is there a difference in the teaching style apart from the number of hours?

Student: I don't think there is a difference because even in my undergraduate they use to give us notes and even here they still give us notes then we go and study the notes everything. I think the system is the same. The difference is only the number of hours.

Interviewer: let's take a typical physics course. The way the lecturers approach teaching a physics course, is it the same way they teach it at undergraduate?

Student: umh…ok. I can say it's the same if I compare fluid with the physics course that was taught by the other lecturer. Because when he came to class, he can come without notes and explain everything and then you understand and even the fluid lecturer he did the same thing. He came to class and explained everything and you understand what he is talking about. So I think they are on the same level. I don't see the difference between the way they take their course there and here.

Interviewer: so if you were doing well in a particular course back at home and you come here and you are struggling what will you attribute that to?

Student: I think maybe it's just that when we came from...when I came, I thought maybe the system might be different or maybe the things that...the way they do things here is different from our university, but now, since I have already seen how they do their things...I can...when I check the difference I can see that they are the same, it's just that when you start you just think maybe they do…the other way.

Interviewer: What other way? How where you thinking it will be different?

Student: ok…ummh when I came here like…it's like in my mind I thought maybe we are only going to do research, I thought we are not going to attend classes, something like that you see…that is why maybe when we are taught always wanted to understand everything, I wanted to like, if they are teaching something, I just want to go in...in depth...like I don't know.. I thought maybe is...is going to be something different so on that part I was left behind, so maybe that is why I have struggled sometimes because I thought maybe we are going to do research and if you are taught something you have to go maybe and search on that thing and then maybe to understand it very well, that where maybe I missed the point...

Interviewer: so after a while you realized is the same? In what ways?

Student: for example if you are writing physics, you can go through all the questions that they have set before. So if you go through all those questions you can pass you see. So when I came here I never realized that maybe I can go through as many questions as that. I just thought maybe you can just read and understand. May be it's because we were doing a different thing like astronomy. Since we were just being introduced to astronomy and when I came here I didn't know anything about stars so maybe that's the thing that makes me to struggle sometimes because I have to understand when they talk about stars, distance and even the scales now are different.

Interviewer: where did you get the idea that it was going to be different at first?

Student: I think it just came to me, I don't know. Maybe when people tell me you are going to start research because they say Honours is all about research, something like that. So I thought maybe I have to work very hard like when you are taught you just have to go deep into those things like you are researching not like you are going to be examined or write test while it's still the same thing. It's like we are still doing undergraduate because they still teach you, they give you notes, and then you write test.

Interviewer: from the last interview it seems that there was this different group in the Honours class and some people were always getting higher marks. What do you think is the reason for the division?

Student: I think those who did their undergraduate at UCT, most of the things that we are doing for them it's like a repeatance (repetition) because if you take astronomy for example those who did it up to third year, for them it's easy. First semester there was another course in astronomy so …some of the questions he gave us were from second year astronomy and some were from third year astronomy so those who did their undergraduate here with astronomy they don't have a problem, they don't even struggle with that work because they have already done it. Even in EM I remember towards the end of the year while we were doing the last part of Dr G in tensors or …something, I forgot. I asked one of the UCT students, I wanted her to clarify me on something, she just asked me haven't you done this thing before? She told me that if you haven't done it you won't understand it, because it's a short time, you have to go through the whole chapter for you to understand it. So then I realized that ok this people they have already done the things that we are doing here for them it's a repeatance (repetition) because it's like they are covering everything that has been done from first year up to third year so for them thy don't have a problem. Also in physics, some of those foreign students they have already done those physics like EM they know it. Some of them were even teaching the same course…they were teaching the same course. So for them they don't even have a problem they just have to attend and go home. So while we are attending we are thinking we are in the same level while they know…you see. I think for us that is why maybe we struggle because we were trying to understand that course and it was hard. We always wrote test every Friday which was helping us to understand but if you get low marks every time you feel that you are not putting a lot of effort like those people but after when they told you that they have already done those things sometimes you feel relieved but you still feel like you want to know more, you just want to study that things so that you understand it also you see, maybe that's the reason because most of them have already done that thing and for us we are facing it for the first time. But for astronomy for us maybe it was better because we have done it-we have done second year astronomy and first year so most of the concepts when they teach us we understand them you see but other things maybe it's because of that.

Interviewer: you said you feel relieved when they tell you that…?

Student: if you are studying with someone and that person tells you that "you know what I have already done this thing" and before you might just be thinking "why can I not do like this people"? "What are they doing that I am not doing"? While you are reading every day. When they tell you that they have already done this work before. Sometimes they won't tell you, you are just surprised. Sometimes you give yourself time to read that thing and you end up not making it but when they tell you that they have already done that thing maybe it might make you feel better, but you don't feel but like…you still feel like you want to get more or you want to be in the same level as them you see but it's just because of time. But always we always want to be in the same level as them and we try to work very hard though I think the problem was because they have already done that thing and we are just doing it for the first time we cannot compete with them that is why maybe if you check the marks that we get for EHP students maybe we were competing with each other but we couldn’t compete with those people, their marks were very…were higher than ours you see maybe that is the reason. Because for us, for EHP you can see that we were ranging…we were in the same level. There was no one who get highest mark from us you see I think maybe that has contributed. Because for us if you just check like…if we are competing there is no one who is up top we are all on the same level. But those who are on top are those people who just came into the programme who just joined the programme. So most of them will tell you that they have already done it, but when they arrive here they don’t say that they have already done it because they still want to see how the system works but when they are on the system they saw that these things are the things they have done before. So maybe that’s why for them it’s easier.

1.4 Sample of the NASSP EHP winter school electromagnetism evaluation

NASSP Winter School Electromagnetism
Evaluation

December 9, 2010

Question 1

Given two vectors $\vec{A}$, $\vec{B}$,

$$\vec{A} = (1, 2, 3)$$
$$\vec{B} = (2, 1, 3)$$

(a) What is the "dot" product (inner product), $\vec{A}.\vec{B}$?

(i) What does it mean(interpretation)?

(ii) What is the angle between the two vectors

(b) What is the cross product $\vec{A} \times \vec{B}$?

(i) What does it mean?

(ii) Is $\vec{B} \times \vec{A} = \vec{A} \times \vec{B}$?

Question 2

Given two static point charges q_1 and q_2, with q_2 at the origin

(a) Coulomb's law says the force on q_1 due to q_2 is

$$\vec{F}_{1,2} = \frac{q_1 q_2 \hat{r}}{4\pi\epsilon_0 r^2}.$$

(i) What do the various symbols mean?

(ii) What is the force on q_1 due to q_2, that is $\vec{F}_{21}$

(iii) Suppose q_2 was not at the origin but at $\vec{r}_2$, while q_1 was at $\vec{r}_1$; What is $\vec{F}_{12}$ now?

1

(b) Another way of writing the force on q_1 is

$$\vec{F_1} = q_1 \vec{E}$$

where (q_2 is at the origin again) $\vec{E}$ is

$$\vec{E} = \frac{q_2 \hat{r}}{4\pi\epsilon_0 r^2}$$

the Electric field due to the charge q_2 How do you understand the concept of the "Electric field"; why is it introduced?

(c) Suppose $q_2 = q$ and $q_1 = -q$ with $r = (0, 0, z)$. What is this called? Sketch the electric field lines and equipotentials.

(d) What is the "electric potential" $V(\vec{r})$?

(i) Why is $V(\vec{r})$ useful?

(ii) What would the potential associated to q_2 at the origin be expressed by?

Question 3

Gauss's law in integral form reads

$$\oint_S \vec{E}.\hat{n}da = \frac{Q_{enc}}{\epsilon_0}.$$

(a) What do the various symbols mean?

(b) Could you use Gauss's law to find $\vec{E}$ in questions (2b)? Explain your answer.

(c) Could you use Gauss's law to find the electric field $\vec{E}$ in the following cases, explain your reasoning:

(i) Charge Q, uniformly spread over the volume of a sphere of radius R.

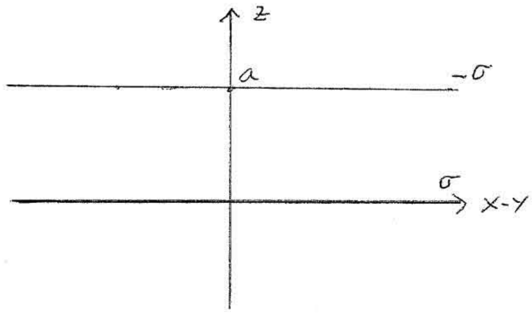
(ii) An infinitely line charge, with charge per unit length $\frac{Q}{L}$.

(iii) A finite line charge of length L and charge Q.

(iv) A cube of edge length L and charge Q, uniformly distributed on the surface.

Question4

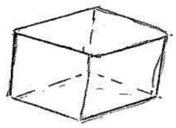
An infinite non-conducting sheet in the x-y plane has a surface charge density $\sigma > 0$. Another parallel sheet at $Z = a$ has surface charge density -σ



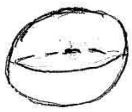
(a) Copy the figure and sketch the electric field lines.

(b) Which of the following would be a suitable "Gaussian surface" to use in calculating $\vec{E}$?

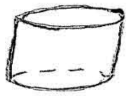
(i) Cube



(ii) Sphere



(iii) Tuna tin



(iv) Ham tin

(c) What is the magnitude of the electric field if $\sigma = 1mC/m^3$
($\epsilon = 8.85 \times 10^{-12} F/m$, where F is Farad)

Question 5

Compare the Biot-Savart's law

(a)

$$\vec{B}(\vec{r}) = \frac{\mu_0}{4\pi} I \int \frac{d\vec{l'} \times (\vec{r} - \vec{r'})}{|\vec{r} - \vec{r'}|^3}$$

and Ampere's law

$$\oint \vec{B}.d\vec{l} = \mu_0 I_{enc}$$

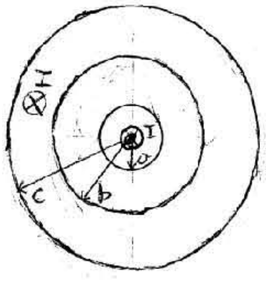
to the Coulomb's and Gauss's laws. What are the similarities and differences?

(b) Which of the two laws will you be able to use to calculate the magnetic field for:

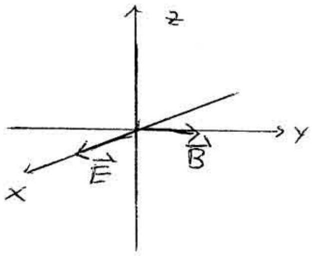
(i) An infinite thin straight wire carrying current I in the $\hat{z}$ direction?

(ii) A ring of wire of radius R in the x-y plane centered at.the origin, carrying current I, clockwise when viewed from above

(c) An infinite wire of radius a carries current I out of the page; it is surrounded by a conducting shell of inner radius b and outer radius c carrying return current into the page. Sketch a graph of the magnetic field.



(d) Suppose one has both an electric field $\vec{E} = (E, 0, 0)$ and a magnetic field $\vec{B} = (0, B, 0)$;



A charge $q > 0$ is released from rest at the origin

(i) What is the force on the charge at anytime?

(ii) Sketch what you believe the motion of the charge will be (explain your reasoning).

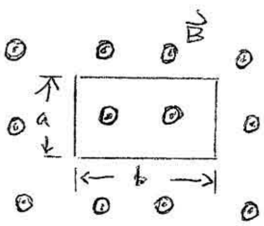
Question 6

Faraday's law states

$$\varepsilon = \oint \vec{E}.d\vec{l} = -\frac{d}{dt}\int \vec{B}.d\vec{a} = -\frac{d\Phi_B}{dt}$$

(a) What do the various symbols mean?

(b) In the sketch below, $\vec{B}$ is uniform, out of the page and decreasing in time



The nicrone wire has resistance R/L(per unit length).
What is the direction of the induced current in the wire? Can you find its magnitude?

Question 7

Is Ampere's law complete? What does Maxwell have to say on this issue? and what are the implications of Maxwell's equations?

1.5 Syllabus for NASSP Honours

In the list below

- 1 unit = 30 study hours
- 1 unit = 24 lectures and 6 tutorials (for lectures)

Description	Units
Project and presentation	2
Computational astrophysics	2
Observational astronomy	2
General astrophysics	2
Supporting Physics	4

The supporting physics module would include the following topics:

- Electromagnetic theory
- Quantum physics and spectroscopy
- Astrophysical Fluids
- Physics for Space Physics
- Plasma Physics
- General Relativity

1.6 Sample of Surveys Used for the Project

Epistemological Beliefs Assessment for Physical Sciences

A: Strongly disagree B: Somewhat disagree C: Neutral D: Somewhat agree E: Strongly agree

1. Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn't think about her own experiences; she should just focus on what the book says.

A = 4, B = 3, C = 1, D = 0.5, E = 0

2. When it comes to understanding physics or chemistry, remembering facts isn't very important.

A = 0, B = 1.5, C = 2.5, D = 3.5, E = 4

3. Obviously, computer simulations can predict the behavior of physical objects like comets. But simulations can also help scientists estimate things involving the behavior of *people*, such as how many people will buy new television sets next year.

A = 0, B = 1, C = 2, D = 3.5, E = 4

4. When it comes to science, most students either learn things quickly, or not at all.

A = 4, B = 3, C = 2, D = 1, E = 0

5. If someone is having trouble in physics or chemistry class, studying in a better way can make a big difference.

A = 0, B = 1, C = 2, D = 3, E = 4

6. When it comes to controversial topics such as which foods cause cancer, there's no way for scientists to evaluate which scientific studies are the best. Everything's up in the air!

A = 4, B = 4, C = 2, D = 1, E = 0

7. A teacher once said, "I don't really understand something until I teach it." But actually, teaching doesn't help a teacher understand the material better; it just reminds her of how much she already knows.

A = 4, B = 3, C = 2, D = 1, E = 0

8. Scientists should spend almost all their time gathering information. Worrying about theories can't really help us understand anything.

A = 4, B = 3, C = 1.5, D = 0.5, E = 0

9. Someone who doesn’t have high natural ability can still learn the material well even in a hard chemistry or physics class.

A = 0, B = 1, C = 2, D = 3, E = 4

10. Often, a scientific principle or theory just doesn’t make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense.

A = 4, B = 3, C = 2, D = 1, E = 0

11. When handing in a physics or chemistry test, you can generally have a sense of how well you did even before talking about it with other students.

A = 0, B = 1, C = 2, D = 3, E = 4

12. When learning science, people can understand the material better if they relate it to their own ideas.

A = 0, B = 0.5, C = 1, D = 3, E = 4

13. If physics and chemistry teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own.

A = 4, B = 3, C = 1, D = 0.5, E = 0

14. Understanding science is really important for people who design rockets, but not important for politicians.

A = 4, B = 3, C = 2, D = 1, E = 0

15. When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the "big ideas" might be helpful for specially-written problems, but not for most regular problems.

A = 4, B = 3, C = 2, D = 1, E = 0

16. Given enough time, almost everybody could learn to think more scientifically, if they really wanted to.

A = 0, B = 1, C = 2, D = 3, E = 4

17. To understand chemistry and physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.

A = 4, B = 3, C = 1.5, D = 0.5, E = 0

Part 2

DIRECTIONS: *Multiple choice. On the answer sheet, fill in the answer that best fits your view.*

18. If someone is trying to learn physics, is the following a good kind of question to think about?

"Two students want to break a rope. Is it better for them to (1) grab opposite ends of the rope and pull (like in tug-of-war), or (2) tie one end of the rope to a wall and both pull on the other end together?"

 (a) *Yes, definitely*. It's one of the best kinds of questions to study.

(b) *Yes, to some extent*. But other kinds of questions are equally good.

(c) *Yes, a little*. This kind of question is helpful, but other kinds of questions are more helpful.

(d) *Not really*. This kind of question isn't that great for learning the main ideas.

(e) *No, definitely not*. This kind of question isn't helpful at all.

A = 4, B = 3.5, C = 1.5, D = 0.5, E = 0

19. Scientists are having trouble predicting and explaining the behavior of thunder storms. This could be because thunder storms behave according to a very complicated or hard-to-apply set of rules. Or, that could be because some thunder storms don't behave consistently according to *any* set of rules, no matter how complicated and complete that set of rules is.

In general, why do scientists sometimes have trouble explaining things? Please read all options before choosing one.

 (a) Although things behave in accordance with rules, those rules are often complicated, hard to apply, or not fully known.

(b) Some things just don't behave according to a consistent set of rules.

(c) Usually it's because the rules are complicated, hard to apply, or unknown; but sometimes it's because the thing doesn't follow rules.

(d) About half the time, it's because the rules are complicated, hard to apply, or unknown; and half the time, it's because the thing doesn't follow rules.

(e) Usually it's because the thing doesn't follow rules; but sometimes it's because the rules are complicated, hard to apply, or unknown.

A = 4, B = 0, C = 3, D = 2, E = 1

20. In physics and chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one.

(a) The major formulas summarize the main concepts; they're not really separate from the concepts. In addition, those formulas are helpful for solving problems.

(b) The major formulas are kind of "separate" from the main concepts, since concepts are *ideas*, not equations. Formulas are better characterized as problem-solving tools, without much conceptual meaning.

(c) Mostly (a), but a little (b).

(d) About half (a) and half (b).

(e) Mostly (b), but a little (a).

A = 4, B = 0, C = 3, D = 2, E = 1

21. To be successful at *most things in life*...

(a) Hard work is much more important than inborn natural ability.

(b) Hard work is a little more important than natural ability.

(c) Natural ability and hard work are equally important.

(d) Natural ability is a little more important than hard work.

(e) Natural ability is much more important than hard work.

A = 4, B = 3, C = 2, D = 1, E = 0

22. To be successful at *science*...

(a) Hard work is much more important than inborn natural ability.

(b) Hard work is a little more important than natural ability.

(c) Natural ability and hard work are equally important.

(d) Natural ability is a little more important than hard work.

(e) Natural ability is much more important than hard work.

A = 4, B = 3, C = 2, D = 1, E = 0

23. Of the following test formats, which is best for measuring how well students understand the material in physics and chemistry? Please read each choice before picking one.

(a) A large collection of short-answer or multiple choice questions, each of which covers one specific fact or concept.

(b) A small number of longer questions and problems, each of which covers several facts and concepts.

(c) Compromise between (a) and (b), but leaning more towards (a).

(d) Compromise between (a) and (b), favoring both equally.

(e) Compromise between (a) and (b), but leaning more towards (b).

A = 0, B = 4, C = 1, D = 2, E = 3

Part 3

<u>DIRECTIONS</u>: *In each of the following items, you will read a short discussion between two students who disagree about some issue. Then you'll indicate whether you agree with one student or the other*

24.

Brandon: A good science textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit," because they're not really separate.

Jamal: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.

With whom do you agree? Read all the choices before circling one.

(a) I agree almost entirely with Brandon.

(b) Although I agree more with Brandon, I think Jamal makes some good points.

(c) I agree (or disagree) equally with Jamal and Brandon.

(d) Although I agree more with Jamal, I think Brandon makes some good points.

(e) I agree almost entirely with Jamal.

A = 4, B = 4, C = 2, D = 1, E = 0

25.

Anna: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant.

Emily: Maybe she is. But when it comes to being good at science, hard work is more important than "natural ability." I bet Dr. Kinoshita does well because she has worked really hard.

Anna: Well, maybe she did. But let's face it, some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science!

 (a) I agree almost entirely with Anna.

(b) Although I agree more with Anna, I think Emily makes some good points.

(c) I agree (or disagree) equally with Anna and Emily.

(d) Although I agree more with Emily, I think Anna makes some good points.

(e) I agree almost entirely with Emily.

A = 0, B = 1, C = 2, D = 4, E = 4

26.

Justin: When I'm learning science concepts for a test, I like to put things in my own words, so that they make sense to me.

Dave: But putting things in your own words doesn't help you learn. The textbook was written by people who know science really well. You should learn things the way the textbook presents them.

 (a) I agree almost entirely with Justin.

(b) Although I agree more with Justin, I think Dave makes some good points.

(c) I agree (or disagree) equally with Justin and Dave.

(d) Although I agree more with Dave, I think Justin makes some good points.

(e) I agree almost entirely with Dave.

A = 4, B = 4, C = 2, D = 1, E = 0

27.

Julia: I like the way science explains things I see in the real world.

Carla: I know that's what we're "supposed" to think, and it's true for many things. But let's face it, the science that explains things we do in lab at school can't really explain earthquakes, for instance. Scientific laws work well in some situations but not in most situations.

Julia: I still think science applies to almost all real-world experiences. If we can't figure out how, it's because the stuff is very complicated, or because we don't know enough science yet.

 (a) I agree almost entirely with Julia.

(b) I agree more with Julia, but I think Carla makes some good points.

(c) I agree (or disagree) equally with Carla and Julia.

(d) I agree more with Carla, but I think Julia makes some good points.

(e) I agree almost entirely with Carla.

A = 4, B = 4, C = 2, D = 1, E = 0

28.

Leticia: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can't the scientists agree?

Nisha: Maybe the evidence supports both theories. There's often more than one way to interpret the facts. So we have to figure out what the facts mean.

Leticia: I'm not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts speak for themselves.

 (a) I agree almost entirely with Leticia.

(b) I agree more with Leticia, but I think Nisha makes some good points.

(c) I agree (or disagree) equally with Nisha and Leticia.

(d) I agree more with Nisha, but I think Leticia makes some good points.

(e) I agree almost entirely with Nisha.

A = 0, B = 1, C = 2, D = 3, E = 4

29.

Jose: In my opinion, science is a little like fashion; something that's "in" one year can be "out" the next. Scientists regularly change their theories back and forth.

Miguel: I have a different opinion. Once experiments have been done and a theory has been made to explain those experiments, the matter is pretty much settled. There's little room for argument.

 (a) I agree almost entirely with Jose.

(b) Although I agree more with Jose, I think Miguel makes some good points.

(c) I agree (or disagree) equally with Miguel and Jose.

(d) Although I agree more with Miguel, I think Jose makes some good points.

(e) I agree almost entirely with Miguel.

A = 0, B = 2, C = 4, D = 2, E = 0

30.

Jessica and Mia are working on a homework assignment together...

Jessica: O.K., we just got problem #1. I think we should go on to problem #2.

Mia: No, wait. I think we should try to figure out why the thing takes so long to reach the ground.

Jessica: Mia, we know it’s the right answer from the back of the book, so what are you worried about? If we didn’t understand it, we wouldn’t have gotten the right answer.

Mia: No, I think it’s possible to get the right answer without really understanding what it means.

 (a) I agree almost entirely with Jessica.

(b) I agree more with Jessica, but I think Mia makes some good points.

(c) I agree (or disagree) equally with Mia and Jessica.

(d) I agree more with Mia, but I think Jessica makes some good points.

(e) I agree almost entirely with Mia.

A = 0, B = 1, C = 2, D = 3, E = 4

Identity survey

Name: September 2011

Please rate (by marking the appropriate box) how confident you are for each of the following questions on a scale of 0-10 where 10 means you are completely confident about the statement, 5 is neutral, and 0 is completely unconfident:

1. How confident are you that you can convince another person of your reasoning?

0 = completely unconfident	1	2	3	4	5 = neutral	6	7	8	9	10 = completely confident

2. How confident are you that you can critique the reasoning of another person?

0 = completely unconfident	1	2	3	4	5 = neutral	6	7	8	9	10 = completely confident

3. How confident are you that you could ask a meaningful scientific question that could be answered experimentally?

0 = completely unconfident	1	2	3	4	5 = neutral	6	7	8	9	10 = completely confident

4. How confident are you that you could explain something that you learned in your Masters coursework to another person?

0 = completely unconfident	1	2	3	4	5 = neutral	6	7	8	9	10 = completely confident

Please write a few sentences explaining why you selected the number ranking that you did for this previous question:

5. How confident are you that after reading an article about an astrophysics experiment, you could explain its main ideas to another person?

0 = completely unconfident	1	2	3	4	5 = neutral	6	7	8	9	10 = completely confident

6. How confident are you that after watching a TV documentary dealing with some aspect of astrophysics, you could explain its main points to another person?

0 = completely unconfident	1	2	3	4	5 = neutral	6	7	8	9	10 = completely confident

7. How confident are you that after listening to a colloquium regarding some astrophysics topic, you could explain its main points to another person?

0 = completely unconfident	1	2	3	4	5 = neutral	6	7	8	9	10 = completely confident

Please write a few sentences explaining why you selected the number ranking that you did for this previous question:

8. How confident are you that you will be successful in your Masters work?

0 = completely unconfident	1	2	3	4	5 = neutral	6	7	8	9	10 = completely confident

9. How confident are you that you will learn enough in the Masters work to be successful in the PhD program?

0 = completely unconfident	1	2	3	4	5 = neutral	6	7	8	9	10 = completely confident

Please write a few sentences explaining why you selected the number ranking that you did for this previous question:

10. How confident are you that you could use a scientific approach to solve a problem in everyday life?

0 = completely unconfident	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely confident**

Please rate (by marking the appropriate box) how much you agree with each of the following statements on a scale of 0-10 where 10 means you completely agree with, 5 is neutral, and 0 is completely disagree

11. As a student, I am supposed to think about what the teacher tells me.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**

12. As a student, I expect the teacher to be willing to listen to what I have to say about astrophysics.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**

13. I expect the teacher to provide learning opportunities.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**

14. To understand astrophysics I discuss it with friends and other students.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**

15. Working together to come up with a solution to an astrophysics course problem helps me understand the astrophysics concepts.

0 = completely	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely**

disagree										agree

Please write a few sentences explaining why you selected the number ranking that you did for this previous question:

16. Learning in groups is not helpful because I have to take exams individually.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**

17. Trying to convince other students that my answer is correct helps me understand the main ideas in astrophsics.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**

18. As a student, I can help other students learn.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**

19. As a student, I am responsible for making sure what the teacher tells me makes sense to me.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**

20. As a student, I am responsible for seeking help when I do not understand.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**

Please write a few sentences explaining why you selected the number ranking that you did for this previous question:

21. As a student, I am responsible for my own learning.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**

22. I expect the teacher to respond to what I say in class, whether or not I am correct.

0 = completely disagree	**1**	**2**	**3**	**4**	**5 = neutral**	**6**	**7**	**8**	**9**	**10 = completely agree**