PHYSICS

This is a supplementary report following the May 2010 session and should be read in conjunction with the May 2009 extended essay report.

Overall grade boundaries

Grade:	E	D	C	B	A
Mark range:	0 - 7	8 - 15	16 - 22	23 - 28	29 - 36

The range and suitability of the work submitted

There was clear evidence that students and supervisors took into account the extended essay criteria as well as the information given in the Guide. The enthusiasm and dedication of the majority of students were recognized. Many supervisors used observations (well appreciated) from the *viva voce* to illustrate their comments on the cover sheet.

In general, the topics were well chosen, even for those candidates who did not manage to fully develop, throughout the essay, what they had initially planned. A wide range of essays varied in standard from excellent to very poor. Some students presented experimental work more suited to an internal assessment investigation easily carried out in a single laboratory session. Highly unsuitable topics were rare (time travel, Schrödinger's Cat, dark matter, terra forming). As usual, the selection of the research question showed its fundamental importance in terms of enabling a suitable investigation or an unmanageable load of basic information. Many essays still show the framework of a laboratory report where students seem to structure the essay as to be guided by the Internal Assessment descriptors rather than by the extended essay assessment criteria.

A wide range of topics were covered including potentially complex aerodynamics (airfoil dimples, aircraft and parachute stability, shuttlecock drag, motion of projectiles in sports..), astrophysics (occultation of an asteroid..), sports (martial arts, rugby, archery, baseball bats, sailing, basketball..), waves and music (sound frequencies and distortion in violin and guitar, bell shape and brass sound, resonance in bottles and glass..), mechanics (elastic limit, mast position and sail thrust, resonance in model bridges, wind energy, air hockey puck, surfing waves, power and rotor blade pitch, bumper shape,..), gas (nitrogen effects on a basketball), electricity and magnetism (rechargeable batteries, train levitation, green thunderstorms..), spectral response of solar cells, home insulators, efficiencies of nuclear fuels, turbines, light bulbs.. Among interesting and innovative topics were: *The flight of the Maple Seed*, *Archery Draw Length*, *Modelling Street Lighting*, *Wind energy in Pakistan*, *Wavelength sensitivity of Solar cells*. Particularly impressive essays combined theory, experiment and iteration.

Personal interest can play a positive role in the selection and execution of a topic but it can also be a regrettable experience if the student blindly pursues an avenue with little relevant physics involved or problematic data collection. The use of internet seemed to encourage the reproduction of information instead of argument and analysis. Critical evaluation of sources and original input were expected. Experimental investigation generated the most success, possibly because it was/appeared easier to respond adequately to all of the criteria. There were examples of students involved in advanced research in university departments. In many such cases, it was difficult to assess the level of the actual understanding and real contribution of the student. Usually the best essays are accessible to other students and certainly to their supervisor and examiner. Some essays read like a PhD thesis which is being presented to experts in a narrow field of study. Such an approach is not what is expected for an extended essay in physics. “Essays based on research carried out by the student at a research institute or university, under the guidance of an external supervisor, must be accompanied by a covering letter outlining the nature of the supervision and the level of guidance provided.” (EE guide 2009, p 142)

With the use of the Internet, theoretical aspects of the investigated topics are now more complete. However, essays do not always synthesize information as they should and a lot is lost in collateral considerations. There was a noticeable improvement in the manipulation of uncertainties and significant figures. Still there were recurrent difficulties e.g. not identifying the origin of uncertainties, lack of consistency in not making the decimal figures in the measurement results coincide with the measurements given to the associated uncertainties e.g. (2.4 + 0.05) cm (a common mistake in data tables), carrying large number of decimals before final calculations or not being able to determine the uncertainty in the **average** value. The difference between the maximum value and the minimum value, divided by two, does not statistically represent the uncertainty range for the **average** value but rather the overall uncertainty range for raw values. The uncertainty range for the average takes advantage of repeated measurements which help reinforce the average value. Some good efforts made in propagating errors.

Candidate performance against each criterion

The intent of this section of the report is to underline areas requiring improvement. It might tend to sound negative, however, it should not shadow the good work submitted by many students.

A: research question

The large majority of candidates offered a suitable, well defined and clearly stated RQ. Some lost marks by not including it in the Introduction, possibly thinking it was sufficient for the RQ to be on the title page. Some RQ were too vague and/or not well- focused. The RQ should not just be a reiteration of the essay title but be carefully “unpacked” and qualified. The RQ should not be included with the title.

B: introduction

A good number of solid introductions were produced. However, there were several recurring weaknesses. Too often there was too much emphasis on the student’s personal experience/interest at the expense of presenting the physics *principles* relevant to the RQ. Some students gave a rehash of book-based physics without *personalizing* it to the RQ at hand. The detailed development of the relevant theory belongs to a separate chapter of the essay. The content required for the introduction and the abstract are different.

C: investigation

A significant number of students demonstrated good or satisfactory planning. Weaknesses included limited data gathered, elementary physics or simplistic theory based on incorrect physics (which weakened the reasoned argument). Greater efforts shown in gathering a significant number of data but improvement along those lines is recommended. Some theory relied too much on mathematics, the physics being left behind. Basic/well-known equations should not be derived nor the definitions of basic terms given. Only the immediately relevant and well-focused physics, vital to the RQ, should be in the essay. Too often the planning lacked any substantive detail as to the uncertainties and limitations inherent in techniques and apparatus. At times, students jumped into their research without giving much thought to their specific aim. Best students were adaptive, picking up on the unexpected and refining their set-up and technique. Others tolerated clear and serious flaws in their procedure relying on the evaluation as an (invalid) excuse. Some students consulted a very narrow range of resources, usually internet-based and others submitted an unrealistically long list of references. Results are not always compared to literature values. Some students doing a data-based essay failed to show an understanding of the procedure and equipment used to get these data. These basic data should be contrasted and analysed. Other students used specialised equipment in university or industrial laboratory as “black boxes” without really knowing their working.

D: knowledge and understanding of the topic studied

The challenge is to put the investigation into a proper academic context. The level reached varied widely. Padding in terms of elementary physics was too often present, which gave little indication of any depth of understanding. For example, if an essay involves something to do with waves then nothing is gained by giving textbook definitions of wavelength, frequency and speed and then deriving the relationship between them. Many candidates also took the opportunity to give a completely artificial or unnecessary hypothesis and this, too often, got in the way of their reasoned argument, the essay becoming centered on the hypothesis rather than on the RQ. Experiment-based essay were rarely without a theoretical basis, a significant improvement on past situations. Candidates who chose topics within the contents of the IB Physics diploma program generally showed a good to satisfactory understanding of the topic area. Those candidates who explored unchartered areas requiring the development of models out of the syllabus *per se* found it difficult to gain full credit for this criterion; however, there were a good number of successful attempts. Those candidates who used the results from university research departments found it difficult to express their understanding without relying heavily on quotation and thus be convincing in manifesting their understanding. Able students demonstrated their knowledge with the help of personalised diagrams. Simple rehash of borrowed diagrams were a characteristic of poor essays. Often, diagrams and sketches are essential to illustrate physical processes, for example free body diagrams. Multi disciplinary topics can generate challenging theoretical development and, for this reason, should be avoided.

E: reasoned argument

A number of students did not do well for different reasons, for example, arguments, at times, were hard to disentangle, limited presentation of ideas or lack of continuity in the reasoning, information merely collated without providing a coherent argument (in survey-based essays) or lost sight of stated goal (experiment-based essays) or simply lack of reasons why things are done or describing graphs without assessing the reasons for them. In resolving the RQ, the student must try not to leave gaps in the development of the argument. In some cases, the argument digressed into areas not relevant to the RQ. When analysing graphs , students must construct their reasoning/establish a correlation step by step and not simply invite the reader to do so by writing " It can be seen from the graph that …" or "The graph shows a positive trend." Top mark requires **close reasoning** as well as **good communication.**

F: application of analytical and evaluative skills appropriate to the subject

Correlations and uncertainties were the Achilles' heel of this key criterion. A significant number of students do not understand "inverse proportion", "direct proportion". More complicated correlations were rarely fully understood.

Too often the students have suggested a simplistic theory to predict a result and then tried to fit the results to their prediction and/or hypothesis when clearly the results did not fit the theoretical prediction even thought a clear (and unexpected) "curve" trend was evident. Students would still conclude a linear relation or produce an Excel generated empirical relation. Error bars were often ignored when using Excel to draw line of best fit. In this respect, many candidates placed too much dependence on Excel to produce equations instead of, say, doing a log-log plot to find a simple power relation. For example, a candidate would be quite happy with an Excel analysis that gave a relation such as $y = 12.66 \log x + 84.3922$ or $y = 4.3098 x^3 + 2.1 x^2 + 9.6667 x$.

The software should be used to support or invalidate a theoretical model not to become an end by itself. Some candidates showed an excellent understanding of uncertainties and error propagation whereas others fell victim to their calculators and to Excel. In general, a greater awareness of uncertainties (incorporated into data tables, graphs and final values) as well as greater sensitivity towards significant figures was shown. However, on the whole, uncertainties tended to be underestimated. A number of students felt, wrongly, that the uncertainty in a measurement is basically half of the smallest digit or division an instrument can give, ignoring the effect of this methodology. The uncertainty in the *mean value* still represented a serious challenge. Many graphs were too small to show error bars so students assumed they were negligible. In a number of cases, the fit should be constrained to pass through the origin (0, 0) for physical reasons. There was a tendency to make an exhaustive list of limitations of techniques and procedures without identifying the essential one as well as their impact on the results. Reliability of secondary data was often not mentioned. The analytical and evaluative skills of many candidates were demonstrated through their collection of measurements, analysis of data and treatment of uncertainties. Many propagated errors correctly.

Often, many opportunities to display student analysis, critical thinking, and reflection are not seized by relating a statement or value to a simple calculation or comparison (e.g., "what if

…", or, "given …, under the limiting conditions of … an upper-bound estimate would be …", a comparable situation (e.g., "this can be related to … where we find that …"), an alternative perspective (e.g., force dynamics versus energy exchange analyses), an analogy or model (e.g., wave or particle theories of light). Such interjections would highlight the student's thinking, and that is what the exercise is about.

G: use of language appropriate to the subject

Most students made a serious effort to use proper terminology, identifying unusual terms, defining clearly symbols and giving units. Unfortunately, some students used non SI units. Some lack of precision describing the shapes of curves as linear, exponential, proportional to, etc. Expressions as "direct", "positive", "direct positive" and "negative" were vague and undefined. Diagrams, a *powerful* and *helpful* tool to use in descriptions and explanations, were much too often neglected. Often, they are needed to illustrate physical processes. Some graphs were overcrowded and multicoloured making them difficult to read and interpret. Unnecessary diagrams taken from the internet or other sources were inserted without full explanation of each and all information it carried. It is often much preferable to draw one's own diagrams, a skill in danger of disappearance. Diagrams, photographs (often useless), data tables and graphs were not always clearly and completely annotated with titles, units and symbol identification thus weakening communication. A lack of proper style in writing values and their corresponding magnitudes with their units and uncertainties was common. For example, the unit of speed is $m\ s^{-1}$ not ms^{-1}, ms being millisecond. It would be good policy to follow the conventions adopted by IBO or to refer to the **International Organization for Standardization (ISO)[1].** Often equations, tables and graphs were not numbered and referred to by number in the text. Such careful presentation is in line with scientific language and enhances its clarity and precision.

H: conclusion

A conclusion should synthesize the established facts in light of the RQ. Most students achieved a good or satisfactory level. Many conclusions were weak, limited or incomplete, students repeating preceding arguments and explanations. Unresolved questions and limitations of the experimental procedure were generally well recognized; at times, suggestions were nonsensical or new issues never discussed through the essay were included. A clear and firm stand must be taken and kept if, in reality, no conclusion in line with the RQ can be reached. Conclusions tended to be sensible and humble.

I: formal presentation

Most performance varied between satisfactory (2) and excellent (4). Students made serious efforts toward improving their presentation thus achieving good results. Alas, a number of students unnecessarily lost marks. Often the bibliography is not completed properly: only (and all) references cited in the core of the essay should appear in the bibliography. Citations in the core should carry details, possibly as footnotes. There is a clear tendency to seriously abuse

[1] http://www.springer.com/cda/content/document/

the appendix which is **not** an integral part of the essay. The essay should be entirely complete and totally understandable without the help of an appendix. Very often the layout followed is the same layout used for laboratory reports as part of Internal Assessment. The layout of the Essay should be ***different*** and correspond to the layout and style of scientific papers. List of equipment should be replaced by clearly and completely annotated diagrams which, often, are much superior to unclear/un-annotated photographs. A large majority of Table of Contents were generic rather than specific. Many titles could have been more *pointed*. When 2 or 3 different manipulations are involved, the first experiment should be completed, including analysis and conclusion, before going to the next. Great improvements have been observed along those lines.

When using a numbered footnote identifying a source, the student should make sure that the number (superscript) is not confused as an exponent in an equation.

J: abstract

Elements, at times missing, were the conclusion or how the investigation was undertaken. Often, they were unclear or incomplete (insufficient details). Some abstracts went over the word limit. The very large majority of students should be able to get full mark under this criterion.

K: holistic judgment

No doubt, determination and enthusiasm were present but creativity tended to be replaced by search on the internet. Several creative, ingenious and interesting topics were presented. Fewer students spent too much time building apparatus or accumulating data thus lacking time to do a proper analysis.

Recommendations for the supervision of future candidates

Supervisors should:

- Ensure students are **familiar** with all criteria and their interpretation. Through an automatic application of the requirements of "technical" criteria (A, B, H, I and J) students should score at least 10 marks by just following the correct procedure.
- Play a **key** role assisting students choosing a **topic** and a research question relevant to physics and appropriate to their intellectual skills and abilities. Obviously this is of critical and vital importance. For most students, this is the first scientific essay they will research and write about. Guidance is a *sine qua non* condition for a majority of students. The ambition and enthusiasm of the student might need to be modulated or tempered with wisdom. Extra care should be shown before choosing a completely theoretical topic. A topic needs to be accessible to a crisp theoretical summary coupled to a carefully designed RQ and study. Purely empirical essays must be avoided at all costs. Overall, it is very sad when students set themselves up for failure. The best essays are an adventure into the unknown.
- Some fine data-based essays (meteorological for solar power, astronomical for parameter estimation, etc.) have been produced. There has been well focussed and interesting work carried out on data supplied by external agencies. This provides

wonderful opportunities to study some topics at a “system” level, correlating “big picture” data to large-scale models.

- Intervene rapidly to avoid a **disastrous error** be it theoretical, experimental or numerical. In a past essay, a student calculated $(v_2 – v_1)^2$ rather than $v_2^2– v_1^2$ when calculating changes in kinetic energy. The very negative impact of such an error on the analysis and evaluation can easily be imagined. This type of error should not be corrected for the student by the supervisor but it is quite permissible to suggest the student looks at the calculation again.
- Follow closely the progress of the student, focus on the RQ and bring **support** and encouragement.
- Encourage preliminary work, **practice** for experimental essay (**not** to be included in the essay).
- Invite the students to clearly *think* while they are proceeding with the practical work; the extended essay is not just about thinking at the write-up phase.
- Invite the student to read some good examples of **scientific articles** early. The student will learn about the nature of telling a scientific story highlighting steps taken to control and measure variables rather than presenting exhaustive list of materials or an irrelevant detailed, step-wise, recipe-like procedural instructions i.e. “Fix the spring with a clamp” or “Start the chronometer”. An annotated scientific diagram of the set-up is the way to go. A scientific paper will illustrate the general and condensed framework which will be sufficient to a reader intending to reproduce the experiment. It will also reveal how the text refers to numbered diagrams or figures, numbered graphs or numbered equations thus helping the reader follow the argument.
- Guide student towards proper sources dealing with **uncertainties**, errors, propagation of errors, uncertainty in the mean… Essentials to be considered here, no need to go deep into highly sophisticated statistics.
- Assist with the **presentation** of the essay e.g. clear references and citations (footnotes in core of essay), effective annotated diagrams, *specific t*able of contents (many are *generic*), organisation of the essay which should **not** be an IA lab report (chapters with titles, numbered equations, data tables and graphs, with sub-titles..), proper style (avoid the use of I, me, myself and irrelevant personal details). Strict logical order. Symbols defined and coherent. Error bars on graphs. Units shown. It is recommended that students consult the writing guidelines in **International Organization for Standardization (ISO)**[2] and **NIST Guide to the SI**[3]**.**
- Remind students that free body diagrams, , energy flow diagrams, representations of objects (e.g., airfoils, bicycles), or experiment set-ups can be used to more easily, more compactly, and more clearly explain things. Indeed, with too many words students often manage to get mixed up or misstate themselves.

[2] http://www.springer.com/cda/content/document/

[3] http://physics.nist.gov/cuu/Units

- There is rapidly increasing use of computer data acquisition and graphing software. While in favour of that, it is important that students recognize and comment on uncertainties sampling rate (and Nyquist), aliasing, and the use of FFT (if used). These black box systems are flexible, sophisticated, and easy-to-use tools but students must have at least a functional understanding of what they do and what their limitations are. This is a new computer literacy.
- Web-based references are ubiquitous. Ideally, the school Librarian should play a role in designing a curriculum focusing explicitly on information literacy. This would help students become better information searchers, analysts, and evaluators. It is another not-so-new literacy that is vital in a world not of information silos and paucity, but rather, information overload.
- Remind students that very good essays **do not require** a hypothesis or an appendix. (Examiners do not have to read the appendix). Also, quality and in-depth are superior to quantity and superficiality.
- Ensure the **authenticity** of the student's work.

Supervisors are strongly encouraged to write a few comments on the cover sheet about the motivation, perseverance, self-reliance, intellectual initiative, insight and depth of understanding, originality and creativity of their student.