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Gareth Renaud & Karen Renaud

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ORIGINAL ARTICLE

Computing Science in the Classroom: Experiences of a STEM Ambassador

Gareth Renaud[1] & Karen Renaud[1]

[1]School of Computing Science, University of Glasgow

Corresponding author:
Karen Renaud, School of Computing Science, University of Glasgow, 18 Lilybank Gardens, Glasgow, G12 8RZ, UK
Email: karen.renaud@glasgow.ac.uk

Abstract

Computing Science is not a popular subject choice in UK secondary schools. Teachers complain of low numbers due to a lack of interest from parents and pupils. This unfortunate trend means the current education system will very likely fail to meet the skill needs of industry in the future, and it is unfortunate for a nation which has a long and proud history of innovation and technical expertise. In the following report we will reflect upon one of the authors' (Gareth's) experiences and observations as a STEM Ambassador (http://www.stemnet.org.uk/content/ambassadors/whoareambassadors) in a Scottish High School. We highlight the differences he observed between first and third year students. We reflect on his experiences, consider them in the light of the literature on creativity in schools and make some suggestions as to how the situation could be improved.

Keywords: secondary schools, teaching, creativity, computing in schools

Introduction

There is a sense that Computing Science is not as popular at school level as it should be, given the subject's potential for being exciting and relevant. Why this should be so has been explored by Carter (2006) who carried out a survey of high school students and found that three factors primarily caused pupils to choose Computing Science:

- The fact that they could see the link between Computing and some other subject.
- A pre-existing interest in computer games.
- Previous experience with computing.

The strongest reason advanced for *not* choosing to take Computing, for both males and females, was that they did not want to sit in front of a computer all day. This is echoed in a study amongst Australian school pupils who rejected school Computing because they perceived it to be boring and old-fashioned (Reid 2009). Many in Carter's study wanted to go into a field that was more people-oriented than Computing. When the field of Computing started out this would have been a valid objection, but there is no longer any question about the importance of designing for the human user, and modern day computing has a great deal to do with people. Perceptions of computing science as a programming-only field (Denning 2004) need to be adjusted, and the exciting nature of the subject communicated to school pupils more effectively. If we fail to meet this challenge, we might well be unable to reverse the trend of decreasing numbers of students studying Computing at university (Denning & McGettrick 2005).

The current system appears to encourage pupils to ignore what they enjoy in school to choose the subjects which have become traditionally acceptable, or are perceived as easy (Pimlott 22 February 2006). A subject that is perceived as dull is thus particularly likely not to be chosen (Rodiero July 2007). Computing, based on anecdotal evidence, seems to be boring pupils, probably as a direct consequence of the curriculum and the fact that it focuses on application usage rather than encouraging individual creativity. This is regrettable, since Computing has a unique potential to support linkage to several other subjects, which can help to foster creativity and keep pupils following their dreams by using their talents and achieving something to be proud of.

Within the UK, it is becoming increasingly clear that drastic action is required. Cellan-Jones (2012) reports that pupils find the subject dull, and that businesses feel school leavers are ill-equipped in terms of core computing skills. He concludes that the teaching of this subject in schools is unfit for purpose. In February, 2012, the UK chancellor, George Osbourne, was sent a petition signed by many in education and industry, asking for Computing teachers to be better trained (http://www.bbc.co.uk/news/technology-17190910). This, they argued, would support the government's new Computing Science curriculum.

Clearly the UK is facing a challenge and the government is well aware of it. HM Treasury (2004–14) says: "Harnessing innovation in Britain is key to improving the country's future wealth creation prospects". There are plans afoot to recruit more highly trained teachers, to train existing teachers and to revise the curriculum.

The STEM Ambassador scheme has a vital role to play in this. University students, who are closer to the school pupils in age, but who come into the classroom with experience of university life *and* Computing, can make a substantial impact. The student can be a positive role model to the pupils and encourage pupils to raise their aspirations. The student also develops his or her own communication and knowledge transfer skills, something which is prized in industry (Lee *et al.* 1995). In this paper we report on the experiences of a final year university student (Gareth) who participated in the STEM ambassador scheme. In the following section he relates his experiences.

The voice of the STEM Ambassador

I participated in the STEM Ambassador scheme, which sends senior Honours students into high schools. (Students in Scotland do a four year undergraduate degree. Senior Honours students are in the final year.) There we work with the Computer Science teacher in the classroom, assisting with teaching and learning about education first hand. There are benefits for the student, the school and the pupils (Harrison & Shallcross 2009). I was required to craft lessons (called workshops) which I would present to the class. This requires some core computing concept of the teacher's choosing be simplified and made accessible to a far less educated audience than I was used to interacting with at university. I also spent some time as a classroom assistant.

One of the first lessons I observed was one in which students were required to write some code to solve a problem. Something that struck me immediately was that some pupils were being left behind. This was not attributable to negligence; the teacher did try to circulate to help students, but with multiple students one-to-one continuous assistance is infeasible. Some possible reasons for students lagging could be:

- Poor coping strategies: Pupils would struggle with topics and, instead of asking for help, would engage in displacement activities such as browsing the Web or talking to other pupils.
- Poorly designed course materials: The course materials seemed to be hindering the pupils, not helping them. They were like recipes, and did not encourage or require pupils to exercise their creativity in coming up with solutions. This exacerbated the previous point because pupils, in simply following recipes, were not developing critical problem-solving skills.
- Focus on assessment: Pupils are increasingly trained to pass exams (The Huffington Post 2012). They are given exercises to work through and are conditioned into giving the correct answers. The correct answer gets a high mark, a wrong answer is penalised. Pupils are not encouraged to experiment and to fail, thereby learning from their mistakes. When they fail, they might well attribute that to a lack of ability, rather than an inevitable stepping stone in mastering a new skill (Ames & Archer 1988).
- Focus on knowledge: For many exam questions, there does not seem to be the need for understanding. Pupils can pass exams by memorising the facts, without demonstrating much understanding of, or ability to apply, the underlying concepts. This is disastrous for Computing, since it is a skill-based subject. In terms of Bloom's Taxonomy (1956), students inhabit the knowledge level and do not progress up towards true comprehension and application. Knowledge fades when not used (Winter 1987) and represents a relatively superficial level of learning. By progressing higher up Bloom's Taxonomy to application we can engage pupils at a deeper level of learning, and promote skill-acquisition.

The convergence of focus on grades, rewards for fact regurgitation, and provision of recipe-like course materials led me to conclude that computing was being taught in the same way as history and other fact-based subjects. This is damaging: Computing Science needs to be seen for what it is; a creative skill-based subject. Did these pupils perceive Computing as an exciting subject? The majority did not seem to.

At the teacher's request, I prepared a series of workshops for the following weeks. My initial impressions led me to decide to make my workshops creative, exciting and designed to develop problem-solving skills in the pupils. I chose not to focus on facts, but rather on understanding. Each week I presented the same workshop to both the first and third year classes. I developed workshops which encouraged full-class participation, required group work and presented the pupils with problems which required creative solutions. From the first week I noticed subtle differences between the first and third years. These differences became more obvious as the weeks progressed and I delivered more workshops.

As time progressed I became aware of differences between the two groups. The pupils in the first year classes were clearly eager to participate, answered questions in class, worked harder, remained more focused and were prepared to venture opinions. They performed consistently better than the third years in each workshop and I became increasingly concerned that something was happening between first and third year to stifle their creativity. My workshops concentrated on creativity and problem solving and did not necessarily focus on traditional measures of academic prowess. I believe this gave each class a clean slate when it came to performing well. The idea for each workshop was to introduce several concepts to the class and then to assign groups an activity which required them to use these concepts to come up with a creative solution to a problem. The differences between performance of the first and third years, what I will refer to as 'the creative chasm', were so striking that they demanded an explanation.

The following sections will present the two main workshops in detail. In the subsequent sections my experiences and reflections will be discussed.

Meeting needs: mobile phones and market segments

I created this workshop to get the class excited about computing science and to show them that studying computing was about more than just coding or using applications. I wanted to give those who struggled with code some confidence in the class, but also to inspire those who found the course content too easy. The workshop is actually a mix of computing science, psychology and marketing since it is essential for anyone delivering a computing application to be aware of the findings of these areas. I wanted to link different areas in order to ensure that everyone would have a strength to play to. I also wanted to ensure that these pupils, when they were faced with a subject choice, would be aware of the first of Carter's choice predictors (Carter 2006). The main areas this workshop focused on were:

- Human computer interaction (ergonomics, usability, human cognitive limitations, individual differences, providing solutions for people with disabilities or specific needs).
- Market research (conducting a questionnaire with a grandparent or elderly relative).
- Software engineering (extracting requirements from the questionnaires).
- Group design and presentation.
- Individual finalised design homework.
- Mobile phone design and applications.

During the development of the workshop, I pictured myself as the pupil to try to figure out what I would have enjoyed and how to get the pupils engaged. I decided that the only way to achieve this would be to run my workshop over two weeks. In the first week I would give the pupils complete freedom in the workshop to create solutions relating to their needs, and in the second week I wanted them to use what they had learned thus far to hone their efforts on a task with clear guidelines, where they would need to create a solution related to requirements gathered from a particular market segment.

Workshop overview (Week 1):

- Introduction to principles of human computer interaction.
- Explain market segments and add interest by using the anecdote about Dell as a school pupil and how he sold thousands of newspapers and ended up earning more than his teachers using this technique (Dell & Fredman 1999).
- Facilitated a discussion with pupils about their phones, what they liked and did not like, and asked them to think about how their grandparents would feel about their mobile phones.
- Split the class into groups of three and instructed them to design their ultimate phone: they were told to focus equally on design, applications and features.
- Conduct a presentation session where groups individually presented their designs to the rest of the class and the class could ask questions.
- Conduct a short class discussion about why elderly people sometimes do not like their phones.

- Introduce the homework task: a questionnaire for them to conduct with a relative over the age of 65. This was to help them to understand what the elderly want from mobile phones.
- Conclude by showing several short videos of elderly people using new technologies to challenge presumptions and encourage the pupils to engage with the material in the intervening week.

Workshop overview (Week 2):

1. Short discussion of the feedback the pupils obtained using the questionnaires to highlight general areas of interest and elderly-specific needs.
2. Explanation of the limitations of short-term memory and a short demonstration to entrench the concept. Discuss the mechanism by which short-term memories are recorded in long-term memory.
3. Discussion about individual differences and ergonomics.
4. Split the class into the same groups as before and instruct them to design the ultimate phone for the elderly. They were asked to focus on design, applications and features of the phone, but their design should be informed by the insights they gained from the collective research of the group.
5. The groups then presented their designs to the rest of the class questions were asked at the end of each presentation.
6. Pupils were given a homework task: to use what had been learned to produce a poster of an individual mobile phone solution.

Much of the planning for this workshop focused on ensuring that pupils were not overwhelmed. Many of the concepts were not simplified, but instead introduced in novel ways so as to keep the attention of the class and make learning fun.

My plan was that the pupils would learn by doing (Schank *et al.* 1999). To achieve this I kept introductory segments short and to the point. This allowed me to spend more time on interactive activities, discussions, group work and presentations. The first session concentrated on making the pupils aware of their individual mobile phone needs; this provided opportunity for engaging participation. This engagement, it was hoped, would feed into the second part of the workshop where they would only be focusing on the needs of the elderly. The pupils thoroughly enjoyed this workshop and the teacher observed a high level of engagement. However, there was a notable difference in the performance of the two classes. Both classes submitted a design for an elderly person's phone. The Ambassador and the co-author independently rated these designs, and both noted significant differences. The first years were more creative and innovative in their ideas and solutions. They used the concepts which had been introduced and created impressive posters of their designs. They came up with ideas for interesting new applications, the most innovative of these was a 'heart starting application', which impressed the teacher and the Ambassador. The first years came up with many more ideas than the third years for useful applications and phone design.

The third years, on the other hand, did not produce creative solutions. Instead of coming up with new ideas, they enhanced existing technologies, and parroted existing ideas and designs. Furthermore, they put little effort into their individual exercises. Where the first years produced intricate designs which had been meticulously illustrated, the submissions by the third years were much less detailed, almost done in a halfhearted way as if the creativity this exercise required was too much effort.

Doing a million things at once

This workshop was chosen from an archive created by previous years' STEM Ambassadors. The workshop is intended to explain how scheduling is done by an operating system. I chose this workshop because it required everyone in a group to have a role and to participate in the class. I had noticed a pupil in the third year class who never seemed to get involved. This workshop required pupils to be on their feet and to move around, and I hoped that this activity would engage this pupil in particular.

I tailored the workshop to my own presentation style. I used pictures and references that the pupils were likely to recognise and find engaging. This workshop concentrates on the following areas:

- Processor scheduling (round robin; first come, first served).
- Thrashing.
- Group work.
- Team leadership.
- Discussion.

The pupils really enjoyed this workshop. The pupil I had been concerned about volunteered to take the role as processor and seemed transformed by the activity. The workshop was presented in two parts, the first part being a trial run and the second being the learning run. The trial run helped me ensure all the pupils understood their roles properly and also allowed me to observe and identify good leaders for the next part. Good leadership was pivotal to the success of this workshop as the leader needed to organise the rest of the team. In the first part there were some issues with pupils not listening and doing their own thing rather than their assigned tasks. When the good leaders were put in charge the pupils pulled together as a team and performed really well. This was the same for both the first and third years. This workshop reminded me of how competitive pupils are and how much fun they have doing competitive group work (Cohen 1994).

After the workshop had concluded there was a short discussion about what they had learned from the workshop and the pupils all understood the concepts the workshop had aimed to teach them. The teacher commented that pupils are not usually expected to grasp these concepts until their fifth year.

Creativity and computing

The Ambassador's observations and the evidence gathered from the pupils' submissions had focused attention on creativity and the question of how pupils' innate creativity could be nurtured. Creativity is a complex topic, with a variety of definitions. Watson (2007) extracts the following key concepts mentioned in a range of definitions of creativity:

- Product – outcome of creativity.
- Person – characteristics of creative individuals.
- Persuasion – ability to convince others of the merit of the product being created.
- Environment – the society, the educational environment and family values.

Smith and Carlsson (1985) studied creativity in puberty and found that pupils showed a decrease in creativity after the age of 12, and only recovered their previous potential for creative thought once they reached 16. However, Rothenberg (1990) argues that: "Engaging in creative types of fields and outlets helps generally to establish coherent identity during adolescence and beyond; the beginnings of a specific creative identity in adolescence

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are a necessary foundation for creative motivation and ability to create throughout life". Amabile (1995) argues that one cannot attribute creativity purely to individuals: it is a result of a complex interplay between individuals and their situational factors. In schools situational factors can and should be manipulated to maximise the potential for creativity. Certainly, the educational environment can actually impede and crush creativity. Albert (1996) says: "education regularly inhibits the transformation of early giftedness and talent into creativity".

Hence the environmental factor, mentioned by Watson (2007), needs to be as conducive as possible to nurturing creativity. Moreover, pupils should be encouraged to produce something creative, and to be able to talk about their product to other pupils. In this way another two of Watson's factors can be nurtured. A period of suppressed creativity in the adolescent does not need to dampen their potential for creativity altogether. One can ensure that the other three factors are maximised so that adolescence is not written off as a period during which one cannot expect any creativity from pupils.

It is essential for a curriculum to engage adolescents and to specifically encourage creativity. It is fairly clear that computing science teaching in schools, in its current state, fails to achieve this (Moody 2012). Eric Schmidt of Google recently criticized the British education system for these failings (Robinson 2011). Rather surprisingly for an extremely technically competent person, he called for the integration of Art and Science in schools. This proposed linkage is particularly interesting. Science is known for its rigour, its mathematical content, and the idea of particular core truths which drive practice. Art, on the other hand, is seen as intensely creative, with no *one truth*. Could linking these very different subjects do something about the perceptions that computing is boring?

An educational revolution?

The current educational system does not seem to place great importance on creative abilities (Bowes 1986). Sir Ken Robinsons' research suggests that the current system, having been designed in the industrial revolution, steers pupils from what they really enjoy into areas that were perceived as valuable to the economy (as it was then) (Robinson 2006). This, Robinson believes, leads to many gifted people believing they are not intelligent since they cannot fit into the mould required by current education systems. Sir Robinson argues that if you teach children to fear failure, it kills creativity.

Schools need to teach their pupils that it is acceptable to get things wrong and to allow them to make and learn from mistakes (Oliver 1984). There should be more emphasis on the fact that struggling and taking a long time to arrive at a solution is an expected and acceptable part of learning. We believe that encouraging this change in emphasis will also help break the stigma which appears to prevent pupils from asking for help in lab sessions. In this respect the first years seemed to be less affected: they were eager to participate without fear of giving the wrong answer. The third years, on the other hand, seemed almost afraid to venture into anything out of the ordinary.

The crux of this argument is that the system needs to shift its view on intelligence in this era of academic inflation (Vedder 2010). Intelligence should be seen as diverse, as diverse as there are ways of thinking about the world (Robinson 2006).

Something the Ambassador managed to avoid with his workshops was conformity. Each group was expected to come up with their own unique solution to each problem. We agree with Robinson that education must be shifted from an industrial to an agricultural process. Instead of viewing pupils as mechanical they should be seen as organic, and the correct conditions should be established to allow the pupils to flourish. It was Einstein who said: "I never teach my pupils; I only attempt to provide the conditions in which they can learn" (http://onestoplearning.blogspot.co.uk/2011/01/from-teaching-to-learning-paradigm.html).

Teachers need to take care that they create and facilitate conditions that will encourage pupils to be creative. One of the biggest blocks to creativity is the feeling of inferiority (Alamshah 2011). If a teacher believes a class or pupil is not capable then this can become a self-fulfilling prophesy (Oliver 1984). The thrust of this argument is that teachers must do more to combat fear, be it fear of failure or of what others might think (Bowes 1986).

It is important to note that the creative chasm between the years appeared to have narrowed by the end of the Ambassador's time at the school. This observation may suggest that initial poor pupil performance may have been due to unfamiliarity with creative problem-solving activities as opposed to pupils being considered as having 'low ability' or equally, for this paper's focus low/poor creativity. As the weeks progressed he saw a distinct improvement in the third year class. They became more confident, more creative and participated in class far more than they had previously. The observed phenomenon is in line with research on encouraging creativity (McFadzean 1998). It is possible that the third years began to exercise the creativity that they had subconsciously abandoned.

Suggestions

A number of interventions will be suggested here, based on the Ambassador's experiences and the previous discussion:

- We recommend that Computing Science is given the same recognition as any other science and not considered as ICT, which may cheapen its subjective value (Denning 2005). Educators need to remember that parents often influence subject choice (Tripney *et al*. 2010) and their presumptions also need to be challenged. There are consistent complaints from Computing teachers that parents assume that the ability to use a computer is comparable to computing science skills. This misunderstanding has been sufficiently recognised by Computing Departments worldwide for them to publish, on their Web pages, what Computing Science is actually about (eg. Oxford, Dundee, Boston).
- For coding exercises, instead of being given recipe-like step-by-step instructions, pupils should be taught the building blocks and then be instructed to come up with their own solutions. This will help them to progress up Bloom's taxonomy into deeper learning and skill acquisition. Furthermore, code should first be written in pseudo code, on paper (away from the computers). This will ensure that the teacher can resolve any fundamental problems the student might have with semantics and logic before they commence with the coding stage of the exercise. If the teacher is involved from the start, pupils will probably be less reticent about asking for help. Even without the teacher's intervention, writing pseudo code requires a level of abstraction and consideration that will be beneficial in terms of arriving at the correct solution (Bentley 1983).
- Examinations, in their current form, are a dated method of measuring ability (Major 1999). They originated from the dark ages when books were scarce and the purpose of exams was to encourage memorisation (Karjalainen 2001). This made sense when books were scarce, but that is hardly the case any more. The way students are assessed needs to change in light of the fact that information is at everyone's fingertips all of the time in the 21st century. To really make a difference, traditional examinations need to be scrapped (Oliver 1984). This will require courage, but it will pay great dividends. Alternatives include lab-based exams where students solve problems, or oral exams where students are required to interpret a piece of code, or to explain how they would go about solving problem. The exams need more focused understanding rather than recall.

It must be acknowledged that these recommendations are based on the Ambassador's experiences in one school and these might not be representative of other schools. However, the literature seems to confirm the validity of many of the Ambassador's observations and recommendations.

The Scottish government has recently published a new action plan (Robinson 2010) to promote creativity in schools. The British government also wants to improve Computing Science (Computing at School Working Group 2012) in particular. The action plan seeks to provide teachers with the resources to boost creativity and to combine subjects from science and the arts to promote creative thinking. The report, however, is only a guideline and will require schools to make all the changes without changing the assessment of pupils in these schools. It will be a pity if schools opt only for the parts of the plan which do not affect the syllabus. If they are bold and implement as much of the syllabus as possible everyone will reap the reward and computing might well become a popular subject in schools, as it deserves to be.

Conclusion

This paper has reported on a STEM Ambassador's experience in a Scottish secondary school. We have outlined his experiences, his observations, and our recommendations based on his experiences and the literature on creativity. Our primary aim, in writing this paper, is to help schools to communicate the excitement and potential that exists in computing, so that more pupils will be engaged and enthralled and consider computing as a career path or as a valuable complement to any other area of study. The UK needs more people with computing skills, and our schools are the ideal place to initiate this interest.

The last word comes from Gareth: "As my ambassadorship progressed it became clear that a mini revolution was happening in school computing. I realised that I wanted to be part of it; to make a contribution and to communicate my own enthusiasm about computing to the next generation. I applied for a place in the teacher training course and was accepted, and will enter this programme next year. I highly recommend being an Ambassador to all Computing students."

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