The Smartphone microscope - interdisciplinary approaches in the classroom.

Background

In 2008 the Scottish Government (Scottish Government, 2008) set out a number of challenges in respect of the education system including the need to:

- **Maintain our global pre-eminence in science teaching and research and continuing to attract science-related inward investment.**

- **Encourage more young people to study science subjects and build careers in science, technology and engineering in Scotland; developing a science workforce which is aligned and responsive to the future needs of the science base and the economy as a whole.**

More recently a new Curriculum for Excellence (CfE) has been introduced and the rationale, aims and objectives for CfE coupled with an appraisal of progress in terms of curriculum change have been explored in some detail (Brown, 2014). From August 2015, the full range of CfE national qualifications (from National 3 to Advanced Higher) will be available across all science subjects. The introduction of CfE raises the expectation that teachers will have greater responsibility and control over how the curriculum is delivered and should allow for a greater focus on inter-disciplinary teaching across Science, Technology, Engineering and Mathematics (STEM) disciplines (Scottish Science Advisory Council, 2011).

In a recent publication (Royal Society, 2014) it is pointed out that developments in science and technology usually happen through collaboration and open, dynamic dialogue within and across disciplines although it is also recognised that in order to ensure students acquire comprehensive knowledge, skills and understanding it will remain important for the sciences (mathematics, physics, chemistry, biology, and computing) and technology disciplines to be taught separately in schools and colleges. A number of examples of interdisciplinary projects suitable for use in the classroom have been reported (for example see Riechert and Post, 2010) and typically such approaches seek to bring STEM subjects together although projects which work across subject areas where such interactions are less common have also been explored (Hall et al., 2014a; Hall et al., 2014b).

Many of the challenges associated with delivery of inter-disciplinary projects in a ‘typical classroom’ have been explored and recommendations for how these might be addressed have been detailed elsewhere (Graham et al., 2014).

In this report we explore how the construction of a microscope which uses a Smartphone as an imaging device can lead to significant improvements in the quality of learning and teaching.
Development stage - altering original instructables design

The image below shows the first version of the Smartphone microscope (without the Smartphone on top) adapted from the instructables.com website (http://www.instructables.com/id/10-Smartphone-to-digital-microscope-conversion/). This design, although a useful starting point, had a number of flaws and design features making it unsuitable for an interdisciplinary learning (IDL) school project –

- The microscope below used a 5mm laser collimating lens (5mm focal length) which has a good magnification (x42) and was housed in 3mm clear Perspex. 3mm Perspex was not ideal for shaping with S1/2 pupils in Craft design and technology classes so this idea was rejected.
- The 5mm lens has a focus depth of approx. 0.2mm and so the design in its form below was too cumbersome as the wing-nuts used below to raise and lower the stage (where the slide sits) moved to quickly and would shake around making focussing the object a challenge.
- The structure itself felt over engineered and had too many unnecessary parts to the design, including the wooden base, small led light, excess amount of Perspex.
- The lens was housed by drilling through the Perspex with a 4mm drill bit and then carefully drilling partially through using a 5mm drill bit to approximately 0.5mm away from the bottom edge creating a ledge for the lens to sit on. Pupils would not be able to do this themselves and the lens was not held securely in place and so could fall out when pupils were using the microscopes in class.

![Figure 1- Original design](image)

Final design stage - How the microscope has changed

Following discussion with SCDI Young engineers and Science clubs, a meeting was arranged with their regional coordinator (Dave Craig, SELEX Es) as well as ST Microelectronics (Hazel McInnes) and as a group we discussed alternatives to the design. Improvements were made and further suggestions discussed and the outcome is shown below.
Improvements made are listed below –

- 7mm laser collimating lens (7mm focal length) used in place of 5mm (see fig 3). The magnification is less but it has an improved resolution and can be housed in thicker Perspex without creating a tunnelling effect.

- Thicker 5mm Perspex is now being used which can be shaped by S1/S2 pupils in CDT classes.

- The stage where the slide sits is no longer raised and lowered using the wingnuts but instead but a ‘flexible stage’ system whereby a ‘focus bolt’ pushes down onto a long 3mm Perspex platform, causing it to flex.
Housing the lens - The main challenge that was not overcome was the method of housing the lens. We tried a variety of techniques including -

- Drilling 6 mm right through the Perspex and then using a 7 mm drill bit to drill approx 4.5 mm deep into the 5 mm Perspex creating a ridge. This idea was workable however we felt that it would be too challenging for S1/2 pupils to do and that it would be too time consuming for a school technician to do for a large number of pupils.
- Using glue to hold the lens in a 7 mm hole. The glues we tried would either melt the lens or be extremely challenging to mount without getting glue on the lens itself affecting the image. Again we felt this method was too challenging for pupils and too time consuming for technicians.
- Using ring binder hole supports, works fairly well but did not last as long and decreased the diameter of the lens affecting the final image (albeit slightly). This could be used as a low cost option or for those who do not have access to a laser cutter.

Laser cut lens housing technique

To overcome the challenge of housing the lens we decided to move away from a pupil led technique but to find a technique that can be repeated by many School CDT department technicians or teachers. As following a variety of discussions we felt that housing the lens added too much complexity to the project for the pupils. However the above techniques could be demonstrated or trialled by pupils for them to discuss if they are a suitable long term solution.
After several attempts we found a solution that would house the lens in place securely without any glue. This involved ‘tapering’ the inside of the Perspex lens hole by burning ridges at increasing diameter until we reached 7 mm (the same diameter as the lens). This involves setting the laser cutter to cut a 6 mm diameter hole right through the Perspex then set deep engraving at 6.2 mm and 6.4 mm then 6.5 mm, 6.6 mm, 6.7 mm etc up to 7 mm. Through trial and error for our particular laser cutter (60 W Techsoft AS LaserCam) we managed to create a hole that held the lens in place without glue and as flush with the top ridge of the Perspex as possible.

To finish we chose clear 5 mm Perspex with a slight tint to allow more light down onto the stage, removing the need for a light source (see fig 4 below). However clear and colourless Perspex will always be best as the image will not be affected by the tint in the microscope Perspex.

A list of resources required for 100 of the above microscopes (approx A5 in size) is detailed below, many of the components can be purchased from local hardware stores with the lens purchased from Ebay or Amazon via the following link http://www.ebay.co.uk/itm/5-x-Collimating-lens-Focusing-Lens-7mm-for-Laser-Diodes-/261072485854.
<table>
<thead>
<tr>
<th>Part</th>
<th>Description of use on Microscope build</th>
<th>Cost per pack</th>
<th>Number in a pack</th>
<th>Cost per 100 microscopes</th>
<th>Cost per Pupil (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5mm x 50mm Roofing bolts</td>
<td>Legs for microscope, they come with a bolt included x 3 per pupil</td>
<td>£0.99</td>
<td>10</td>
<td>£9.90</td>
<td>0.10</td>
</tr>
<tr>
<td>Clear 3mm Perspex A3</td>
<td>Stage where samples will sit. 3mm to allow greater flex. 10 per A3 Sheet, 1 section per pupil</td>
<td>£4.08</td>
<td>1</td>
<td>£40.80</td>
<td>0.41</td>
</tr>
<tr>
<td>5mm Washers</td>
<td>To act as a spacer between stage and top platform x2 and help secure bolts and nuts on other legs x 2</td>
<td>£0.90</td>
<td>100</td>
<td>£3.60</td>
<td>0.04</td>
</tr>
<tr>
<td>Tinted 5mm Perspex A3</td>
<td>Top platform that phone sits on. A3 Sheet will make 4 microscopes</td>
<td>£6</td>
<td>1</td>
<td>£150</td>
<td>1.50</td>
</tr>
<tr>
<td>4mm x 30mm Pan Head machine Screw</td>
<td>Bolt that runs through top platform and pushed down on stage to allow focus x 1 per pupil</td>
<td>£1.66</td>
<td>25</td>
<td>£6.64</td>
<td>0.07</td>
</tr>
<tr>
<td>5mm Hex Nuts</td>
<td>To secure legs x3 per pupil</td>
<td>£7.29</td>
<td>1000</td>
<td>£7.29</td>
<td>0.07</td>
</tr>
<tr>
<td>Lens</td>
<td>To be secured into top platform. 1 per pupil</td>
<td>£127</td>
<td>170</td>
<td>£74.70 (not including postage from China)</td>
<td>0.75</td>
</tr>
</tbody>
</table>
Glenrothes High School successes and challenges

After agreement from SELEX ES to supply the nuts and bolts, ST Microelectronics to supply lenses and SSERC to provide Perspex and technician time for a trial run of the project in a secondary school I met with Robin Wallace (Physics teacher) from Glenrothes High School who agreed to take on the challenge of implementing an IDL project involving two large departments and every S1 pupil in the school.

At first the CDT department were reluctant to be involved as there was a concern about the amount of drilling required by the pupils in the design of the microscopes. However all of the Science department were on board and other departments were in the process of considering how they could use the device.

The IDL idea proposed was –

‘Pupils in S1 (age 12) learn about history, design and applications of Microscopes and are given a brief overview of how they work, including fundamental parts. Pupils are also given the opportunity to investigate different shapes of lenses. This knowledge will allow them to learn about the history and use of microscopes in Science but with the added benefit of working with their Craft and Design and Technology teachers to design and build a microscope in their CDT class for their specific mobile device (or school loaned device).

Following the design and build, pupils can then (due to the affordability of the design) take their microscope home and use their devices (or friend/family) to take images of whatever they want to observe and bring this back into school for discussion. It may be that the teacher sets their pupils a task of imaging an insect/plant life in their garden.

As an end point to the task pupils can work in Social subjects to discuss the benefits of enhancing such technology. For example they can discuss the health benefits of affordable microscopes in third world countries, possibly looking at new innovative projects such as ‘FoldScope’.

Following discussions with the school we opted for a more multidisciplinary approach rather than setting the pupils a challenge of designing the device from scratch. This meant that CDT built the microscopes (see fig 5) and the pupils could then use them in Science as well as other subjects. Pupils undertook a variety of projects with the microscopes from images of different subjects to videos of living microscopic Daphnia. One pupil even decided to take a time-lapse image of Copper sulfate crystals forming (https://youtu.be/4OLrJfXrXtE).

To overcome the issue of drill holes, SSERC agreed to laser cut the top platform including the lens holes for the pupils so that the pupils can focus on the skill of cutting and shaping Perspex.
Figure 5 - Example of Glenrothes pupils' microscope

Figure 6 - Pupils investigating water fleas with their microscopes
Robin Wallace, the Physics teacher at Glenrothes High School who led the project from the school made some closing remarks on the project below:

1. What experience of IDL did you have prior to this project?
   ‘None’

2. What feedback did you receive from the pupils?
   ‘A majority of the pupils thought the project was either “Very good” or “excellent” when polled. Pupils viewing live daphnia were genuinely surprised that they could see such detail and were “amazed”. Pupils used traditional microscopes during the same topic and over 80% of pupils polled preferred the phone microscopes. Pupils were aware that some did not have camera phones but were happy to share their phones to allow others to access the project. However, those who did not have a phone camera were not as happy with the project with around half of them put off by the fact they couldn’t use their own phone. Around, 20% did not have a phone that could be used to take photos.’

3. Is this project sustainable in the future for your school?
   ‘Yes, the rector has offered funding for next session on a similar scale to this year. The biggest issue will be sourcing a laser cutter to get past the lens mount issue - SSERC will be the first choice.’

4. Has undertaking this project improved your confidence to deliver more IDL projects in future?
   ‘Yes, my confidence has improved. It would not have stopped me doing an IDL project previously but my learning experience has been invaluable. There are several places I would like to improve next time such as giving individual departments more ownership.’
5. Do you feel the pupils have a better understanding of the science and technology behind the microscope? Evidence for this?
   ‘All pupils successfully underwent a Biology topic focussed on cells and using a microscope - including naming of parts, function and calculating magnification. The phone microscope improved pupils ability to access this content more easily - particularly (though not exclusively) lower ability pupils.’

6. Would you say that other departments are now willing to work with you on future IDL work?
   ‘More departments are willing to get involved with IDL. We managed to get 7 departments on board initially but due to logistics we were only able to get 3. The aim next year is obviously to make time to get all involved.’

7. What challenges were overcome to allow this project to go ahead in your school?
   ‘Logistical movement of the microscopes from department to department - this was tricky due to the fact that practical classes were not made of the same pupils and microscope could not be shared easily between depts. We also had resistance from departmental staff, who were won round and pretty happy in the end. This was mostly due to resolving unfounded anxieties but they were also able to see the value of the project.’

8. Has this project had an influence on your/departments attitude towards IDL?
   ‘The project has been an investment of time which is always a precious resource as a teacher. We have previously been involved in smaller one off projects but this was more worthwhile. While we have always been open to IDL it is rare to find a project that is genuinely worth the investment and to get such a payback from the pupils.’

9. Any other comments?
   ‘I am still trying to find the best way to get images off the phones and onto a computer at school. Very few pupils use email.’

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References


