Royal Society Call For Evidence
Response from Dr Kevin R Bond, Mr Paul Meakin and Mr Nathan Barnes

1. Is computing a discipline, in the same way that mathematics, physics, chemistry are?

Computing is a principles-based discipline and it exists in a principles-based framework, unlike ICT, which exists in a technology-based framework – see Peter Denning's Great Principles project. Computing is a discipline in its own right because it is a study of natural and artificial processes, computation in nature, computational tools, computation by artefacts such as personal computers, mobile phones, networks of computers, and more. It embraces aspects of mathematics, science and engineering but extends and reflects on these disciplines in ways that reveal the independence of computing as a discipline in its own right. Computation is the principle and the computer is the tool. Computational principles are important and worthy of study because these principles exist in life not just in man-made computers. The latter are not just powerful instruments but a phenomenon as well, requiring description and explanation. Understanding computational tools leads to an understanding of computation in general and an understanding of the limits of computation. Computing is about concepts, abstractions, problem solving strategies that are relevant to automation. Automation makes abstractions come alive. Automation makes it possible to do things that were never thought possible. Automation makes it possible to cope with very large data sets and to find relationships in these and to visualize these relationships in many ways that would not be possible without automation. Computational abstractions and methods are discovering new science. For example, whereas a chemist analyses by exploring what a chemical structure does, the computational thinking approach asks for the specification of the function required of the as yet undiscovered chemical structure and then figures out the implementation computationally. In biology, the breakthrough in sequencing the human genome was aided by the discovery by computer scientists of the shotgun algorithm. Computing doesn't just provide tools for physicists, chemists and biologists to use in their own discipline but offers explanatory powers about natural information processes that make computing a discipline in its own right. Abstractions have existed for as long as mathematics has existed but in computing abstractions form a hierarchy. Whereas mathematics concentrates on one level of abstraction at a time, computing focuses on two levels at a time, for example, the level below that is going to implement the level above and the level above that is going to use the level below. Automation of this abstraction in computing offers functionality that scales and it is this that distinguishes computing from mathematics. It enables discovery of patterns in massive amounts of data, machine learning based discovery of new galaxies/stars, an understanding of the dynamic processes of nature such as protein folding using finite state machine models and DNA using the computing concept of "interpreting code as data and data as code". Computing is a relatively young discipline but in its short history it has underpinned a radical change in the way that society uses technology just as chemistry in the 18th and 19th centuries made possible the industrial revolution and Physics in the 20th century made possible semiconductor and nuclear technologies and a second industrial revolution so computing has made possible the information revolution and information technology. Students in the age range 5-18 years should be

exposed to curriculum opportunities that explain the role of computing in this revolution, how it came about, its key concepts and principles and its importance to the world around us. However, in this process it is important that sight is not lost of the magic and beauty of the discipline. “Magic” is very important especially at the lower end of the age range. “Magic” is what wins “hearts and minds”. The “beauty comes later. “Beauty” is what keeps people interested over the long haul. The glue is programming. Programming offers “magic” to hook students, initially, and then later to provide opportunities for students to express themselves creatively and to realise the “beauty” in the discipline.

2. Is programming a fundamental form of literacy for the modern age?

It depends on the level of abstraction of the programming language as to whether the language can offer a fundamental form of literacy. Children should have opportunities to develop vocabulary that is relevant to the context in which they are learning and to develop the vocabulary to express themselves be it a storyboard for an animation or a simulation of some interesting phenomena in nature. If the world is computational in nature then learning a programming language that aids computational thinking, precision of expression, organizing thoughts logically, naming appropriately, structuring information, working with hierarchies, specifying what is required, creating mental models to aid debugging, experimentation, linking, visualizing ideas and information must extend a child’s mental view of the world in ways that mathematics, science, the arts and humanities cannot. In the modern age, children are exposed to visual interfaces, operating systems, client/server systems, mobile phones, huge repositories of information, et cetera. They need a language to enable scaffolding of mental models to describe, explain and understand the interactive worldview of computing, concurrency, distributed processing, security, searching reliably for information. Research indicates that the best time for learning a second language is at an early age.

3. What purpose should the teaching of ICT and Computing in schools serve?

ICT teaching should equip students with the ability to work effectively with complex information processing systems, to extract, process, utilize and present information in various forms, for example, how to use a video editor to edit video effectively. ICT teaching should empower students to use facilities for organizing work locally and remotely for ease of access and recall, for pulling together information from different sources. ICT should empower students to make more effective predictions about the future by using information reliably to reduce uncertainty. On the other hand, computing should serve a different purpose. Computing teaching in schools should introduce students to the magic and beauty of computational thinking and programming a computer to automate a task. Computing teaching should develop confidence in working with different levels of abstraction, using decomposition and composition to solve problems, thinking recursively and algorithmically, choosing an appropriate representation for a problem or modeling relevant aspects of a problem to enable automation. Students should be encouraged to experience the wider applicability of computational thinking and computational processes beyond the technology of computers to natural information processes, cognition and vision.

4. Is the teaching of ICT (and accompanying qualifications, such as ICT GCSE) fit for purpose for all students? What should be done to address this?

ICT GCSE cannot be fit for purpose for all students. ICT GCSE provides skills in using information systems, analyzing information systems and designing information systems. However, the richness that is in the discipline of computing to explain, understand and describe computation and computational tools is barely touched upon in ICT GCSE. There are students whose intellectual curiosity extends beyond the effective use of the technology. The expectations of these students, in the main, have not been met by GCSE ICT or the Key Stage 3 National Framework for ICT teaching units**.** ICT at Key Stages 3 and 4 seems, in practice, to be for consumers of the technology. It is about the usage and knowledge of the tools, and systems. This is fine up to a point and a constituency exists whose needs are met partially or fully by studying ICT but there is also a constituency with the ability and potential to be turned onto Computing if only more opportunities were there for these students to experience the difference between ICT and computing. ICT fails to match up to their expectations and worse, many of these students are deterred following their experience in ICT from considering studying computing post compulsory education age (KS5 and beyond). For students in this constituency a failure to offer opportunities at KS3 and KS4 will continue to affect their perception of computing and its difference from ICT.

Specifically, in GCSE ICT there is an over-emphasis on gathering evidence of how tasks are completed and explaining design decisions that more able students regard as trivial. Students are turned off from ICT and (as a consequence) computing by the fact that they spend so much of their lesson time gathering evidence for coursework/controlled assessment rather than learning new skills. Further, the technical skills required to complete GCSE ICT are not particularly challenging and GCSE specifications do not really reward those students who learn more advanced skills. The introduction of the controlled assessment regulations has worsened this situation as exam boards are now required to set specific tasks for students to complete – this has removed the possibility of a class teacher setting a coursework task which will give a more able candidate the opportunity to develop their skills. For an exam board, setting a controlled assessment task that can be accessed by G grade candidates yet challenge candidates targeting an A* grade is surely almost impossible. Introducing different tasks appropriate to different ability ranges is one way that this situation could be improved, and perhaps the expectation of what more able students should be technically capable of to achieve an A or A* Grade needs to rise. Students should not be required to explain trivial decisions. Part of the purpose of gathering evidence about how tasks were completed was for a student to show that the work was their own. Now that the work must be completed under controlled conditions, has the rationale for requiring students to spend a long time on this tedious task disappeared?

The new GCSE in computing seeks to redress the balance and is to be welcomed. However, the imposed QCDA requirement to set controlled assessment tasks that can be accessed by G grade candidates whilst challenging candidates targeting an A* grade devalues this aspect of the assessment. The introduction of GCSE Computing is a positive step but many schools are likely to stick to what they know and smaller

schools may be unable to offer both GCSE ICT and GCSE Computing as options. The possibility to take an optional module in computing as part of a GCSE in ICT might increase the number of schools that offer at least some computing content.

The challenge is to interest and influence students at Key Stage 3 to choose GCSE Computing. This means encouraging centres to incorporate elements of computing into "KS3 ICT Programmes of Study" with units of work that are clearly identified as computing so that students are encouraged to understand that there is a difference. Students should have opportunities to learn at least one programming language in KS3, one that has the potential to capture students' interest and imagination.

5. Is computing and ICT best 'taught' in classrooms or 'learnt' by other means? How do learners learn computing and ICT skills?

It depends on the student and the availability of teachers with sufficient technical and pedagogic knowledge. Some students are very good independent learners and given opportunity and a catalyst from somewhere can acquire ICT and computing skills, knowledge and understanding by other means than the classroom. However, only a relatively small number of students are likely to choose to learn independently. If the number of students leaving school with an understanding of computing and who consider computing as a possible career is to increase, this can only be achieved by teaching it. Whilst some students become interested in computing through an external trigger, exposing students to it within a school is likely to trigger far more interest, even if the amount of teaching that is done is limited. Scratch is a very good example of this.

6. What motivates students to study computing? Is it what they learn in school or something else?

It can be either, but in most cases the students who choose to study computing do so because of an external influence rather than what they have learnt at school. This might be a parent or sibling who is professionally involved in the field or peer group influence. Many students have to be persuaded that A Level Computing is nothing like GCSE ICT before they will consider taking it. Key factors that motivate students are:

- technical curiosity (wanting to know how the things they use work)
- an enjoyment of practical challenges and problem solving
- contact with teachers with good subject knowledge who can enthuse them and show them avenues that they can explore, in fields that they enjoy, that they might not discover for themselves
- seeing the magic of what computing can achieve through contact with HE/industry
- seeing how computing is applied in contexts that they already enjoy e.g. gaming
- seeing positive role models e.g. parents, or speakers at conferences
- understanding how computing can provide an opportunity to apply their knowledge in other subject areas that they also find interesting.

Students are quite often unaware of the range of careers that might be available to them if they studied computing, so work to improve this situation would be useful.

7. How is computing presented at school, and is there a variation between schools? Why?

The profile for computing is very low or non-existent in a large number of schools. ICT has dominated because of its statuary status and the emphasis encouraged by the National Framework, OFSTED and the advisory service, although recently this emphasis has begun to be corrected. There has been no subject discipline on the compulsory education age curriculum called computing and no GCSE Computing until September 2010. Therefore, too many students, teachers, head teachers, parents, university admissions tutors, believe that computing and ICT is the same thing. This has, in some instances, resulted in a negative image for computing. Also, the profile of computing has suffered because of a lack of specialist teachers to fly the flag. Where AS and A Level Computing is offered and taught by specialists the profile of the discipline is high with many students continuing into HE to study the discipline or entering employment in which the skills and knowledge acquired are put to direct use. Decision makers who confuse computing with ICT undermine the status of computing as a discipline. This status perception has had an inhibiting effect. The message from some universities for entrance requirements has also had, unjustly, an effect on the image of computing in schools. In some instances, senior staff of high status university computing departments presenting at events for secondary school students have confused Computing A Level with ICT A Level. The latter has a low status on many university entrance requirements websites often being categorized as a soft science or even not acceptable. This confusion also occurs with some parents. This is a potential problem when their offspring reach the stage in their education when they choose which AS/A Level subjects to study. Computing is often mistakenly accorded a lower status than physics, chemistry when in fact it is just as intellectually rigorous as physics and chemistry.

8. Who is teaching computing, and what qualifications do they hold? Are teachers sufficiently supported with subject - specific CPD? Are there enough specialist teachers? Why do they leave/join the profession? What are the barriers to improving the situation?

Lack of qualified teachers is a huge problem. Most ICT teachers have not studied computing at university. Also, the generation of teachers who did not have a computing degree but who taught themselves how to program on a home microcomputer in the 1980s is disappearing.

It is difficult for schools to attract computing graduates when they are likely to have to teach ICT for most of the week, with only a small proportion of the teaching being computing-related. Teachers with an interest in teaching more computing find that career progression can be restricted because they take on more computing by teaching a narrower age range of learners, e.g. sixth form only.

Some degrees with the word “computing” in their title contain very little computing content which can cause further confusion.

There is also a problem that head teachers often do not realize that there is a difference between ICT and Computing. This is often compounded by an advisory service that is populated with ICT advisers who have little or no background in computing. In at least one county authority, head teachers have been advised that programming is an activity that was relevant in the 80s but which is no longer relevant. Specialist maths and computing schools often only teach ICT – what could cause more confusion between ICT and computing than calling a school that teaches ICT a specialist computing school?.

There is insufficient subject-specific CPD. The cost of courses and the problem of being able to get cover to be out of school are both issues. However, the limitations of CPD must be recognized. Whilst CPD can be useful to teach specific new topics to teachers with an appropriate background, can a few sessions of CPD really turn a teacher of business studies into a teacher of computing? The key must be to attract suitable graduates with a computing background into teaching. Having teachers who know just enough about computing to teach a specific course but no more is unlikely to lead to interesting lessons which enthuse students.

9. Why do some universities prefer their undergraduate applicants to have studied mathematics rather than computing at A-level?

Mathematics is a logical subject requiring precision of thought which enables students to demonstrate some but not all of the skills that they are likely to require on a university computing course. Most schools offer A Level Mathematics as an option. The percentage of sixth formers who are studying maths is very large thus making the pool of potential candidates very large nationally from which university admissions tutors for computing undergraduate courses pick their students. On the other hand, the percentage of sixth formers currently studying A Level Computing is small in comparison with A Level Maths. Indeed, as many schools do not offer A Level Computing (less than 50%), it would be difficult for universities to specify this as a compulsory entrance requirement as they would effectively prevent many potentially good students from applying. In A Level Computing’s favour is evidence from the drop-out rate statistics for computing degree courses. The statistics show the lowest drop-out rate from computing degree courses for students with A Level Computing. This is not surprising because a student who has matriculated with A Level Computing has demonstrated mastery of the discipline to a high standard. In addition, the belief that all maths students make good programmers and vice-versa does not always hold.

Are universities aware of what is in the A Level Computing specifications? In particular, the AQA specification has been designed to bring more of the computational thinking that is required for a computing degree into schools. Is there confusion in Higher Education between ICT and Computing A Level or confusion with previous Computing specifications?

Some students who are interested in Computing are put off from taking it at A Level by the attitude of universities to the A Level.

10. What are the perceptions of computing and ICT amongst learners, teachers and head teachers? How can information, advice and guidance be improved?

Many head teachers are unaware that there is a difference between ICT and computing. Similarly, in schools where the teaching of ICT does not encompass any computing, both teachers and learners believe that they are the same thing. This has consequences:

- Learners mistakenly believe that computing courses in HE are similar to ICT courses in schools, embark on such courses in HE and then drop out.
- Where opportunities for computing are offered post-16, learners with computing potential whose pre-sixth form experience is limited to ICT often elect not to study computing post-16.
- In some instances, learners with limited understanding of the difference between ICT and computing choose to study computing post-16 when there abilities would be better suited to studying ICT.
- Many learners in secondary education have a negative attitude towards ICT because of a poor experience in the classroom, for whatever reasons – constraining specifications/assessments, lack of experienced staff, staff from other departments/disciplines teaching ICT and not having enough support/resources/confidence to deliver effectively. Such learners then avoid going down an ICT or computing future studies route.

The ubiquity of computers has changed the perceptions of learners, teachers and head teachers. The attraction is not what it was because the computing element has been masked by layers of abstractions that enable mass use of the artifacts without needing to understand what happens under the hood. Learners are often now far removed from the internal hardware of computers and don't have an easy route to experimenting with the hardware such as programming the hardware. This makes it much more difficult for learners to appreciate the difference between computing and ICT and therefore to consider pursuing further studies in computing.

11. Are these issues unique to the UK?

No, these issues have arisen wherever the imperative has been to focus on ICT literacy at the expense of Computing/ICT fluency, e.g. USA. This is not the case in the Baltic states, eastern Europe, Israel, South Africa where computing is taught as a rigorous discipline.

12. What can universities do to improve the situation?

Universities can help by being positive about A/AS Level Computing, by raising its status in the eyes of head teachers, parents, learners and by confirming its status as a rigorous discipline. Universities can help by supporting the training of more teachers to teach KS3, GCSE and AS/A Level Computing. Universities can help by forging links to promote Computing in schools and supporting the association for Computing teachers.

Able students with a strong interest in Computing often choose to study A Level Computing as a fourth A Level because they are mindful that some university Computing departments expect particular grades in Maths, Further Maths and Physics and exclude A Level Computing from their entrance requirements. The introduction of the A* grade at A Level and its use as an entrance requirement by some universities is likely to make able students think twice about studying a fourth A Level subject because the extra study time gained by not can be used in support of the three A Levels required for entry. This is not a problem if these universities accord A Level Computing the same status as Physics and the other subjects currently accepted alongside A Level Maths so that A Level Computing can confidently be studied as the third A Level subject.

13. Is there a case for curriculum reform? Is this the barrier?

Yes, greater flexibility in KS2 and KS3 needs to be supported to provide curriculum opportunities for learners to experience the magic and beauty of computing. A clear separation should be flagged between Computing and ICT. Consideration should be given to computing qualifications at KS4 that stretch and challenge learners and which are not compromised by the need to cater for the full ability range.

14. Is there a need for an increased recognition of ICT and computing as part of the T in STEM, through representation in STEM forums and increased funding?

There is a case for increased recognition of ICT as part of the T in STEM. ICT is all pervasive. Employers need an ICT literate and ICT fluent workforce for the UK to maintain its global competitiveness. Computing offers more than support for technology. Computing draws on maths, science and engineering but moulds these into its own discipline. The principles and concepts unique to Computing are used to build the artefacts that are the technology of ICT as well as contributing to a deeper understanding of nature and cognition. Computing should not therefore be considered as just the T in STEM, but the S, T, E and M of STEM.

15. What happens if we do nothing?

The clear danger is that if we do nothing the trend of declining numbers of students taking ICT and computing subjects will continue. We will end up with a workforce that are reasonably competent at using computer systems, but with very few people capable of maintaining and developing them. The key areas of computing that need a continuing supply are software and systems design. Inevitably, this means finding a supply of people who are comfortable coding software on different platforms and confident at problem solving. Confidence and competence grows when people have opportunities at an early age to develop these skills and to discover that they have talent and an interest in computing at a problem solving level. Without opportunities for some exposure to computing at Key Stages 2, 3, 4 and 5 students may never discover that they have a talent for computing and in particular, software and system design. The consequence of not fixing the current situation will be that increasingly we will become dependent on buying in computer systems developed overseas and UK industry will be denied the opportunity to be a leader in an area that the country should be and was very good at. At a time when the country needs to grow its exports and the government is aiming to reduce the number of people coming into the UK to

work, it is self evident that we must be looking at ways to increase the number of people entering the field.
There is a particular risk with A Level Computing because many existing schools (and some colleges) currently only have a very small number of candidates taking the subject. With schools facing financial constraints in the next few years, there is a danger that some might start to see offering the subject as unaffordable, resulting in many more students being denied the opportunity to study it. Continued small annual falls in the popularity of the subject could suddenly lead to major declines if schools decided that these small falls mean that the course was no longer financially justifiable.

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