Hubble Plots in High School: The Faulkes Telescope Project

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Abstract

This presentation describes the progress of a PhD research project into the impact of astronomy-based education resources on students' engagement with their physics syllabus. As part of the Faulkes Telescope Project and Gaia Science Alerts, the resources allow schools to "Adopt a Supernova" and track it over time using remote robotic telescopes. Engagement is measured through student and teacher pre- and post-engagement questionnaires, classroom observations and focus groups on a multiple case-study basis.

Keywords

physics education; science education; astronomy; students; curriculum; UK

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Science and Physics Education in the UK

Physics is consistently seen to be the least popular science throughout many countries around the world, and the UK is no exception (Barmby and Defty, 2006; Mujtaba and Reiss, 2014).

Barmby and Defty (2006) collected data from approximately 200,000 students in England about their perceptions of physics between 1994 and 2004. They found that physics was the least popular of the three sciences for both male and female students and both triple- and double-science students.

Factors that are commonly reported in the literature is that physics is too difficult, there are other subjects that are much more interesting and that students' interest in physics declines as they progress through secondary education (e.g. Aschbacher et al., 2010; Gill and Bell, 2013; Tripney et al., 2010; Barmby et al., 2008).

In the UK, 8.5% of the national economic output is contributed by physics-based businesses.

Individually, each of these workers have a gross value added that is equal to twice the national average (Deloitte, 2012). However, shortages in STEM-skilled personnel remains a long-standing concern for UK businesses. In 2016 it was estimated that the UK was short of approximately 40,000 STEM-based workers each year (Dunn, 2016). The pressure on students to get good grades has led to the perception that STEM subjects are only suited to the extremely bright students and as a result, we are left with just one in eleven students taking both maths and physics at A-level (post-16 qualifications that are subject-based and that can lead to further education).

As a result, UK employers are troubled with a growing recruitment concern and young people are at risk of not possessing the skills that meet the demands of today's economy and society. We have already reached a point where the lack of skills may lead to some operation plans being transferred overseas where there are more reliable skill supplies (Confederation of British Industry (Great Britain)(CBI), 2016).

In 2004, the UK government responded to the

problem and set out to increase A-level participation in science and mathematics by 2014. This was seen to be successful, however since 2014, though uptake of mathematics has continued to rise, uptake of all three sciences has declined (JCQ, 2017).

So in order to understand what is triggering this disengagement with science and how perhaps it can be turned around, naturally we must speak to the students themselves in order to begin to understand their experiences of science education at school.

Worryingly, science is also often regarded by students in England as less valuable than other subjects such as English or mathematics. A report published by the Wellcome Trust 2016 based on focus groups with students in years 10 to 13 (ages 15-18) suggests that although students acknowledge the importance of science in making a difference in the world, on a more personal level it is merely seen as an indication of someone's intelligence. It is not necessarily perceived to be valuable in getting a good job or relevant to their everyday life.

Science is only useful to someone who wants to be a scientist. Generally, students do not recognise its applicability to other careers and do not acknowledge the transferable knowledge and skills it presents to them.

In terms of subject difficulty, Rodd et al. (2014) found even high performing students who would be well suited to STEM careers often hold a perception of not being 'good enough'.

However, the literature is not unanimous and some studies have reported more optimistic findings. A study by the Wellcome Trust, reported by Hamlyn et al. (2017) gathered data from 4081 young people (years 10-13) in England. The results revealed that 68% of students reported that they found science lessons very or fairly interesting. However when broken down, the not unfamiliar feedback of physics being the least enjoyed science was evident, although a significant gender influence was seen in the data. Males actually ranked physics as the most enjoyable science whereas females

ranked it last, not only in science but overall in comparison to English, mathematics, physics, biology, chemistry, languages and history.

But even where engagement and perceptions are positive, it very rarely translates into future aspirations, higher education and related careers as reflected in university applications and the shortage of STEM-qualified workers.

Much of the research is also limited in the sense that it only provides a surface-level view of students' opinions. For example, though it conveys whether students have either a positive or negative attitude to science or physics, or if they recognise its relevance, and many studies use large participant samples and are rich in numbers, they often lack in terms of their depth and detail. This is evident in the work by Hamlyn et al. (2017). They found that when encouraging young people to learn science, two of the most influential aspects were finding science interesting and having a good teacher. Although these results provide a valuable starting point, there was no explanation into what was regarded as "interesting" and what defines a "good teacher". In order to expand these positive perceptions to a larger proportion of the student population, we need to understand the particulars that make these factors successful.

Those determinants that can be changed (i.e. those not related to gender or socioeconomic status) should be the target of interventions. In order to successfully change the perceptions of students, we must learn the experiences that have led to them, the environments they are exposed to and the pedagogical experiences they are subjected to.

Gender Differences

As briefly touched upon, it is also no secret that girls present an even stronger dislike towards physics than boys, and this is something that has been largely unchanged in the past two decades. This is reported in both their attitudes (Barmby and Defty, 2006; Hampden-Thompson and Bennett, 2013) and the uptake of physics post-compulsory education (UCAS, 2017). In 2016, just 25% of

students graduating with a core STEM degree were female. These subjects included mathematical science (39% female), physical sciences (40% female), engineering and technology (14% female), architecture, building and planning (35% female) and computer science (16% female).

Where the reasons behind this divide have been investigated, it is found that girls often report a higher dislike of physics (Barmby and Defty, 2006) and lower confidence (Hamlyn et al., 2017). However, despite males being more confident in their ability in physics, this would appear to be a great underestimation on the girls' part. Generally, girls consistently outperform boys in physics both in GCSE and A-level (JCQ, 2017), they are also 35% more likely to enter higher education (UCAS, 2017).

A reason behind this could be psychological and that physics is typically portrayed as a male subject and girls are generally not encouraged to pursue it. This is speculated by Gill and Bell (2013) who found that the number of students achieving a B grade or above at GCSE (General Certificate of Secondary Education) level was close for both male and females but females were much less likely to continue into AS level. Those that did, 70% of females who passed AS continued into A-level compared to 81% of males.

Astronomy as a Point of Engagement

There is evidence in the research that girls and boys show differences in their preferred aspects of science. Girls prefer areas of science that include health, medicine, the human body and ethics, and boys prefer topics that are more technical, mechanical, electrical and explosive. However, despite these divergences, space and the Universe are topics that are regarded to be interesting to both girls and boys (Sjøberg and Schreiner, 2010; Williams et al., 2003).

What's more, in a study by Osborne and Collins (2001) that looked into pupils' perceptions of their science curriculum, the authors found that 'space'

was an area of physics that was seen to unite groups of students who wanted to continue science and those who didn't. Even students who declared no interest in physics, became rather animated when entering discussions on space.

Osborne and Collins (2001) emphasise that though this topic is often averted by teachers, its universal popularity among students presents a valuable *"point of engagement"* for science education.

Advances in technology over the past decade mean that we are in a position to provide schools with access to research grade telescopes. Students are able to bring the Universe into their classroom and use it as a laboratory to explore and discover all the science and physics it has to offer.

In light of this, several educational projects involving telescope access have evolved across the world. Some examples include Our Solar Siblings (previously, Space to Grow), iTelescope, National Schools' Observatory and SkyNet. Although offering anecdotal success, only a handful of these projects have implemented systematic evaluation measures. A UK based project is Faulkes Telescope Project[1] (FTP) that was founded in 2004 by Martin Dill Faulkes in an endeavour to make a contribution to education that could stimulate students' curiosity and promote their engagement with learning about science and maths. He invested in two 2-metre telescopes, placing one in Hawaii and one in Australia. These locations meant that together, they covered both hemispheres of the night sky and would also be in darkness during the UK school day.

These telescopes are now part of Las Cumbres Observatory[2] (LCO), to which the FTP is an official education partner and provides the FTP with access to 18 research grade telescopes around the world. Users are provided with a free interface that enables them to program the telescopes to image astronomical objects of their choosing and also access the extensive data archive.

The FTP not only offer schools with free access to

[1]http://www.faulkes-telescope.com/
[2]https://lco.global/

the telescopes but also provide a wide range of educational resources, instruction guides, pre-packaged datasets and teacher training workshops.

However, as with many others, up until recently, FTP had also only anecdotal success, save a small scale study with trainee teachers (Beare, 2007).

As a PhD study that was the focus of this talk, a new series of resources were developed and properly evaluated in terms of their impact on student engagement in physics.

When creating the resources, the FTP teamed up with the Gaia Science Alerts team based at Cambridge University to develop a new educational project for schools to be involved with. The resources were designed specifically to coincide with areas of the UK science and physics syllabus.

Gaia[3] is a European Space Agency mission with an objective to produce both the largest and most precise 3D map of the Milky Way Galaxy (ESA, 2017). Whilst the satellite scans the sky, it also detects a myriad of new transient objects.
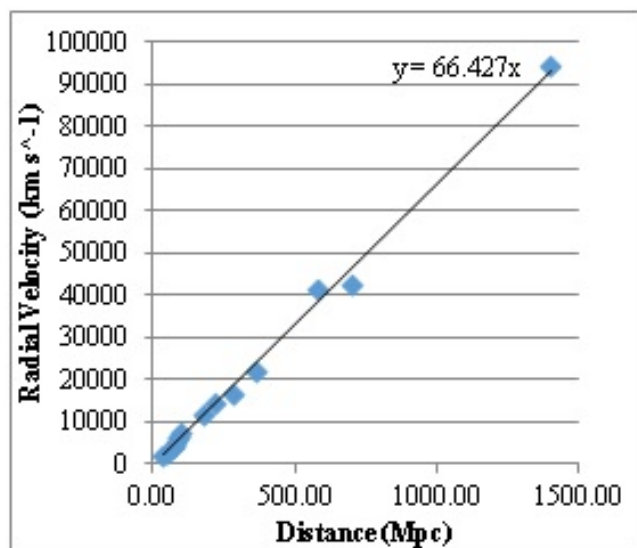
Figure 1. *An Example Hubble Plot with Gradient Equivalent to the Hubble Constant*

The latest series of resources that have been produced is the "Spotting a Supernova" teacher

[3]http://sci.esa.int/gaia/

package. This involves students using type Ia supernovae as standard candles to demonstrate Hubble's Law and calculate the age of the Universe. The activity can be differentiated quite substantially depending on the age or ability of students and how much time the teacher wishes to commit. It is possible to run the activity over one lesson using pre-packaged datasets and automated spreadsheets, but it can also be extended into a longer term project that involves students using the telescopes to observe their own chosen supernova target and performing photometric analysis which they can add to their Hubble plot. Figure 1 shows an example of the Hubble plot students produce.

The activity has been designed to follow areas of the UK curriculum but also gives students the opportunity to use real scientific data, identify relationships and practice graph plotting and interpretation. It presents students with an opportunity to use their own observations and measurements to determine the Universe expansion rate and its age, right from their own classroom.

A second activity can be run both as a computer-based activity or a hands-on activity and is based around Hertzsprung-Russell diagrams on open clusters.

For the hands-on version, each student within a class (averaging approximately 30 students) is given a star card, with a luminosity, temperature and colour for their star. There are also a series of cards with different axis titles and units. Students must decide on the axis of their graph and then each place their star card onto its correct point on the graph. As a result students should identify four main groups of stars on their diagram, the main sequence, white dwarfs, and red giants and supergiants.

To run this as a computer based activity, students use the telescopes to take an image of the open cluster NGC 957, or use an existing image. They then perform photometric analysis on the image to produce a colour-magnitude diagram of the cluster.

The materials for the activities are provided in "teacher packages". These include pre-packaged

datasets, instruction guides for Microsoft Excel and free photometry software, background information on all the relevant astronomical concepts and procedures and some quick quizzes that can be used to test students.

Methodology

The study that is presented investigates secondary school students' perceptions towards their physics education and if it can be promoted subsequent to the implementation of the astronomy-based educational resources described. It aims to go beyond the surface level, of quantitative data alone and produce an in depth understanding of students experiences and what guides their perceptions.

The study has four main research questions:

1. *How does astronomy as a context influence student engagement in physics?*

2. *What are students' perspectives around the materials?*

3. *How does student engagement in everyday physics lessons compare with their engagement with the resources?*

4. *How does engagement compare across gender?*

The research study follows an embedded, multiple-case study (type 4) replication design (Yin, 2009), with a mixed method approach. Case study methods are well fitted to a mixed method approach as they are proficient in dealing with a variety of data and can successfully generate in-depth quantitative and qualitative evidence bases. This in-depth analysis allows the researcher to scrutinise the research setting and gain a fuller understanding of the underlying processes involved with student engagement and learning.

Though case study methods are often criticised for their external validity and ability to draw reliable generalisations, this study recognises that classrooms, by definition, are not generalisable. There are a multitude of factors such as gender ratio, free school meal eligibility and performance that are unique to each classroom. There is no single 'best practice' across classrooms but only for an individual classroom.

The study does not seek generalisability but to gain understanding of different classroom environments, their setting and their requirements. As elegantly described by Cohen et al. (2011), educationists do not seek to uncover 'what works', but why and how it works, for what audience, in what environment and under what circumstances.

The Attitudes towards Physics Questionnaire (APQ) is the guiding data collection tool in this study. It is implemented pre- and post-implementation of the resources in order to make a comparison between responses on these two occasions. The pre-APQ summarises students' attitudes towards their physics education at present. The post-APQ then applies the same method to assess students' perceptions towards the educational resources they experienced from this study.

The types of questions that are used in the APQ are dichotomous, semantic differential, Likert scales and open questions. A 35-item Likert scale makes up part one of the APQ and part two is combination of the other question formats. As attitude is a latent variable that cannot be measured directly, the APQ applies multiple constructs that are deemed as key attributes to what govern a person's attitude towards physics and whether or not astronomy can offer a suitable context. These constructs make up the 35-item Likert scale and are as follows:

- General Interest in Physics

- Self-Efficacy in Physics

- Future Aspirations in Physics

- Interest in Astronomy and Space Science

- Investigation Work in Physics Lessons

- Perceived Relevance of the Physics Curriculum

Many of the items that make up the Likert scale are adopted from previous educational research studies that have previously undergone psychometric analyses to confirm their validity, unidimensionality and internal consistency. These were combined with some original items in order to create a set of questions that collectively addressed all aspects of this research and its objectives.

Classroom observations are the focal aspect for data collection in this study. Robson (1993) highlights that in small scale projects, observation of participants is particularly valuable when there is an aim to "find out what is going on". Where the APQ provides an account of 'what' happened, focused observations are able to explore the 'how' and 'why' and are what ultimately lead to a deeper understanding of the research phenomena.

Preliminary Results

As the data collection phase is still ongoing, only a preliminary analysis has been carried out thus far. This included 66, 14-18 year old students, 46 male and 20 female, from 5 secondary schools (independent and state schools) in England in Wales.

Exploratory factor analysis was carried out on pre-test data on SPSS using principal components and direct oblimin rotation. This revealed 10 factors with eigenvalues greater than 1, however inspection of the scree plot indicated that there were between 7 and 9 factors worthy of investigation. 6 was also the number of intended factors when constructing the APQ so this was also explored.

A constrained 6-factor solution showed to be the most suitable for the data and the factors coincided with those anticipated. Although, reliability analysis reported some inadequate Tukey values for non-additivity. This indicated that 5 of these 6 factors present items that can be added together to produce a reliable scale, only the factor Investigation Work in Physics Lessons was inadequate. However, as this is just the preliminary data the Kaiser-Meyer-Olkin measure of sampling adequacy was only 0.621. This value will improve

and become much closer to 1 as the number of participants increases throughout the duration of the study. In turn, it is anticipated that the reliability of factors will also improve.

Nonetheless, independent sample t-tests were performed to interrogate the data. Initially, t-tests were performed to compare gender differences across pre-APQ scores and a Bonferroni correction of 0.01 was applied to account for multiple comparisons. Results showed significant differences between gender for Perceived Relevance of School Physics $(t (61) = 2.860, p < 0.01)$ where male students perceived a higher relevance (3.26 ± 0.74) than female students (2.68 ± 0.72), and also for General Interest in Physics $(t (64) = 3.515, p < 0.01)$ where again, males had a higher interest (3.61 ± 0.55) than females (3.03 ± 0.75). The three remaining factors, Self-Efficacy in Physics, Future Aspirations in Physics and Interest in Astronomy and Space Science showed no significant differences, although males indicated slightly higher scores throughout. These results are comparable to what is seen across existing literature which is promising, especially given that this study did not employ random sampling.

Independent sample t-tests were then performed in order to compare students' pre-APQ and post-APQ scores, that is, to compare students' attitudes towards their day-to-day physics lessons to their attitudes towards the implementation activity. The t-tests were carried out on 4 of the 5 factors, Self-Efficacy in Physics, General Interest in Physics, Perceived Relevance and Interest in Astronomy and Space Science, this meant a Bonferroni correction of 0.0125 was applied to account for multiple comparisons. Items for the Future Aspirations in Physics scale were not included in the post-APQ as it was anticipated that such a short-term intervention would not have an influence on this.

Results of this showed significant differences between students' pre- and post-APQ scores on two factors. Significant differences were seen

between students' pre-APQ scores (3.19 ± 0.95) and post-APQ scores (3.73 ± 0.66) in Self-Efficacy in Physics ($t(127) = -3.677$, $p < 0.001$). They were also seen between students' pre-APQ scores (3.43 ± 0.67) and their post-APQ scores (3.73 ± 0.57) in General Interest in Physics ($t(128) = -2.677$, $p < 0.0125$). In both instances, students provided more positive responses towards the implementation activity. Although no significant differences were seen in Interest in Astronomy and Space Science or Perceived Relevance of Physics, post-test scores were slightly higher for the former factor and slightly lower for the latter. This slight decrease in students' perceived relevance is not unsurprising given the context of astronomy and space science, this is not a topic students would generally encounter day-to-day and has also been seen in other studies such as Fitzgerald et al. (2016).

Turning now to the data collected from classroom observations during occasions were students were using the astronomy-based materials. Perhaps of most value and support to the argument against seeking generalisability was seen in the implementation structure of the resources. All teachers were given the exact same resources and talked through them by the researcher. However, when it came to implementation, no two teachers so far have implemented the materials in the same way. Variations were seen in working of students, whether individually or collaboratively, levels of computer use, use of classroom discussions and input from the teacher themselves.

Males were largely seen to be more confident than females in their subject knowledge and understanding, even under circumstances where they were found to be incorrect when asked questions. There were particular instances where when asked a question about the work they were doing, females would often answer with a tone that made their answer sound like a question, implying they weren't sure they were answering correctly when typically, they were. Males however, would often answer very confidently with a statement and were often incorrect.

Another feature of the classrooms that was also very apparent was the difference in approach from males and females. The female students would focus on following the instructions carefully and would ask questions if they were unsure – wanting to do everything correctly. Male students would often ignore any provided instructions altogether and dive straight in, though this was not as evident among the older students. This is suggestive that males are perhaps the more "natural inquirers", although they would often make mistakes as they were not focussing on the set task, they would make their own natural discoveries.

The Next Steps
Upon inspection of the preliminary results, several aspects of interest are presented that will become a guide in the following stages of data collection and will also be used to structure following focus groups. As described, no two teachers delivered the activities in the same way, which begs the questions, is there an optimal, most effective method of implementation? Or is it simply unique to each classroom and the students? Is this the same for both students and teachers or do they differ?

Techniques to bridging the divide between genders in the classroom will be further investigated, and whether there are proficient ways for increasing girls' confidence in physics.

A final important question is whether or not there are any students or entire classes that show no differences in their engagement with their physics lessons than with the activity? If so, what are the reasons for this? If on both occasions they show low levels of engagement, can it be attributed to any particular aspects? Or do they simply have no interest in any aspect of science or any learning approach?

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