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# The impact of hand held mobile technologies upon children's motivation and learning.

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## ABSTRACT

Previous work has qualitatively investigated the importance of hands-on learning using mobile technologies in children's scientific investigation. Many studies report 'improvements' when learning is 'hands on' but are these improvements measurable learning gains or an increase in motivation alone? We examined the effects of hands-on activity on both motivation and learning. Forty-six school students took part in a study which explored whether children's understanding of self-collected data differed from that of data collected by peers or teachers, and if levels of understanding of graphed data differed when the graphs were hand-drawn, hand-annotated or computer-generated. Results revealed that hands-on learning effects were limited and very specific to interpretation of graphs. However while self-collection did not seem to affect understanding, it did positively affect motivation. We discuss the relationship between student learning and motivation.

## Author Keywords

Children, experiment, hands-on learning, graphs, data-logging, motivation.

## 1. INTRODUCTION

The use of technology can enhance a hands-on approach to learning. Advances in sensor hardware and mobile technologies, the easy transfer of data into graphs, and the ability to juxtapose this data onto locations using applications such as Google Maps and Google Earth all have the potential to create new opportunities for school science and cross-curricular learning. However, taking advantage of these new opportunities for the purpose of education requires significant work beyond technical development including: engaging teachers; understanding the pedagogical implications of the use of new designs; and engaging companies in design partnerships in order to make the resulting hardware and software appropriate for schools. It also requires the school management to be willing and able to support developments, for instance the ability to add new software to the school network, and allowing teachers time to gain understanding of the technologies. It is therefore important to understand just what aspects of these technologies may be beneficial to children's learning.

Hands-on learning with mobile technology is often advocated as the way forward in engaging children in science, by enabling them to carry out their own studies

of the real world, making scientific data less abstract and more meaningful to them personally, supporting the understanding of the scientific process, as well as the results [Pea (2002); Resnick et al (2000); Rogers et al (2004); Stanton et al (2003); (2005)]. However the majority of this work has been qualitative in nature and, while it has established positive effects of hands-on investigation, it is often not so clear where the advantage actually lies. The elusive causes of 'hands-on learning' benefits are partly due to the varied use of the term to mean for example, self-collection of data, carrying out experiments in the laboratory, or even group work.

In this paper we report work which contributes to understanding the origin of hands-on learning benefits. The two aspects we are specifically concerned with are 1) *self-collection of data* – collecting one's data in the real world and 2) *'working up' or transforming these data oneself to convey the process of translating from raw data to (scientific) concept*. An experimental design reveals some of the subtleties at play in these activities. We explore issues such as: Does carrying out an investigation in the real world enhance motivation and learning? Does 'doing it yourself' - drawing your own graph in this case - give you a better conceptual grasp of such behaviours as interpreting the graph or plotting new graphs or do you gain more from using software to produce graphs, or interpreting the pre-produced input of others?

Previous studies informed hypotheses around self-collection of data, and hand-producing data. We expected: motivation and understanding to improve for data which is self-collected; ability to answer questions on graphs to improve at post-test when students generated graphs themselves; and pre-generated graphs to be better understood if students took the recordings themselves.

Our results have implications for technology designers, particularly highlighting that some qualitative work may be misleading designers on important questions such as when in the educational process automation is best used.

## 1.1 Background

The idea that hands-on learning is beneficial is not new. Dewey (1964) advocates that science is best understood through carrying out one's own inquiry and experiencing scientific phenomena and processes. This is supported by more recent work emphasizing the importance of personal

experience for natural learning (Zoldosova and Prokop, 2006). Authentic work is important, students need to be able to relate to their work (Krajcik et al, 1998) and where possible experience the situation first hand (Johnson et al 1997). Taking part in real world studies of science is considered crucial to students' understanding, the personal involvement in investigation enabling students some autonomy and experience of the process (Resnick et al 2000). Such learning experiences are considered fundamental to understanding the basic representations and concepts that enable students to develop a more complex understanding of the world (Millar and Osborne 1998).

Emerging 'pervasive' technologies such as mobile devices, sensors, and interactive systems have the potential to enhance learning and motivation by enabling innovative hands-on learning opportunities. However, while the use of sensors in science learning is clearly on the curriculum, actual use of the equipment in schools has been limited due to problems with the usability of the technology, time and effort of setup and the complexity of importing data into relevant formats, all these interfering with the rhythm and quality of the learning process (Woodgate and Stanton Fraser, 2005; 2006)

In a study of how 13-year-olds carry out scientific investigations in the classroom, Krajcik et al (1998) found that the children did not choose to use the data they had collected to create graphs, even though it would help them to draw conclusions. Fishman et al (2001) point to the importance of building engaging and motivating small-scale projects which mirror the complexity of science and also reflect larger issues. In this respect, many argue that technology in schools is not being used to promote critical thinking. The Participate project (Woodgate et al 2009) applied both bespoke educational sensors and Bluetooth enabled mobile phones in order to capture data. Once back in the classroom, children explored and analysed their data using graphical representations over Google Earth or Google Maps to view the readings juxtaposed upon the actual locations visited. Images could also be attached to relevant parts of the graph/location as contextual cues. The authors noted that the 'seamlessness' of the experience did not always lead to fruitful discussion, and requiring children to put graphs, contextual data and location together led to more reflection upon the experience and the data itself. When graphs were automatically produced there was little discussion and a short reflection period. In comparison, when there were break downs in the automation of the experience, this initiated additional group discussion and reflection. In addition to considering seamfullness, in their 2008 report on the Participate project, Woodgate et al reflect upon the importance of students obtaining context for their data, positing that by allowing students to collect their own data and gain understanding of the data environment the student will find this a more engaging method of learning.

Others have reported inconclusive effects on students' cognitive achievements following hands-on activities, but state that they promote a more positive attitude towards

science. Salmi (2003) indicated that visiting a science centre increased students' intrinsic motivation. Some would argue that promoting positive attitudes towards learning is in itself a crucial educational outcome (Mee, 2002). An educational policy report states that use of ICT across the curriculum can increase students' confidence and motivation in learning (Osborne and Hennessy 2003).

In this paper, we also explore aspects of hands-on learning that involve carrying out work yourself – in this case either drawing your own graph, using software to create graphs or annotating graphs already created for you. Barton (1998) highlights a number of problems with traditional practical work including: student difficulties linking their practical experience with abstract concepts, especially because the time taken to collect and process data leaves very limited time to 'relate the practical to the theory'; and that "information clutter", including equipment used, measurements, calculations, graphs and the problems associated with these distract students from the task at hand.

While the literature provides no evidence that students are at a disadvantage when drawing graphs manually there are a number of studies suggesting data logging could aid the process. The following advantages have been found for data logging over manual collection and recording of results: Friedler and McFarlane (1997) found evidence that for some age groups data logging over traditional apparatus leads to improvement in children's ability to read, interpret and sketch line graphs. Barton (1998: 366) found that the real-time production of computer graphs enabled younger, weaker students to explain, make predictions and make links to previous relevant knowledge, stating "manual graph plotting should be avoided when the main aim is to interpret relationships via graphical analysis". Choo (2005) states that presenting a number of graphs simultaneously or one at a time representing the same data in different ways can aid pupil's conceptual understanding. Recent work (Baggot et al, 2007) has indicated that students and teachers alike feel that instant graphing software can reduce drudgery. It was also noted that visualisation can be important for understanding, with teachers reporting that the use of simulations being highly motivating for the students. These two ideas underlie our experiment design whereby we were keen to understand whether context and an ability to visualise the situation led to greater understanding of data, while simultaneously comparing instantaneous graph-drawing software with more traditional hand-drawn annotation methods.

In order to explore these findings further we developed an in-depth investigation which manipulated the level of interaction required to maintain the benefits of data loggers while also ensuring students understand the data transformation process. The experiment compared multiple levels of data collection (self, peer, pre-collected) and different methods of presenting the data (pre-presented, software-presented and hand-drawn). We set the study up to be as ecologically valid as possible, with children working in pairs and groups to collect and

discuss data, but assessment was carried out on an individual basis.

## 2. HYPOTHESES

We wish to explore whether technologies that support shared exploration of the scientific data space around them can also measurably enhance children's engagement in more directed pedagogical situations. From the above literature, we hypothesise that:

1. Motivation will improve for data acquired in context (self-collected)
2. Understanding will improve for data acquired in context (self-collected)
3. Pre-generated graphs will be better understood if students acquired the data themselves.

## 3. METHOD

### 3.1 Participants

A total of 46 students from 3 schools took part in the experiment, with a range of ability represented. Eight sets of data were discounted for statistical analysis purposes due to one child having learning difficulties and seven discontinuities within the groupings - some classes arrived with extra students which meant that a few students needed to work in larger groups than required for the experiment. The students ranged in age from 12 to 14, with 14 girls and 24 boys participating.

Half of the students had a 'hands-on' experience of using mobile sound data loggers (which measured and recorded sound in decibels) at a location, while the other half were shown the potential use of a data logger but did not personally use it.

14 students used computer software to generate graphs, 12 students were asked to annotate pre-produced graphs and 12 students were given data tables to display in line graph format by hand.

Each student finished with two graphs, one of Location A (either they or their partner had visited this site) and one of Location B (data collected by the researcher from a location not visited by the students). In addition, each student completed three booklets: a pre-test, a workbook, and a post-test.

### 2.2 Design

The design was a 2x3 between subjects design, the independent variables were Collection method (Self-Collected or Peer-Collected) and Production method (Software-Produced, Manually-Produced or Pre-Produced). Students experienced different methods of data collection and data presentation dependent upon which group they were in.

Sound was used in the experiment as it was a concept students of this age are already familiar with. It can be easily recorded, and most importantly students who experienced the locations can make connections between the sounds they hear and the graphical recordings that they take.

The pre- and post-test booklets were counterbalanced to ensure that they did not differ in difficulty. Of the

students who went out to collect data, students were counterbalanced to three different locations (Pond, Construction Site and Field), to ensure that it was taking the recordings which was important, and not the actual location.

Students who self-collected data were able to view graphs displayed on the data loggers' screens as they collected the data. This allowed them to make contextual connections to the graph shape. The students were asked to take multiple recordings, and were then given the opportunity to reflect upon the graphs and choose which data to use when they returned to the classroom.

Students who did not self-collect were given a talk in the classroom on data loggers to ensure they were introduced to the data loggers and that the only difference between the self-collected and the peer-collected group was that the self- group actually used the data loggers themselves.

## 2.3 Materials

### 2.3.1 Data Loggers

The study used Logbook GL data loggers (see Figure 1) provided by ScienceScope with additional plug in Sound Sensors with the range (30dB-110dB).



Figure 1 Logbook GL with additional Sound Sensor.

### 2.3.2 Software

The students used ScienceScope's Datadisc PT software to generate their graphs. Datadisc Explore PT was also used to show sound levels to half the students. Datadisc is a software package designed specifically for science education in schools and provides the ability to download data from the Logbook dataloggers, create graphs and tables of the data, annotate with labels and perform appropriate manipulation of the data to allow students to analyse the data they have collected.

### 2.3.4 Pre/Post Test

The pre- and post-tests consisted of questions designed to assess the student's ability to read a graph, draw a graph and correctly title and label graphs. These tests were based upon questions that arise in national Maths and Science examination papers for this age group. This meant that the question style would be familiar to the students. The language used in the questions also appropriately reflected this level. The pre- and post-tests also included questions on data reliability and validity, asking students to explain their choices. For instance the students were asked to consider what to do about a missing data point, should they replace it to a specific

location, suggest it goes within a range or not to replace it. Additionally, in the pre- and post-test booklet the students were asked to rate statements using a 5 point Likert scale varying from Strongly Agree to Strongly Disagree such as ‘My understanding of a graph is better if I have drawn it myself’. The post-test varied from the pre-test only in the numbers used for the graphs, the question phrasing was identical. The pre- and post-tests were counterbalanced across the students. The design of these questions was iterative with input from four teachers from different schools.

Question One required students to use a sound graph with three lines on it indicating three different locations. Students were asked to choose which location was the quietest and then report the sound level for each location at a set time. Students were also asked to consider whether they would replace missing data and explain their reasoning. This question was designed around a question which is common to exam papers at this stage “On the graph, circle the result which does not fit the pattern. Suggest one reason for this result.” While our question was not identical, it uses the same underlying understanding by assessing how the students handle odd, anomalous and missing data. We chose to ask the students to explain their choice to gain insight into their reasoning, in contrast to many such questions in which students are often asked to make judgements without the chance to justify them.

Question Two provided students with a table of data and asked the students to plot the data points and draw a line of best fit. This reflects a type of question which is common to science examinations which asks students to finish plotting a graph or to plot a table of data. We included this question to see how students chose to scale their graphs and whether they would correctly label and title them.

Question Three followed on from question two by asking students to provide a graph with axis labels and a title. Analysis of exam papers shows that this is a skill students of this level should hold. Throughout the papers students are asked to add appropriate scales and labels to graphs.

Question Four took inspiration from exam questions which asked students to report what was happening at different times of the graph. We adapted the question so instead of focussing on differences within a graph, the students were asked to consider three lines on the same graph and use the shape of the graphs to infer which graph represented which location.

### **2.3.5 Work book**

The work book provided the students with a guide to what they were doing. Initially it introduced the students to the locations. Location A represented the location that the student or their partner would visit. The actual location varied dependent upon which counterbalancing group they were in: Construction Site, Pond or Field. They were also told about Location B which was a Car Park, but none of the students actually visited the car park. The students were asked to make predictions about the two locations with regard to sound levels and they

were also asked to explain their choices. The workbook also included space for observations which the students filled out following the data logging.

The next section asked them to answer questions by interpreting their graphs, and also to think about how the graphs matched their initial expectations. Finally the conclusions section asked them to consider if the study had been a fair test, how they might change it and what difference this might make.

## **2.4 Procedure**

The study was held over three days with a different school attending each day. The procedure, however, remained identical. Ethical approval was gained for the study and each student and their parents/guardians gave their consent to participate and to be recorded. The activities were video recorded throughout.

### **2.4.1 Introduction and Pre-Test**

At the start of the day the students were given an introduction to the classroom and a summary of what they would be doing during the day. It was stressed that there were no right or wrong answers and that we were interested in reasoning rather than correct answers. The students were placed into groups randomly (assigned a number, colour and shape) and each was asked to complete the first booklet (pre-test) and the first section of the main workbook. They were given 30 minutes to complete this individually.

### **2.4.2 Data Collection**

The students were split into two groups, Self-Collected and Peer-Collected.

#### **2.4.2.1 Self-Collected.**

These students were given individual data loggers and were shown how to use them. Each student then visited one of three possible counterbalanced locations and spent 15 minutes taking a number of twelve-second recordings and choosing which recording they would like to analyse. At the construction site location the students stood on one side of a high safety wall with construction workers on the other side. They took recordings of the sounds made at the site. The students who visited the pond took recordings of the ducks and the fish in the water (see Figure 2). Finally the students who went to the field went to an area which is often quiet so they recorded sounds of birds, and the occasional person walking past.



Figure 2. ‘Self’ group students collecting data by the pond

#### 2.4.2.2 Peer-Collected.

These students were given a talk on sound recording and shown a data logger connected to a computer. They were given the opportunity to interact (without holding the logger) by seeing how loud and quiet they could be, this provided them with an opportunity to understand a data logger without gaining the context of actually taking a recording themselves. When the 'Self' students returned they were asked to get into their pairs with the 'Peer' students. The students who had been outside to use the data loggers were asked to describe to their partners what their experience had been like. All the students were asked to record these observations in their workbooks.

The students were then given a break while the data was uploaded into the ScienceScope software to produce graphs and tables of data for the next stage.

#### 2.4.3 Graph Production

The students were all given 40 minutes to explore their data and produce graphs. They were divided into three groups: Software-Produced, Manually-Produced and Pre-Produced.

##### 2.4.3.1 Software-Produced.

These students were shown how to connect data loggers to computers and use ScienceScope software to upload their data files and explore their graphs. Each student was given the opportunity to upload data collected by them/their partner and data collected by the researcher. Students were encouraged to explore the software, and personalize their graphs by adding labels, titles and colour.

##### 2.4.3.2 Manually-Produced.

These students were given two tables of data; one included the data collected by them/their partner and a second table of data collected by the researcher. The students were given all the data points for each of the twelve-second recordings but they were told they could choose which data to display in each graph and were given ideas such as choosing every other point, randomly picking 10 points or choosing a section of time. The original data table included 96 data points spanning 12 seconds of data. By providing the students with the whole data set it allowed the students to see all the available data while giving them control to graph what they felt was important (See figure 3).



Figure 3. 'Manual' group students considering their graphs.

#### 2.4.3.3 Pre-Produced.

The students in this group were given two graphs, one graph for Location A (data collected by them or their partner) and one graph for Location B (researcher collected). They were given poster paper and pens and asked to annotate each graph considering possible explanations for peaks and troughs.

#### 2.4.4 Workbook and Post Test

All students were asked to spend 45 minutes completing the workbook, which asked questions about the graphs that they had been working on, and then to complete the post-test booklet.

#### 2.4.5 Debrief

Finally the students were given an overview of the research area highlighting their contribution and asked to make comments on the day.

### 3. RESULTS

In the following section we report the results from the pre- and post-tests. These are divided by questions and include both quantitative and qualitative analysis of learning and motivation.

#### 3.1 Learning

ANOVA results are reported in table one. Results showed all students independent of groupings started off at the same level. Analysis of post test performance indicated an interaction between Collection and Presentation groups with students in the Peer-collection group showing a significant difference in their post-test result, dependent on their Presentation group. Students in the Self-collection group showed no difference in their post-test regardless of the presentation group. Post-hoc analysis of the Peer group using the Tukey test showed a significant difference between the Manually-Produced condition ( $M=6.33$ ) and the Pre-Produced condition ( $M=4.50$ )  $p=0.025$ , with students in the Pre-Produced group producing higher post-test scores than those in the Manually-Produced group. The difference between the Software-Produced condition ( $M=6.00$ ) and the Manually-Produced condition is also nearing significance  $p=0.06$ , leaning towards the Software-Produced students on average performing better than those in the Manually-Produced condition.

Table 1. ANOVA results for Question One

Condition	Degrees of Freedom	F Value	P Value
Pre-Collection	1,36	0.143	>0.05
Pre-Presentation	2,35	1.100	>0.05
Post-Collection	1,36	.042	>0.05
Post-Presentation	2,35	2.671	>0.05
Peer Collection*	2,16	4.922	<0.05*
Self Collection	2,16	0.350	>0.05

\*indicates significant result at 0.05 level

#### 3.1.2 Question Two (assesses ability to draw a graph and label it correctly)

ANOVA results are reported in table two. Analysis of change between pre- and post-test using a Repeated

Measures ANOVA shows a significant change in scores for all data. Students show lower scores on their post-test (Mean= 5.46) compared to their pre test (Mean=6.21). Further analysis into Collection type revealed a significant change within the Self group with students performing worse on their post-test (mean=5.13) than their pre-test (mean=6.26). No significance was found within the Peer group indicating that students who Self-collected got significantly worse while those who Peer collected did not.

Further analysis into Presentation type revealed a significant difference for the Manually-Produced group with students performing worse on their post-test (mean=4.92) than their pre-test (mean=6.67). No significant difference was found for Software- or Pre-Produced. These results indicate that students in both the Self group and the Manually-Produced group performed significantly worse at post-test.

Table 2. ANOVA results for Question Two

Condition	Degrees of Freedom	F Value	P Value
Pre-Collection	1,36	0.016	>0.05
Pre-Presentation	2,35	.466	>0.05
Post-Collection	1,33	.619	>0.05
Post-Presentation	2,32	.520	>0.05
Change All**	1,34	7.432	<0.01**
Change Collection*	1,15	16.96	<0.05*
Change Peer	1,18	.503	>0.05
Change Manual*	1,11	5.923	<0.05*

\*indicates significant result at 0.05 level  
 \*\*indicates significant result At 0.01 level

### 3.1.3 Question Three (assesses ability to label graphs) and Question Four (assesses ability to match possible locations with line graphs)

No significant differences were found for questions three and four.

## 3.2 Motivation

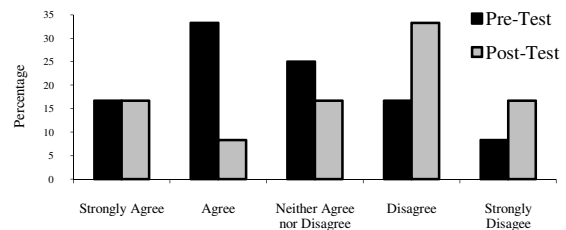
In the pre and post test there were 6 statements assessed using a 5 point Likert Scale from strongly agree to strongly disagree. Of the 3 statements assessing motivation, one statement “I enjoy using computers to draw graphs” was shown to be non significant, while the other two revealed significant differences. “I think collecting data is a waste of time” and “I like working with data I have collected.”

### 3.2.1 I Think Collecting Data is a Waste of Time.

Analysis using a Wilcoxon shows responses changing to the statement was nearing significance  $z=-1.874$ ,  $p=0.061$ . The mean of the negative ranks was 8.80 while the mean of the positive ranks was 9.77. Further analysis into the Presentation factor showed a significant difference  $z=-2.041$ ,  $p<0.05$ , mean negative ranks was .00 and mean positive ranks was 3.00, before and after intervention for students who were in the Pre-Produced category. With the option “Disagree” being picked 16.7% pre-test and 33.3% post-test. “Strongly Disagree also became more popular (8.3% pre test, 16.7% post test) this

indicates a positive change of opinion in response to ‘I think collecting data is a waste of time’.

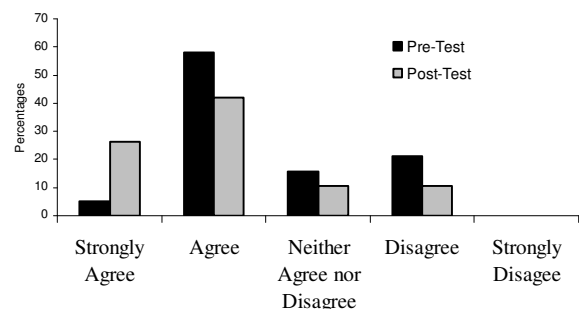
Graph 1. Change in responses to ‘I think collecting data is a waste of time’ for Pre Produced group.



### 3.2.2 I Like Working With Data I Have Collected

Analysis into the Collection factor showed a significant difference  $z=-2.460$ ,  $p<0.05$ , mean negative ranks was 4.0 while mean positive ranks was 0.00, in response to ‘I like working with data I have collected’ before and after intervention for students who self-collect. Further analysis using the frequency tables showed that at post-test there were more Strongly Agree responses than at pre-test (29.4% of responses, compared to 5.3%).

Graph 2. Change in responses to ‘I like working with data I have collected’ for Self collected group



There were two questions that students completed within the workbook which also assessed motivation.

### 3.2.3 Which Set of Data Did You Feel More Comfortable Working With?

Initial analysis of responses to this question indicate that students in the Self group more often indicate Location A (the Student Site) (68.8%) than students in the Peer group (18.8%) The majority of students in the Peer group indicate that they found no difference between the two locations (62.5%). Analysis using Chi Square indicated a significant difference between the observed and expected frequency for collection type and which data students felt more comfortable with, ( $X^2=8.541$ ,  $df=2$ ,  $p<0.05$ ). While initial analysis of the presentation groups shows that 50% of students in the Pre-Produced group felt more comfortable with Location A, students in the Software- and Manually-Produced groups picked Location A only 40% of the time. This was shown to not be significant when analysed using Chi Square ( $X^2=0.83$ ,  $df=4$ ,  $p>0.05$ )

### 3.2.4 Which Set of Data Do You Feel You Can Explain Better?

Initial comparison of the Collection group indicate that 60% of Self students felt they could explain Location A best compared to only 18.8% of Peer students. This was supported by a significant Chi Square result ( $X^2=6.880$ ,  $df=2$ ,  $p<0.05$ ). Analysis of presentation type showed no significant difference ( $X^2=1.248$ ,  $df=4$ ,  $p>0.05$ ).

Both of these questions indicate that students who collected the data themselves felt more comfortable with that data and felt that they could explain it better. This is shown clearly in the explanations given by the students; Which data did you feel more comfortable with?

Student in the Self Group "*Location A- Because this was the one I tested and it took less time to draw a graph because I understood the data better*" compared to a student in the Peer Group "*No Difference-I didn't go and find any data so it doesn't really matter to me which one I worked with*".

Which set of data do you feel you can explain better?

Student in the Self Group "*Location A-Because with this one I know why the data was varied, however I couldn't find out why the other set of data was varied*" compared with student from the Peer Group "*No Difference-I think I understand each both the same because I didn't go out and collect the data so I was just working with the data I got given and it didn't matter which one I had*".

## 4. DISCUSSION

This experiment was designed to answer three specific hypotheses:

1. Motivation will improve for data acquired in context (self-collected)

This hypothesis was confirmed, with those who self-collect, regardless of graphing, provide significantly more positive results at post-test to 'I like working with data I have collected'. The self-collected group is significantly more likely to state they are more comfortable working with data from the location they visited compared with the peer-collected group, and chose this location as the one they could explain better more often than those in the peer-collected group.

2. Understanding will improve for data acquired in context (self-collected)

This hypothesis was not supported, with those in the self-collected group performing worse at post-test specifically on their ability to draw a graph. This unexpected result appears, from observation, to be down to a fatigue issue, with two students failing to complete the post-test graph and a number of others only partially completing it.

3. Pre-generated graphs will be better understood if students acquired the data themselves.

Interestingly, the results showed the reverse of this hypothesis with students who collected the data showing no difference between production types, while students

who used peer data showed a better post test score when they used pre-generated graphs.

In the following sections, we discuss the implications of our findings for the importance of focussing on interpretation, methods and techniques for assessment, and the relevance of motivation for hands-on learning.

### 4.1 Motivation for Learning

Our data shows no immediately observable relationship between increasing motivation and an impact on understanding. That such a relationship would emerge in the long term needs to be established if sensors are to be used more, and indeed if methods of assessment are to be redesigned to reflect this pedagogical change. We are therefore currently carrying out long-term studies of an environmental science group using the most up-to-date sensors and displaying readings using tailored software, mapping these observations onto the real environment and adding contextual data (particularly digital photos), to explore the opportunities and the demands facing this type of work in a real setting.

While our results were not always as we predicted our study design has enabled us to gain valuable insight into the subtleties of data collection and graph production. It seems that in terms of motivation self-collection of data is important. However, within the current study this does not necessarily transfer into better performance on post-tests. It also seems that the pre-produced group were more motivated about collecting data, potentially because they had the opportunity to annotate their graphs, so connected the graphs with the importance of knowing the context, whereas students in the manually-drawn and software groups showed less annotation. The motivation factor of hands-on learning found in the current study is in line with the literature (Dewey 1964). Beyond this confirmation, however, we have provided new insights around peer-collected data and the effect on interpretation. Our results hint towards advantages for software-produced graphs. This may be affected by the length of the intervention period; in this experiment it was only a 30-minute intervention. The next stage of this research is to develop an understanding of how we can tap into this increased motivation to produce a better standard of work and understanding. We plan to carry out a delayed retention test after several months with the same students in order to see if there is any difference in the results following a delayed period. Do they retain more information over the long term if they self-collected? Are students in the pre-produced group still performing better than the hand-drawn groups?

This research has implications for designers of educational hardware and software. This study reveals the importance of breaking down the elements of hands-on learning to see where the advantages lie. The importance of constructing the data oneself was crucial to explore in terms of both motivation and learning benefit. This breakdown is key to designers for these kinds of activities, because without pinpointing the advantage clearly it is difficult to design technologies in such a way that they can be tailored to effectively aid learning or



motivation or both. If designers were to just access the results of qualitative research in this area, it would be very hard to separate the factors that are contributing to the 'advantage' of a hands-on approach. Our study shows that the relationship between automation and learning is not simple at all – in fact, in our example, automating the process of graphing data highlighted an important change in performance under the subsequent post-test.

## 5. CONCLUSION & FUTURE WORK

While we have taken a step in the direction of moving some of our observations into exploring more concretely how these factors really are having an impact on learning, we still have some way to go. We need to continue to explore the importance of contextual data. Sensors enable ever increasing functionality, such as adding media in real time, and displaying a graph immediately on the sensor display, (rather than just the raw data). Initial work has found these to be important to understanding and reflecting upon data (Stanton et al 2005). However, we now aim to break these down and take a deeper look by carrying out specific studies looking at different types of contextual data.

We have begun to examine the effects of collecting and manipulating scientific data oneself, and how this impacts on motivation and learning. While we find clear motivation effects it is less clear how self-collection in the real world affects learning and we find those who create their own graph manually are worse at post-test than those who annotate pre-produced material. Importantly we have employed a range of methods from observation to experimental design in tackling this question. This work is important to those studying learning with mobile devices and designers of hardware and software to support learners.

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