Classroom-based research projects for Computing teachers: facilitating professional learning

SUE SENTANCE, King's College London
JANE SINCLAIR, University of Warwick
CARL SIMMONS, Edge Hill University
ANDREW CSIZMADIA, Newman University

The introduction of Computing to the national curriculum in England has led to a situation where in-service teachers need to develop subject knowledge and pedagogical expertise in computer science, which presents a significant challenge. Professional learning opportunities can support this; these may be most effective when situated in the teachers' own working practices. This paper describes a project to support Computing teachers in developing pedagogical skills by carrying out classroom-based research in their schools. A group of 22 primary (Grades K-5) and secondary (Grades 6-10) teachers from schools across England planned, designed and implemented research projects either individually or in small groups, supported by a team of university colleagues. Inter and intra group progress was shared online and face-to-face within a distributed community of inquiry. Data collection included surveys, video data, and the projects completed by the teachers. The findings from the project are analysed using Clarke and Hollingsworth's Interconnected Model of Teacher Professional Growth (IMTPG), which enables an identification and exploration of teacher change. Results of the analysis demonstrate that the approach can foster "growth networks" - the construct used within IMTPG to indicate teacher change which is likely to be sustained and fundamental to teachers' understanding. The individual nature of this change indicates that the approach supports personal change related to each teacher's specific situation. Although there is a huge literature on action research as part of teacher professional learning, we believe this to be the first time this has been carried out in the context of computer science education. We conclude by critically reflecting on the lessons that we have learned in leading this project.

CCS Concepts: • **Social and professional topics → Computing education**; **K-12 education**;

Additional Key Words and Phrases: action research, computer science education, computing teachers, professional learning

ACM Reference format:
Sue Sentance, Jane Sinclair, Carl Simmons, and Andrew Csizmadia. 2018. Classroom-based research projects for Computing teachers: facilitating professional learning. *ACM Trans. Comput. Educ.* 0, 0, Article 0 (January 2018), 26 pages.
https://doi.org/0000001.0000001

1 INTRODUCTION

The introduction of Computing to the national curriculum for schools in England represents a major advance in recognising the subject as being of fundamental importance [2]. However, it has obvious implications for the number of teachers needed and currently many teachers are having to develop

1946-6226/2018/1-ART0 $15.00
https://doi.org/0000001.0000001

both subject and pedagogic skills at the same time. This is a challenging position for teachers, and points to the need for effective professional learning (PL) initiatives to provide support.

A recent paper on teacher professional learning in computer science looked at a range of studies describing PL programmes in the USA [29]. Primarily the studies under consideration were workshops or courses, several (19%) as short as one week. Menekse describes that, of the 21 studies under examination, many were summer programmes focusing on subject knowledge. In addition, less than half had more than 50 hours of professional learning. There are parallels here with the professional learning opportunities open to computing teachers in England which are typically workshops ranging from several hours to a short series of such sessions.

Purely using content-driven workshops to offer professional learning in computer science for teachers suggests an emphasis on a deficit model [21]. Such a model is based on a concept of remedying perceived subject weakness in individual teachers and does not acknowledge the more collective, collaborative dimension of PL. Further, dependence on subject training workshops suggests that little has changed since Clarke and Hollingsworth observation in 2002 that:

> *"The application of contemporary learning theory to the development of programs to support teacher professional growth has been ironically infrequent"* [6, p.947]

There are however other approaches to PL that have been used successfully and which involve more collaboration between teachers, incorporating activities which take place within a community of practice [14, 30, 34, 36, 39]. These examples of professional learning reflect a more sociocultural view of teacher learning; learning which is distributed across people and tools [38]. Recent work by Margolis, Ryoo and Goode on the coaching aspects of the ECS professional development programme offers another example [26]. Drawing on the work of Lave & Wenger on situated learning [25, p.29] it is apparent that teacher expertise is closely linked to the circumstances to which it pertains: not to precise situations, but to the particular working practices and their associated ways of thinking which define their school circumstances. Teacher professional learning in computer science is no exception and we should seek approaches to PL which are situated in a teacher's own working practices and which help embed teachers within an appropriate network or community of practice.

Much evidence points to the lack of effectiveness of professional development programmes which are based on the deficit-training-mastery model, particularly those delivered as "one-shot" training workshops [13, 15]. The failure of such training to effect the desired outcome in terms of teacher change is potentially costly, especially in terms of the opportunity cost of teacher time. More recent conceptions of teacher change recognise that it is less likely to be effected by following a passive, knowledge-transmission model, than by acknowledging a more complex process involving the need for active, reflective and situated ("interactive") learning [37]. Those initiatives which enable greater agency and which allow teachers to become active learners who reflect and act on their learning may prove to be more effective in terms of long lasting change in teacher capability to be reflective practitioners. In the light of this, the continuing predominance of training workshops as PL for Computing teachers points to the need to explore different models of professional learning for Computing. Two further models of PL noted by Kennedy [21] are the action research model and the community of practice model. In this context, action research involves teachers acting as researchers in their own classroom. Action research PL has been noted as having a much greater impact on practice when combined with a community of practice approach [3]. Both of these models embody a more active approach to facilitating teacher change and involve extended, reflective engagement on the part of the teacher. It is also worth noting that what Kennedy terms as a "transformative" model of change - one most likely to produce meaningful and long-lasting effect - necessarily combines different aspects of a variety of other models [21].

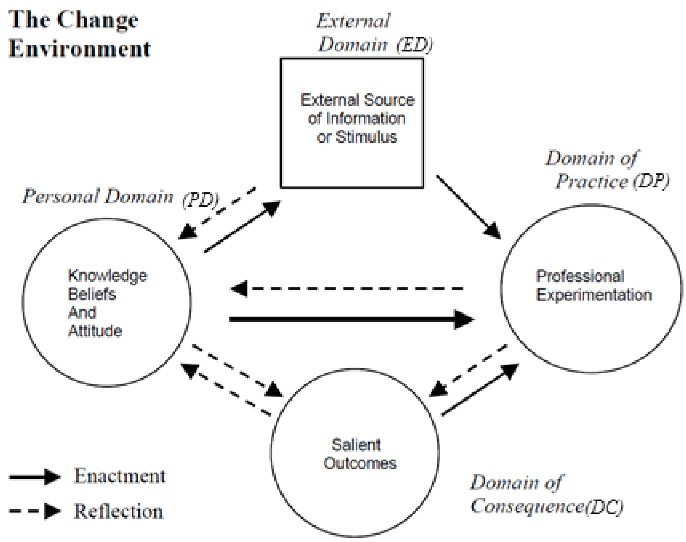

Fig. 1. Clarke and Hollingsworth's Interconnected Model of Teacher Professional Growth (IMTPG) [6]

It is therefore likely that an approach to Computing PL which brings together components of these different models will be more beneficial than passive training based on a deficit model.

2 CLARKE & HOLLINGSWORTH'S IMTPG

Whichever model (or combination of models) is used to design and plan PL opportunities, it is helpful to identify a framework which can provide a basis for evaluating the effects of a PL initiative. Clarke and Hollingsworth propose a model to examine and explain teacher change as a complex, interwoven learning process [6]. The impact of new initiatives can be explored using this lens. Their Interconnected Model of Teacher Professional Growth (IMTPG) (depicted in Figure 1) describes how teacher change might happen, locating this change in one or more of four connected domains:

- Personal domain (teacher knowledge, beliefs and attitudes)
- Domain of practice (professional experimentation)
- Domain of consequence (salient outcomes)
- External domain (sources of information, stimulus or support)

Of the four domains in which change can take place, three constitute the teachers' professional world of practice: the knowledge and beliefs of the teacher (personal domain), the practice of the teacher (domain of practice) and the actual salient outcomes in the classroom (domain of consequence). In this paper we will refer to these as PD, DP and DC respectively. The last domain is the external domain (ED) which represents outside sources such as training and support that can be influential for teacher change. The interconnected aspect of the model is explained by Clarke and Hollingworth as follows:

> *Change in one domain is translated into change in another through the mediating processes of "reflection" and "enaction". The term "enaction" was chosen to distinguish the translation of a belief or a pedagogical model into action from simply "acting", on*

> *the grounds that acting occurs in the domain of practice, and each action represents the enaction of something a teacher knows, believes or has experienced.* [6, p951]

Hence, the arrows between certain domains represent the possible steps by which change in one domain influences another. Professional growth may be observed as change according to any or all of these paths.

The IMTPG model can be used to analyse or predict teacher growth as a result of professional learning initiatives. However, in order to apply the model in practice it is necessary to examine further the explicit meanings of the transitions in the specific context of teacher professional development. In order to use the IMTPG as a tool for assessing the effectiveness of the current project we provide this contextualised interpretation when the results are discussed in Section 7.

Using this theoretical lens, this paper reports the use of action research in the classroom to support professional learning for Computing teachers. A project designed to support Computing teachers in developing and implementing their own research projects in their classrooms is described. The project was driven from a desire to engage teachers fully in their own professional learning in Computing. The results are discussed in line with the IMTPG framework, and potential improvements identified to make classroom-based research projects more likely to be successful in Computing. Although there is a significant body of literature regarding action research as part of teacher professional learning, the contribution this paper makes is to demonstrate its implementation in the context of computer science education and evaluate its effectiveness in terms of teachers' professional growth.

3 THE TICE PROJECT

The Teaching Inquiry in Computing Education (TICE) project ran from July 2015 - June 2016. Its intention was to give Computing teachers an opportunity to develop their understanding of computer science pedagogy by supporting them in the implementation of a classroom-based research project.

Participants were recruited from the Computing At School[1] community and selected by application form. Selection criteria were used to identify teachers who were currently teaching Computing, not in their pre-service training year, and in either primary or secondary education. The project was structured around two face-to-face training days in October and March. Funding was used to support teachers to be released from school for the two days of training.

The first meeting was used to explore research methods and to formulate a research question. Teachers were divided into groups with a University-based academic helper and supported in creating a research question that related directly to their own teaching.

Between the two meetings, an online area was used to share progress and send updates and reminders. The second meeting was used to report on progress and to give guidance on data analysis and reporting. Teachers were asked to bring data that they had collected during and after their intervention and the volunteer academics supported them in understanding and analysing their data.

Teachers completed their research projects in their schools and were encouraged to write them up as two-page poster style reports that could be shared with the teaching community. A template was provided for the report to make this as easy as possible for the teachers to structure their work into a readable form. The collection of reports was published as an action research booklet[2] and shared at an annual Computing teacher conference. Individual posters created from teachers' reports were sent to each of the teachers' schools so that their work could be displayed and acknowledged.

[1] http://computingatschool.org.uk

[2] Available at http://community.computingatschool.org.uk/files/7989/original.pdf

Teachers were also invited to share their work by presenting in special interest research sessions at the teacher conference in June 2016.

4 CLASSROOM-BASED RESEARCH

The term "Action Research" was popularised by Kurt Lewin in 1946 [1], and has been enthusiastically taken up within education for several decades. Action research involves teachers working with their own students and carrying out research on their own work [20]. It can be generally defined as "the study of a social situation with a view to improving the quality of action within it" [12], although Cohen and Manion prefer to define action research as a "small-scale intervention of the functions of the real world and a close examination of the effects of such an intervention" [7]. Some traditional researchers often hold a poor opinion of action research [17]. Specific criticisms of action research relate to the fact that it is localised [5], that it is "idle self-contemplation" [28] and that it lacks scientific rigour. However, Corey [8], cited in [7], argues that it is a process in which practitioners study problems scientifically so that they can evaluate and steer decision-making and practice. Indeed McNiff [28] describes it as wanting to understand how one can impact social change.

Classroom-based research seeks to create a local impact which is often small-scale, rather than producing large-scale generalisable results. It is a way of empowering teachers to investigate changes in teaching and learning and measure the impact of those changes on their learners. Action research should be reflexive [42]. Judgements are not made, instead, reflection on the current situation leads to more questions being asked and more options being opened. This leads to a deeper and wider understanding as a result of the classroom-based research. This is in contrast to more didactic teacher training in which content may be dictated to them during a formal taught session. It therefore "recognizes teachers' central roles in decision making, based upon the needs of their students and schools" [3, p.501]. However, teachers are most likely to be able to engage in action research if there is a culture of action research in their school. Ebbutt hypothesised that it would take ten years for a school to move from no culture of research to an established and embedded research culture [11]. Part of effective professional learning (PL) is trying out new ideas in the classroom and evaluating their effectiveness [33], by carrying out action research or classroom research. The benefits, according to Pine, are many:

> *"Action research enables teachers to reflect on their practice to improve it, become more autonomous in professional judgment, develop a more energetic and dynamic environment for teaching and learning, articulate and build their craft knowledge, and recognize and appreciate their own expertise."* [33, p.30]

Teacher research is not new and there are many examples of studies from the 1970s and 1980s where teachers were funded to carry out research projects [5]. Participation in research engenders reflection [16] and engaging with inquiry collaboratively helps teachers understand their philosophy of teaching [10]. A coach or teacher education professional may have a role in supporting teacher inquiry [23] and helping teachers to be more reflective [16]. This is particularly important in Computing, a relatively new subject in the school curriculum. Reflection and research is in clear contrast to the more passive, knowledge-transmission approach of the training-focussed workshops evidenced in the majority of current computing PL programmes [29]. Teachers may have perceptions that cause them not to identify fully as computing teachers [31] and teacher research in computing may ameliorate this as teachers investigate effective strategies in the classroom.

Action research has a clearly defined methodology and more general versions of the approach (which may not adhere as tightly to the defining features of action research) are commonly known as classroom-based research, collaborative inquiry, teacher inquiry, etc. In this paper we will use the term classroom-based research.

5 THE STUDY

5.1 Research outline

The TICE project, described in Section 3 took place from 2015-2016. Our research questions were as follows:

- *RQ1: How can teacher research impact Computing teachers' professional learning?*
- *RQ2: What are the key elements of a teacher professional learning programme based on classroom-based research?*

During the ten month project teachers contributed to a range of data sources including teacher surveys, videos of meeting presentations, video interviews and project reports. Surveys were completed during the application process at the end of the initial meeting, the second meeting and at the end of the project. This enabled teachers to describe their research interest and question and later on, to describe their progress and evaluate what they had learned on the meeting days.

5.2 Data collection

Teachers wishing to participate in the project completed a short survey prior to being accepted on to the project. This included questions about their academic and teaching experience as well as ideas for research. Data were collected via online questionnaires that were subsequently anonymised. Two other questionnaires (Q1 and Q2) were completed by the teachers after each of the meetings (M1 and M2) to collect data from teachers about their experiences of each of the two meetings and their feelings about their ability to undertake research, their research question, and where they needed additional support. As well as providing data for the project these questionnaires were used to plan the support that was subsequently provided by the academics. In this way the project developed in a fluid way, in response to the needs of the teachers: it was at all times seen as a collaborative venture with the teachers' experiences shaping how the project progressed. Finally, a follow-up survey was circulated to participants 10 months after the end of the project and responses collected anonymously on the impact of the project. The questionnaires gave us limited quantitative data to analyse due to the number of teachers being small and the free-text nature of most questions. Video data was also collected. In the first meeting, the teachers presented their research ideas in front of the whole group and were filmed doing this. In the second meeting, most teachers had results from their projects to discuss so were filmed privately during the second meeting talking about their perceptions of the programme. The second set of films gave us qualitative data about the teachers' experiences of the programme, their insights into their teaching gained from their participation and their results, and this provided rich data with which to assess the extent to which this activity has supported their pedagogy and confidence.

Ethics procedures were strictly adhered to: all teachers were given full information about the research being carried out and gave their permission, before joining the project, for their data to be used for research purposes. Any reference to individual teachers has been anonymised in this article.

5.3 Data Analysis

The data were analysed within the QDA software NVivo to which all researchers had access. Teacher data was organised as cases to elicit useful comparisons; coding was organised around main themes drawn out during an inductive process [24, 27]. Furthermore teacher data was coded against the four domains of the IMTPG to explore the teacher data within this framework. As

Table 1. Profile of teachers

Type school	No.	Computing teaching (average hours)	Experience (average years)
Primary	7	5	9.6
Secondary	14	16	14.5
Middle	1	17	9
Total	22		

a group of researchers split amongst different institutions we triangulated our analysis using a cross thematic matrix approach to fully investigate the data [9]. Using this method the cases are presented in a table against data relating to themes, some of which related to our IMTPG analysis. This approach enabled individual researchers to qualify their interpretations of the coded data and for a depth of analysis leading to a case by case analysis of the data. At this stage, two cases were identified which demonstrated a high level of change using the IMTPG and these are presented below.

5.4 Participants

Twenty-two teachers attended the first training day and 15 the second training day. Of the 7 that did not attend the second training day, 3 remained on the project meaning that 18 teachers completed the whole project. The four teachers that did not continue with the project had a variety of personal reasons for not doing so. Teachers were reimbursed for travel expenses and a contribution was made to their schools to cover the cost of their time to attend.

Teachers were given a basic introduction to research methodologies and some suggested ways of working. In the first meeting types of research were described and how to devise a research question and plan a research project. Teachers identified their areas of research interest, selecting an appropriate methodology through discussion and support with their academic helper. On the second meeting day, methods of data analysis were described and how to present results.

Of the 22 teachers joining the project, 7 were primary teachers with 14 secondary teachers and one from middle school (age 8-14). All the teachers who did not continue (4) were from secondary education. The three that continued but could not attend the second meeting day were also secondary teachers. Thus in our experience the primary teachers were more able to see the project through to its completion. The profile of the teachers is shown in Table 1.

Teachers were encouraged to reflect on their interests when completing the application form and before the first meeting to establish a research question that interested them. They were asked to explain and justify their choice of a research project at the end of the first meeting and this was videoed as data. Eleven teachers agreed to be interviewed either individually or in project groups at the end of the second meeting.

Seventeen teachers completed the project by writing up their projects for the published resource: Figure 2 shows two examples of part of the reports from teachers (anonymised). Eleven teachers presented their project results to a teacher audience in June 2016. Table 2 shows teachers' engagement with the project.

Five academics volunteered to support the teachers through the process. This meant that there was a ratio of between 3 and 4 teachers to one academic support in the meetings. Academics met with their teachers during both training days and provided online and telephone support as the projects progressed. The academics met with the teachers at the two meetings and then each teacher was assigned to a group. Some of the teachers had phone calls and video conferences with

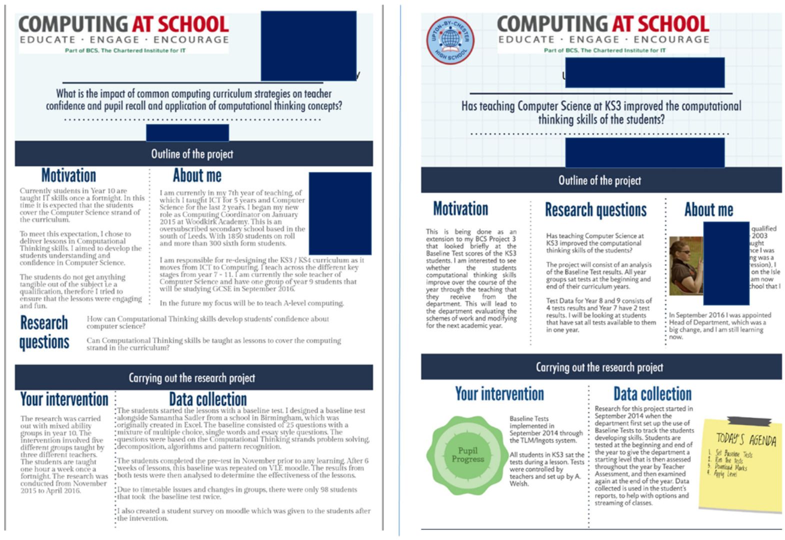

Fig. 2. Examples of research reports produced by teachers

their assigned academic in between the two meetings; others were too busy to make contact or arranged meetings which they subsequently cancelled. Four academics were present for both of the meeting days which meant they had made met all the teachers face-to-face. Teachers were asked to upload progress at regular intervals between meetings but only a few did this. Thus most of the contact between university academics and teachers took place at the two meetings.

6 PROJECT RESULTS

With different forms of data collection, we were able to track the participants progress through the project. In this section we describe the findings of the project by summarising the key points from the data from a number of perspectives:

- Computing topics chosen by teachers
- Opportunities to improve as a Computing teacher
- Development of research skills
- Impact of the project beyond the participants
- Longer-term impact of the project

6.1 Computing topics important to teachers

Teachers carried out a variety of research projects, and on several occasions were asked to confirm the research question that they were focusing on; these remained consistent throughout the project in nearly all cases. Writing about action research for teachers, Johnson [18] suggests that most research topics fall into one of the three following areas:

(1) The study or evaluation of a teaching strategy
(2) Identification and investigation of a problem
(3) Examining an area of interest

Most teachers chose the first category: a particular teaching method to try and to investigate the difference made. Examples of research questions chosen are as follows:

Table 2. Teachers' engagement with different aspects of the project

Name	Meeting 1	Meeting 2	Survey 1	Survey 2	Interview	Write-up	Presentation
Lewis	Y	Y	Y	Y	Y	Y	Y
Harry	Y	Y	Y	Y	Y	Y	Y
Joanne	Y	Y	Y	Y	Y	Y	Y
Leanne	Y	Y	Y	Y	Y	Y	Y
Carrie	Y	Y		Y	Y	Y	Y
Paolo	Y	Y	Y		Y	Y	Y
Joachim	Y	Y	Y	Y	Y	Y	
Wendy	Y	Y	Y	Y	Y	Y	
Carlos	Y	Y	Y	Y	Y	Y	
Fatima	Y	Y	Y	Y		Y	Y
Karen	Y	Y		Y	Y	Y	Y
Rashida	Y	Y	Y			Y	Y
Jennie	Y	Y		Y	Y	Y	
Ghita	Y	Y	Y	Y		Y	
Leon	Y			Y		Y	Y
Bart	Y	Y	Y				
Yves	Y		Y			Y	Y
Freda	Y		Y	Y		Y	
Yota	Y	Y	Y				
Phil	Y		Y				
Lucy	Y						
Octavia	Y						

- *How do unplugged pattern activities support pupils' learning of programming competencies?* (primary)
- *Does the use of computational thinking impact progress of SEN learners in writing?* (primary)
- *Does a child-led teachers' code club improve teachers confidence and knowledge?* (primary)
- *Exploring how flowchart tasks support the learning of programming.* (secondary)
- *What is the impact of common computing curriculum strategies on teacher confidence, pupil recall and application of Computational Thinking concepts?* (secondary)
- *How can perseverance in computing improve achievement across the curriculum?* (primary)

An example of an **investigation of a problem** was *'What are the issues facing dyslexic students studying programming?'* (secondary). An example of a research topic which **examined a particular area of interest** was *'How does the perception of Computing change from Key stage 1 to Key stage 5?'* (group project across phases).

These projects spanned a range of areas of the curriculum. Some teachers chose topics that related to concerns that they had in their own teaching. For example, Lewis, who chose to look at the use of flowcharts in developing algorithmic thinking said *"I teach programming at KS3-4 [Grade 6-10] and have had varying success: perhaps this would be a good field of inquiry . . . "*. Another chose a topic that his school had been looking at using a methodology known as lesson study. A further participant chose to look at exploratory approaches to teaching because the school had noted that those who were successful at computing were those who came from backgrounds where parents were already working or involved in IT-related or science fields, and he wished to explore whether more active learning would support other students. The variety of topics chosen reflects the different situations teachers are in and their different learning needs. Often professional learning programmes do not take into account the individual context in which the teacher is working: this is one of the reasons that classroom-based research has been shown to be useful [22].

6.2 Opportunities to improve as a Computing teacher

Turning to the reasons for participating in the project, some teachers were very clear on the benefits of research to themselves and their learners:

> *"By engaging with research, I will empower myself and others to adapt and reflect on classroom practice. This will benefit our pupils and further equip them for a future in Computing."* (Joachim)

Teachers were self-selecting for this project, although they needed to have the support of their headteacher. They reported a variety of reasons for taking part in the project. Some felt that they had undertaken a range of subject knowledge courses but if they could undertake research they could help others. Others were already involved in research projects in their schools, but these were not focused on Computing, and they wanted an opportunity to find out more about the teaching of Computing. A few teachers commented that they were interested in enrolling for a postgraduate degree at some stage in the future.

Teachers were also driven by their interest in Computing and how to teach it better:

> *"I suppose I personally like looking for different things and different avenues that I can do as a teacher to both improve my own understanding and the way of thinking. And I think that's really happened in this. "* (Carrie)

Carrie carried out an investigation about the use of computational thinking in the teaching of literacy, together with another teacher, Jennie, from another school. Prior to the research project, these two teachers had never met, but it became clear in the first meeting that they had had similar experiences in their schools and could identify the same problem. They designed an intervention to be carried out in both their schools, and Carrie came to the second meeting with examples of student work and other data from her project. The intervention involved teaching computational thinking in primary schools and then referring back to the skills when developing story-writing skills.

When interviewing teachers they discussed how their understanding of teaching Computing had developed through the project. Karen was a specialist computing teacher in a primary school and, although an experienced teacher, was relatively new to Computing herself. She wanted to look at links between unplugged activities and confidence in programming. Having carried out her research project she reports that:

> *"What I have noticed is that those children who more recently have been exposed to unplugged CS or activities which have involved the processes where they've got to actually think logically, they've got to stick thinking in a step by step algorithmic way, I've noticed that those children tend to be better programmers or be better at problem solving in a programming environment and that's really stimulated the process."*(Karen)

Reflecting more on the learning of Computing in this way was often followed by conversations about changing teaching practice, and also the benefits of sharing these reflections with other teachers during the meetings.

6.3 Development of research skills

The project involved a lightweight introduction to classroom-based research, with just two days of training and discussion with some support in between. Teachers in their video interviews reflected on their learning about research, with some evidently having learned more than others. Some had just learned how difficult research was!

> *"[I have learned] about the amount of time that this sort of stuff takes actually ... we started off with quite an ambitious programme that we wanted to do lots of observations, have lots of children in lots of different settings before and after the intervention. And actually life gets in the way "* (Harry)

Harry was an experienced primary school teacher who had recently become a CAS Master teacher[3] in his local area. He already supported teachers in his school and was now going to be supporting other teachers in the local area. Harry chose to look at the way in which children can develop perseverance when learning Computing, and engaged other teachers in his school in his research.

Some teachers carried out pre-tests and post-tests:

> *"We ... designed a baseline test around the computational thinking skills where there's different strands to which I baselined year ten students, and there's a sort of pre-test. And then we plan lessons around the computational thinking skills abstraction, algorithms, pattern recognition, and then we post-tested the students as well on the same test to see if there was any impact or progress."* (Paolo)

Although pre-tests and post-tests were a very popular way of measuring the impact of their intervention, one teacher interviewed students and then coded his data around themes, which he used the second meeting day to do:

> *"And this is one of my codes as well for the various types of misconception that emerge from teaching it. So right now, I'm coding the data. So I'm at, I don't know, the early stage of coding that data but I've already found that types of misconception is a theme, so I have the notes along the sides."* (Lewis)

The teachers had difficulties narrowing down their research foci to specific questions and in future projects we would recommend that academics spend more time to help them do that effectively:

> *"The thing I found hardest was having to whittle down my great big question into one little realisable project. I'm very glad to have the chance of doing this research with guidance."* (Ghita)

However, for those teachers who had not known anything much about classroom research prior to the project they learned a lot that they could take away and use going forward; this even applied to those with some experience of research through other projects:

> *"I think I've learned quite a lot about the different types of research methods, how you would go about doing things with different groups of children, or different groups of adults for particular purposes. So rather than an assumption that everything had to be done through a questionnaire for example, different ways of doing that."* (Harry)

A group of three teachers were looking at gender across the whole curriculum – the group of teachers spanned primary to secondary schools. They collected a substantial quantity of data, then had problems analysing it and queried their data collection methods:

[3] A Computing At School Master Teacher supports other teachers locally

> *"Looking at some of the answers in the students that we got the data from, it did make us start to raise questions of whether the answers are valid in reality or are they thinking about the teachers."* (Joachim)

It was this project that made the research team focus on some of the limitations of the project (see Section 8) as the group had some difficulties with the amount of data that they had gathered and there were inconsistencies between the group members.

To gather data from the university academics working on the project, the academics were surveyed about their perception of the project and three, fairly lengthy, responses were received. The academics were more conscious of the limitations of the project and the difficulties of supporting teachers remotely when they were working on completely different projects, had limited time, and also limited research skills. The following comment is representative and refers to the teachers' lack of experience in research design:

> *"In some cases teachers perhaps over-complicated their research by being a little too ambitious in the claims they hoped to make. Nevertheless this was a very useful learning experience for all parties and foregrounded or formalised some unconscious critically analytical practices that teachers were engaging in day-to-day.* (Anonymous academic, follow-up survey)

This perspective is very important and future iterations of the project will be designed with more awareness of the teachers' prior knowledge and need for training in research methods.

6.4 Impact beyond the participants

The nature of some of the interventions meant that teachers had to work with other teachers in their school to implement the intervention that they had planned. This was easy in some cases and less so in others. In Harry's case, he was already regarded as the Computing 'expert' in the school, so the teachers were likely to be willing to cooperate with his ideas around encouraging children's perseverance in Computing:

> *"They [the teachers] reported that they thought it had helped them to reflect on their practice as well and being able to look at how different children react in ways that maybe they wouldn't always expect of some of the children were better at this stuff than we would have assumed. And so yes, just being able to have a chance to step back I suppose and to think about these critically."* (Harry)

However, Paolo, a secondary school teacher, a Computing coordinator in his school, found it more difficult to ensure that the other teachers in his department implemented the intervention:

> *"However, I think if I do it again in the future . . . I need to think about the impact. So, for example, try and make it more worthwhile for the students. I think I struggled with my staff really."* (Paolo)

Paolo had previously been an ICT teacher prior to the curriculum change, and had spent several years up-skilling in computer science. His initial research question was around the impact of common computing curriculum strategies on teacher confidence and pupil recall and application of computational thinking concepts. He worked together with another teacher, Joanne, although their final reports were produced separately. He said he benefited from the project in terms of networking with others and finding out more about computational thinking, but he had more difficulty in persuading his staff to carry out the intervention. In contrast, Joanne, a teacher who qualified only a few months previously, found her school very supportive and other teachers in the department willing to try out her ideas:

> *"I think the thing that surprised me is the way that the teachers have responded to it more than anything . . . Not just the way they've responded to being involved in it but actually that they're coming back to me and saying, you know, I've really understood that and I enjoy doing it for the students."* (Joanne)

Finally, we can summarise the lasting results of the project by a small amount of data collection carried out after the project had finished.

6.5 Project Legacy

We revisited the project several months after completion to find out if it had had any impact on teachers' practice. Nine of the original participants completed a survey asking them to comment on the impact that the project had had on their teaching or understanding of Computing since the study.

Figure 3 shows the results of this survey to questions about the teaching and thinking about teaching with relation to Computing. The impact has been moderate, 7 out of 9 teachers reporting that they either partly, or more than partly taught aspects of Computing differently as a result of the project, and 6 out of 9 teachers saying that they (partly or more than partly) thought differently about how to teach aspects of Computing and that their understanding of Computing teaching has changed. This was the only survey instrument that was anonymous and we feel that this is a positive result, even on a small scale, some months after the project completed. 8 out of the 9 participants said they would (partly, or more than partly) be interested in carrying out another research project in the future.

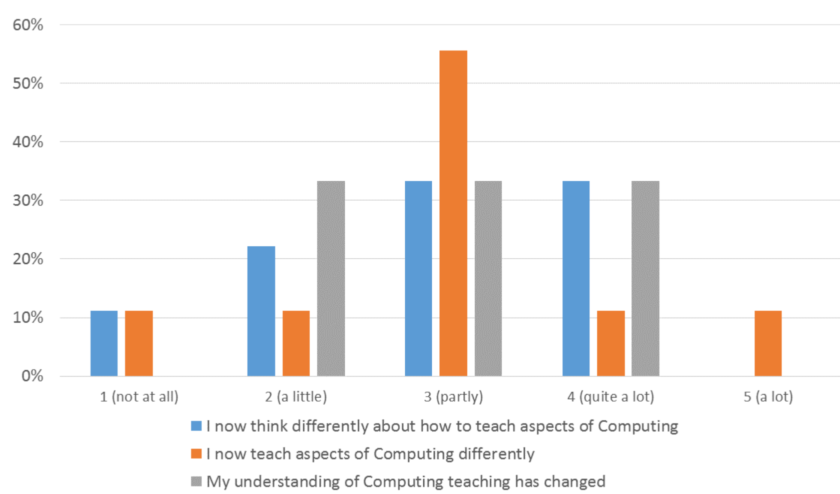

Fig. 3. Impact of project on teaching (after 10 months)

More interesting are the written comments where teachers have reflected after the event on the impact of the project. One participant said:

> *"I found the project extremely useful and would have liked more time with colleagues working on the project to share ideas so that I could put them into practice."* (Anonymous participant, follow-up survey)

Another teacher said that the opportunities to reflect on teaching and try out new approaches to teaching the subject were unfortunately rare in the busy teaching day, and that the project enabled them to capture their reflections in a structured way:

> *"The teacher learning curve is a steep one, although the pace of the classroom means that so many valuable reflections are lost in the school day. However, having a well-organised, professional research task to become involved in meant that some of these reflections would not be lost in the school year."* (Anonymous participant, follow-up survey)

In summary, the data reveals that teachers reflected on their Computing teaching as well as their developing (or not) skills in researching in their classrooms. In the next section we move on to analysing the data further in line with the Interconnected Model of Teacher Professional Growth (IMTPG).

7 FURTHER ANALYSIS: TICE AND THE IMTPG

The project was an opportunity for teachers and academics to work together on small classroom-based projects. Although there are areas of the design and execution of the project that may need to be modified if it were to be scaled up (see Section 8), the project results speak to the fact that overall both groups reported positively about the project. As might be expected, teachers enjoyed the whole experience of being given time out of the classroom to really think about the teaching of their subject:

> *I really enjoyed the experience as it allowed me to sit with other teachers from around the country and discuss different approaches and ways of delivering aspects of Computing, particularly how to overcome difficulties. It also gave me time within my standard working week to focus on a specific area of CS that I wanted to develop.* (Anonymous)

However, as a potentially key aspect of a larger programme of professional learning [36], our intention is to be able to identify the impact of the project in terms of teacher change. For this we return to the work of Clarke & Hollingsworth [6], and examine the data from the two perspectives of reflection and enaction.

7.1 Using Clarke & Hollingsworth's model of teacher change

As discussed in Section 2, Clarke & Hollingsworth proposed a framework for analysing teacher growth. This provides a means for evaluating potential teacher change that has been facilitated by this project. As noted in section 2, to apply the IMTPG model to the analysis in the context of teachers' professional growth, specific interpretations must given to the domains and transitions used in the model. This is illustrated in Figure 4. Note that Clarke & Hollingsworth use the term 'enactment' in this diagram, but this is synonymous with 'enaction' which they also use, and that we consistently use.

Contextualised domains

We first consider the four domains. In the context of the Computing curriculum in England, the **external domain** (ED) is quite easy to identify for teachers. It includes the curriculum change, new qualifications, presence of communities such as Computing At School (CAS) to support teachers, pressures from schools to evidence student success in a time of great change, etc. In terms of our specific project, the external domain (ED) was the TICE project itself. This included the opportunity to work on a research project, the opportunity to network and the meetings covering some research

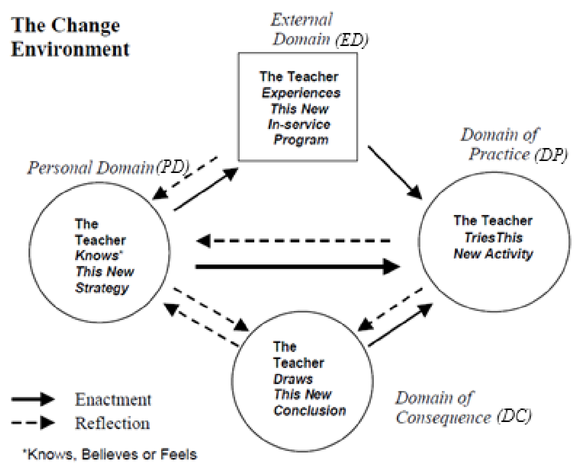

Fig. 4. Interpreting the IMTPG - showing reflection and enaction links [6, p.957]

methods training. The **domain of practice** (DP) is what Computing teachers do in the classroom, and in the case of this project will include the interventions that they carried out in the classroom. The **domain of consequence** (DC) – or salient outcomes – is the improved learning outcomes, that happen as a result of change in the other domains. In the case of the Computing teachers in our study, they were hoping for a greater understanding of Computing topics, or increased motivation and improved attitudes towards Computing. The **personal domain** (PD) is the knowledge, beliefs and attitudes of the teacher and in the context of our teachers, this was very varied. Some reported that they had experience of research from prior courses, while others were unsure of their Computing knowledge. What they had in common was that they had all volunteered for the project because of a personal interest in carrying out classroom-based research.

Contextualised links

In order to give meaning to the relationships between domains from the IMTPG model we follow the work of Justi & Van Driel who used the framework to assess the professional learning development of science teachers' subject knowledge in a particular aspect of the curriculum (models and modelling) [19]. We use this as a basis for interpreting the nine links in the IMTPG model in the context of the TICE project where the focus was on classroom-based research in computer science education. The resulting descriptors are shown in Table 3. The equivalent table for the TICE project, where the focus was on classroom-based research in computer science education, is shown in Table 4; this enables us to consider where change sequences or growth networks are evident from the data.

7.2 Change sequences and growth networks

Using the definitions of domains and descriptors outlined above we were able to code the data to assess where evidence of change along any of these dimensions was evidenced by the participants.

In this relatively small intervention we cannot claim to have substantially affected teacher change in all the teachers who participated in the programme, but we believe that the IMTPG

Table 3. Criteria for establishment of relationships in the IMTPG (taken from Justi & Van Driel [19, p. 443])

Relationship	Criteria for establishment
1. From PD to ED	When a specific aspect of teachers' initial content knowledge, curricular knowledge, or PCK on models and modelling influenced what they did or said during one of the learning activities in which they took part.
2. From ED to PD	When something that was done or discussed during one of the learning activities modified teachers' initial content knowledge, curricular knowledge, or PCK on models and modelling.
3. From ED to DP	When something that was done or discussed during one of the learning activities influenced something that content knowledge, curricular knowledge,in activities involved in their research projects or in other teaching activities they had conducted after the meetings).
4. From PD to DP	When a specific aspect of teachers' content knowledge, curricular knowledge, or PCK on models and modelling influenced something that occurred in their teaching practices (either in activities involved in their research projects or in other teaching activities they had conducted after the meetings).
5. From DP to PD	When something that teachers did in their teaching practice modified their content knowledge, curricular knowledge, or PCK on models and modelling.
6. From DP to DC	When something that teachers or their students did in their teaching practice caused specific outcomes.
7. From DC to DP	When a specific outcome made teachers state how they would modify the associated teaching practice in the future.
8. From DC to PD	When teachers reflected on a specific outcome, thus changing a specific aspect of their previous content knowledge, curricular knowledge, or PCK on models and modelling.
9. From PD to DC	When a specific aspect of teachers' content knowledge, curricular knowledge, or PCK on models and modelling helped them in reflecting on/analysing a specific outcome of their teaching practice.

PD = personal domain; ED = external domain; DP = domain of practice; DC = domain of consequence.

model provides a glimpse into the types of transformative effects that this style of professional learning activity could have on teaching. As Clarke & Hollingsworth state:

> *"The non-linear structure of the model provides recognition of the situated and personal nature, not just of teacher practice, but of teacher growth: an individual amalgam of practice, meanings, and context."* [6, p.965]

We suggest that our data shows that all teachers who completed the programme, and carried out an intervention on which they reflected and reported (18 out of the original 22, although only 17 produced a report), can be seen to evidence change in that the external stimulus, the TICE project, has facilitated a change in their Computing teaching practice.

Further, many of the teachers also demonstrate change occurring across multiple links within the framework. Clarke and Hollingsworth suggest that for any individual, the combination of their paths of change can be viewed as representing a 'change sequence' or a 'growth network' [6, p.957]. A change sequence can be described as a change in any two of the domains evidenced by empirical data, with a reflection or enaction between them suggesting a causal relation. This

Table 4. Criteria for the establishment of the relationships in the IMTPG in the TICE project (E for enaction and R for reflection)

Relationship	Criteria for establishment
1. From PD to ED (E)	When knowledge or beliefs about Computing, how to teach it and how to conduct action research influenced what they did or said during the TICE meetings.
2. From ED to PD (R)	When something that was done or discussed during the TICE meetings modified teachers' knowledge or beliefs about Computing, how to teach it and how to conduct action research.
3. From ED to DP (E)	When something that was done or discussed during one of the learning activities influenced something that occurred in their teaching practices (either in activities involved in their research projects or in other teaching activities they had conducted after the meetings).
4. From PD to DP (E)	When knowledge or beliefs about Computing, how to teach it and how to conduct action research influenced something that occurred in their teaching practices (either in activities involved in their research projects or in other teaching activities they had conducted after the meetings).
5. From DP to PD (R)	When something that teachers did in their teaching practice modified their knowledge or beliefs about Computing, how to teach it and how to conduct action research.
6. From DP to DC (R)	When something that teachers or their students did in their teaching practice caused specific outcomes.
7. From DC to DP (E)	When a specific outcome made teachers state how they would modify the associated teaching practice in the future.
8. From DC to PD (R)	When teachers reflected on a specific outcome, thus changing a specific aspect of their previous knowledge or beliefs about Computing, how to teach it and how to conduct action research.
9. From PD to DC (R)	When knowledge or beliefs about Computing, how to teach it and how to conduct action research helped them in reflecting on/analysing a specific outcome of their teaching practice.

PD = personal domain; ED = external domain; DP = domain of practice; DC = domain of consequence.

can be momentary, whereas a growth network refers to change that is long-lasting and leads to professional growth.

A convenient, visual way to represent a growth network is by means of a network diagram [6]. We choose two of the teachers, Carrie and Lewis, to demonstrate this diagramatic approach. Figure 5 presents their growth networks, with solid arrows representing enaction and dotted arrows indicating reflection. We discuss these two cases further in the following section.

7.3 Evidencing lasting change

For change to be classed as "growth" there must be an indication of lasting effect in a teacher's practice or attitude, rather than a momentary thought or one-off action. Demonstrating change along multiple paths (as for the teachers in Figure 5) provides strong evidence of on-going, reflective reassessment and continuing experimentation likely to be associated with long term change and meaningful growth. Examining the rich, qualitative data from the interviews can provide further evidence on how the teachers' perceptions, beliefs and practice are changing and the likelihood of permanence in these effects. Using the two teachers for whom most change paths were observed (Carrie and Lewis) we present two case studies which illustrate the reasons they were coded as shown in Figure 5 and also demonstrate the level of reflection and continuing experimentation in practice indicative of lasting change.

Case study: Carrie

Carrie is a Computing coordinator in a primary school, with three years' experience of teaching. Her current class is a Grade 1 (Year 2) class, and in the next academic year her school was planning to give her a role as a specialist Computing teacher, teaching every year group. Carrie was mentioned in Section 6.2 and was looking at teaching computational thinking alongside literacy, with a focus on children with special educational needs. She had a first degree and a teaching qualification and did not have any prior experience of research. She was very enthusiastic about the project and presented at a local networking meeting in her area during the project.

The following comment from Carrie shows an enaction link from the ED to DP as she uses what she has learned in the TICE project to design her intervention and find a means of collecting data on the children's progress:

> *"We make our own rubric and adapt one that's already created at the moment and make it more appropriate for our age level of children and you try and use that to, sort of, formulate some numeric data."* (Carrie)

We can see that Carrie is also reflecting on the effect of the TICE project on her own personal beliefs and knowledge. In the following comment she reflects on the opportunity that she has had through the project (ED) to improve her understanding and way of thinking (PD):

> *"I personally like looking for different things and different avenues that I can do as a teacher to both improve my own understanding and the way of thinking. And I think that's really happened in this [project]."* (Carrie)

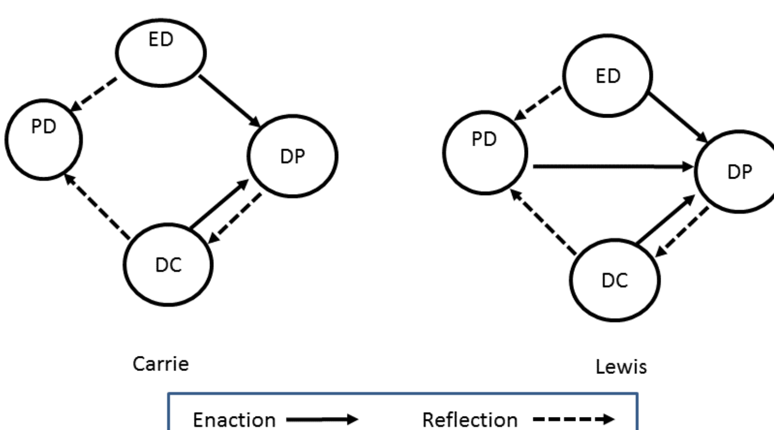

Fig. 5. Growth networks for Carrie and Lewis

The nature of the project is that it should enable teachers to reflect on the impact of their teaching, in other words, the salient outcomes or DC. Here Carrie reflects on what she has seen of the children's learning as a result of her intervention, and how this has subsequently had an impact on the way she is teaching other subjects. This is an enaction link from DC to DP.

> *"I think it's changed my own teaching because I've started using the aspects of the computer and the computational thinking and the debugging even, in the other curriculum subjects."* (Carrie)

Going in the other direction from DP to DC, this comment shows how in the process of the intervention, Carrie has thought about how she might extend what she does as a result of this current intervention. This is a reflection link:

> *"How different things cropped up and made us think about other things that we perhaps haven't initially thought of or different directions we could go in and sort of, just further research."* (Carrie)

Finally, we can see that Carrie is thinking about the consequences of the project (DC) and how it has impacted on her personal understanding.

> *"…myself as a teacher being more effective and mindful of different ways in which I can help children in my class learn."* (Carrie)

When discussing what she felt she had achieved through the project, Carrie was clear that her own personal beliefs had changed about ways in which she could help children in the class. This had impacted on her teaching too but we feel that there is an impact on her personal beliefs in this quote.

The five links exemplified here combine to form the growth network as depicted for Carrie in Figure 5. Levels of impact and engagement evidenced in the case study indicate the likelihood of more lasting change associated with professional growth.

Carrie worked with another teacher in the project and benefited from the sharing aspects as they worked together on the same topic in their different schools. The two teachers had never met prior to the project. Thus there is a social element to the consequences of this project that may not be addressed in the IMTPG. This is discussed in Section 7.5.

Case study: Lewis

Lewis had been teaching for six years at the time of the project; he was an ICT teacher prior to the change, so had been gradually learning and introducing the computer science elements of Computing into his teaching. In this, we look at Lewis's progress through the project, particularly focusing on six quotes from his video interview.

Lewis is very modest about his teaching ability in the topic he is researching (flowcharts and computational thinking). He has recently learned to teach Computing. This comment shows how his knowledge and understanding (PD) is being used in the domain of practice (DP) at the beginning of the project:

> *"I mean, if you asked me what it was a year ago, I would have struggled and I mean, I haven't studied it in any depth either. So I've only started to teach it and I could only really feel how it helps."* (Lewis)

Lewis relates how much more confident he feels about his teaching after carrying out the project and has gained an understanding of both the subject and how to teach it as a result of the project. This demonstrates the link from the outcomes of the project (DC) back to his knowledge and beliefs and also to his practice (DP). It also shows how his developing knowledge is impacting on his practice, so strengthens the link from PD to DP. This is a link that we did not see evidence of in Carrie's data.

> *"I would imagine that by the time I've written this up, I'll be, you know, on a moderate level, an expert on teaching flowcharts because I would have an informed opinion about, you know, what they're expected to get to or how far they get. "* (Lewis)

Lewis also considers how the project has helped him with his thinking about the teaching of Computing, and this topic in particular. Lewis looked very carefully at his data and coded interviews with students using a manual QDA system which made him really focus on his students' understanding. He reflects that without participating in this project, he would not be able to have done this:

> *"... being a teacher is a fast lane in life, so if you accept something, you must think about it deeply and you must read and code what they say. So once you've coded what kids are saying or, you know, what people have written, you're thinking quite deeply about it already ... So what I've learned is what they know about flowcharts."* (Lewis)

This comment shows that his personal understanding (PD) has been impacted by the project (ED). As well as the project and his intervention helping him to understand what the children know and understand, it has affected his teaching practice (DP):

> *"It's good to look at how a subject is settling in my student's minds because I never really know. If I set them some homework, I might mark that homework in a hurry ... so I wouldn't really think as deeply about what is going on upstairs as I would if I was researching it. "* (Lewis)

Having come to understand more about flowcharts, Lewis can see that they have potential for learning and thus we can see that the change in practice (DP) has links to the outcomes for students (DC):

> *"So I'm beginning to feel that it has potential to support learning computing and other subjects".* (Lewis)

Finally, Lewis reflects on the outcomes of his project (DC) and how, as a result, he now believes his topic has uses outside of his subject area:

> *"A positive surprise I had was once one of my learners came to me and said 'hey, guess what? I used the flowcharts in science. So we had to describe flow process and so I just started to draw a flowchart and it really helped me get it'. So that was a positive moment and I thought okay, maybe this does have potential to support learning outside my classroom as well."* (Lewis)

In Figure 5, we contrast the growth networks of Carrie and Lewis. In fact, they are very similar with the only difference being that Lewis has more evidence of applying his personal knowledge to his practice in his interview data. Both teachers can be seen to demonstrate growth networks and others do so also.

We know from following through with Lewis during the following year that he has now started to support other teachers by running professional development sessions and becoming a Computing At School Master Teacher. This gives us a longitudinal perspective on his developing learning after the project.

7.4 Other teachers

It is possible to draw growth networks or show change sequences for some of the other teachers, where those teachers were interviewed. In the project 11 of the 18 teachers completing were video-interviewed and we have shown the evidence that we obtained from the other 9 interviewed teachers in Figure 6. Three teachers, Wendy, Joachim and Leanne, worked together in a group investigating perspectives of computing amongst students of different ages and genders. Because

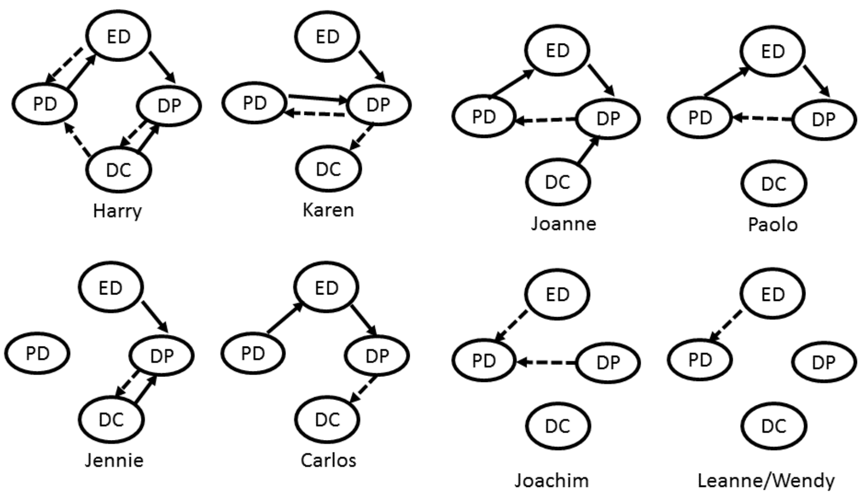

Fig. 6. Growth networks and change sequences from 9 other teachers interviewed during the project

they did not carry out a classroom intervention and were interviewed together in a group, there is limited evidence for the growth network from their data: as with the teachers that were not interviewed, it is not possible to draw out growth networks in more detail from the data. This does not necessarily mean that these teachers did not experience change from the project, but that we do not have data to evidence this.

7.5 Beyond the IMTPG

It can be seen that the IMTPG is a suitable tool to analyse this professional learning intervention. In a predictive way, we could predict that the TICE project would have an impact on both the practice of teachers but also the salient outcomes in the classroom. The analysis has demonstrated that this is the case and we have illustrated with two teachers in particular evidence beyond the growth networks described by Clarke & Hollingsworth.

There may be contexts where the IMTPG needs to be amended to describe the professional learning [41]. Voogt et al suggest that the domain of consequence be replaced by a domain of collaborative design in the context of their project on curriculum design as professional learning. However, this seems a specific change to support just one initiative and not applicable in our case.

Our study leads us to reflect whether the IMTPG does actually capture all the depth of this type of project sufficiently. In particular the project causes teachers to reflect on their professional learning in a meta-cognitive way. The interviews we held with them, and surveys, and conversations we held with teachers during the process, were intended to enable them to not just carry out their research projects and learn from it, but also to reflect on the usefulness of this activity. It may be that this produces another dimension to the model that could be a useful element of professional learning. Some other professional learning initiatives in computer science education do involve an element of reflection on the process [32, 34, 35] enabling teachers to reflect on their own learning. This may give a meta-cognitive link between the domain of consequence back to the personal domain that has not been captured in the IMTPG model; all professional learning programmes should encourage teachers to reflect on and, to some degree, self-regulate their own learning [4], and the model could perhaps be enhanced to include this additional dimension.

Another area that we were not sure was fully captured by the model is the social or collaborative element. As already stated, the work by Voogt et al indicated a need for an analysis that included a collaborative domain [41]. In their discussion of data supporting the IMTPG, Clarke and Hollingsworth discuss the benefits to professional learning being afforded by a community of colleagues [6], and we assume that this community appears as part of the external domain in their framework. However an enhancement of the model could be for this to be explicitly stated, as for some teachers in the TICE project, this was a crucial element that enabled them to be successful:

> *"I love the networking side of these things as well, so I've learnt a lot from different people from all over the UK which is quite nice."* (Paolo)

Many teachers made comments in the survey data about the value of sharing with other teachers. Where teachers worked together (there were two pairs and one group of three in our project, with all other teachers working on independent investigations) they all completed all aspects of the project and it could be that the shared commitment to their professional learning had an impact. Further, even the teachers who did not explicitly collaborate in their research project chose to involve colleagues in their school and for all, the aspects of working with like-minded others and networking were seen as major benefits. Harry, Paolo and Joanne all involved teachers in their school in their classroom research projects:

> "*Towards the end of the project when we did a little focus group of the class teachers that I'd worked alongside, they reported that they thought it had helped them to reflect on their practice as well*" (Harry)

This supports the case for recognition of a collaborative domain, although perhaps not sufficiently separate enough to form a fifth *networking* domain. As the model has roots in situated learning theory [25], the element of *community* can be expected to resonate throughout this representation of professional learning. The community of teachers working together can be empowering. One teacher commented in a survey response that "*the whole tone of the TICE project has made me feel that we have been empowered to advance Computing in Education - quite a unique opportunity*" (Leanne). This comment also suggests positive teacher identity within Computing [31].

8 LIMITATIONS OF THE PROJECT

There were several limitations to the way in which we carried out the project. Some of these are noted from our own observations, and others were highlighted in the feedback from teachers. In the project design, there was a trade-off to be made between time directly working with teachers and resultant commitment needed by teachers. We decided to ask for the teachers to attend for only two full days, as school leaders might not approve any more absence from school. Decisions made around the length and extent of the project were taken for practical and financial reasons, and it was clear that only two days was too limited an amount of time for some participants, who needed more support with honing down their research project and analysis of data. Some teachers were over ambitious with their research question, and collected too much data without a very clear focus. Analysing this data caused problems, even with the help of the university academics, and this was due to limitations of our project, not to the teacher. Another limitation of the project design was that of scalability, as the project involved a small number of teachers and thus had reduced impact.If the project were to be scaled up the online aspect would be much more important as communication with a larger number of teachers would not be easily facilitated by emails, phone calls and video conferencing. The online aspect of our project ran on a platform with which teachers were not familiar or regularly using, so it was not utilised as much as we had hoped; a future iteration of the project should include more consideration of what online environments teachers will readily use; and incorporate more investment into providing regular, relevant content for teachers and stimulating discussion.

Having identified the limitations discussed we are seeking the opportunity to run the project again with some amendments; we would make these recommendations to others who are inspired to carry out professional learning based around classroom-based research:

- Encourage more teachers to work in groups; we found that those teachers working together all continued with the project to the end and shared the data analysis between them.
- Spend longer working with teachers to clearly define their research question.
- Provide additional data analysis training before teachers carry out their intervention.
- Develop or signpost more accessible resources to support teachers
- Enhance online support for teachers between meeting days with relevant content and resources.

We believe that these changes would improve the initiative and give more support to the teachers. However the length of the project (one school year) was appropriate for the project, and the design of the output and our ideas for asking teachers to present their work at a teacher conference were positive aspects of the project that we would incorporate in any future version.

9 IMPLICATIONS FOR COMPUTING TEACHER PROFESSIONAL DEVELOPMENT

In this section we revisit the research questions first identified in section 5.1.

- *RQ1: How can teacher research impact Computing teachers' professional learning?*
- *RQ2: What are the key elements of a teacher professional learning programme based on classroom-based research?*

In terms of RQ1, we have used the IMTPG to demonstrate that teachers' involvement in teacher research can be seen to impact teacher change. The results of the project indicate that individual teacher's self-efficacy, opportunity to develop as a critical self-reflective practitioner, development of research skills, teaching aspects of Computing differently and engagement in further professional learning are positive outcomes for teachers from this project.

Teachers learned a range of new skills in terms of being able to plan and execute a small-scale research project, and their data shows that they gained an understanding of how children learn computing and ways in which deeper learning of computing can be facilitated. This makes it an important approach for computing professional development where teachers can develop an awareness of good pedagogical strategies. The IMTPG approach enables us to model this.

Since the project ended some teachers have shared with us developments in their careers: for example, Karen has become a teacher educator in Computing, Harry has signed up for a part-time professional doctorate and Lewis has become a CAS Master Teacher.

We have addressed RQ2 by the discussion of the structure of the project, including the organisational structure and timescale of the project, peer-to-peer support, supportive computer science education researchers acting as both face-to-face and virtual coaches and mentors allowed teachers to benefit from being involved in this project. Whilst there are some improvements that can be made, we hope that the insights provided would be useful for those who wish to implement a similar project.

10 CONCLUSION

Classroom-based research supports professional learning in an empowering way [22] and also has been seen to improve student outcomes [40]. In a domain where there has been a substantial recent focus on teacher professional learning in schools, there is a need to find approaches that have lasting and significant impact on student outcomes, and puts the control back in the hands of the teacher.

Our research questions set out to explore how teacher research impacts Computing teachers' professional learning and what key elements needed to be included in a teacher research professional learning programme. Aligning our data to a conceptual model of teacher change we have evidenced the ability of this approach to PL to affect the sustainable type of change captured as growth networks. The domains involved in the growth networks show the effects to be reaching the teachers' professional practice as well as their understanding of or attitude towards the subject. The links between the domains evidence both a high level of reflection and enaction. That these networks differ between participants demonstrates that the approach can enable teachers to develop in ways specific to their particular circumstances.

The suggestions given in the previous section outline practical ways (such as encouraging collaborative research and providing support at a further crucial stage) in which an action research approach could be tailored to be most beneficial to participants.

The TICE (Teaching Inquiry in Computing Education) project has been described as an approach to professional learning that can be used in computer science education to develop reflection and improved practice amongst computing education. In particular, this analysis has demonstrated that the TICE project has demonstrated lasting and effective change in participants. The IMTPG model has been a useful tool to explore how this has been achieved. There may be enhancements to the IMTPG that could be explored in future work around whether collaboration and meta-cognition could be better represented in the IMTPG.

ACKNOWLEDGMENTS

We acknowledge the support of Google and Computing At School in providing funding for this project.

REFERENCES

[1] Clem Adelman. 1993. Kurt Lewin and the Origins of Action Research. *Educational Action Research* 1, 1 (1993), 7–24. http://www.informaworld.com/10.1080/0965079930010102

[2] Neil CC Brown, Sue Sentance, Tom Crick, and Simon Humphreys. 2014. Restart: The resurgence of computer science in UK schools. *ACM Transactions on Computing Education (TOCE)* 14, 2 (2014), 9.

[3] Mary Burbank and Don Kauchak. 2003. An Alternative Model for Professional Development: investigations into effective collaboration. *Teaching andTeacher Education* 19 (2003), 499–514; 499.

[4] James Calderhead. 1987. The quality of reflection in student teachers' professional learning. *European Journal of Teacher Education* 10, 3 (1987), 269–278.

[5] Anne Campbell, Owen McNamara, and Peter Gilroy. 2004. *Practitioner research and professional development in education.* Paul Chapman, London.

[6] David Clarke and Hilary Hollingsworth. 2002. Elaborating a model of teacher professional growth. *Teaching and teacher education* 18, 8 (2002), 947–967. http://www.sciencedirect.com/science/article/pii/S0742051X02000537

[7] Louis Cohen, Lawrence Manion, and Keith Morrision. 2000. *Research Methods in Education* (5th edition ed.). Routledge Falmer, London.

[8] Stephen M. Corey. 1953. *Action Research to Improve School Practices.* Teachers College Press, New York.

[9] John W Creswell and Vicki L Plano Clark. 2007. Designing and conducting mixed methods research (1st & 2nd ed.). (2007).

[10] Christopher DeLuca, Jason Shulha, Ulemu Luhanga, Lyn M. Shulha, Theodore M. Christou, and Don A. Klinger. 2014. Collaborative inquiry as a professional learning structure for educators: a scoping review. *Professional Development in*

Education (Nov. 2014), 1–31. https://doi.org/10.1080/19415257.2014.933120
[11] David Ebbutt. 2002. The development of a research culture in secondary schools. *Educational Action Research* 10, 1 (2002), 123 – 142.
[12] John Elliott. 1991. *Action Research for Educational Change*. Open University Press, Buckingham.
[13] Michael Fullan. 2007. *The new meaning of educational change*. Routledge.
[14] Joanna Goode. 2007. If you build teachers, will students come? The role of teachers in broadening computer science learning for urban youth. *Journal of Educational Computing Research* 36, 1 (2007), 65–88.
[15] Thomas R Guskey. 1986. Staff development and the process of teacher change. *Educational researcher* 15, 5 (1986), 5–12.
[16] Susan Herbert and Marcia Rainford. 2014. Developing a model for continuous professional development by action research. *Professional Development in Education* 40, 2 (2014), 243–264. https://doi.org/10.1080/19415257.2013.794748
[17] David Hopkins. 1993. *A Teacher's Guide to Classroom Research*. Open University Press, Buckingham.
[18] Andrew P. Johnson. 2001. *A short guide to action research*. Pearson.
[19] Rosária Justi and Jan Van Driel. 2006. The use of the interconnected model of teacher professional growth for understanding the development of science teachers' knowledge on models and modelling. *Teaching and Teacher Education* 22, 4 (2006), 437–450.
[20] S. Kemmis and R. McTaggart. 1992. *The Action Research Planner* (third ed.). Deakin University Press, Geelong.
[21] Aileen Kennedy. 2005. Models of Continuing Professional Development: a framework for analysis. *Journal of In-Service Education* 31, 2 (2005), 235–250. http://www.tandfonline.com/doi/abs/10.1080/13674580500200277
[22] Joe L Kincheloe. 2012. *Teachers as researchers (classic edition): Qualitative inquiry as a path to empowerment*. Routledge.
[23] Desirae E. Krell and Nancy Fichtman Dana. 2012. Facilitating action research: a study of coaches, their experiences, and their reflections on leading teachers in the process of practitioner inquiry. *Professional Development in Education* 38, 5 (Jan. 2012), 827–844. https://doi.org/10.1080/19415257.2012.666052
[24] Udo Kuckartz. 2014. *Qualitative text analysis: A guide to methods, practice and using software*. Sage.
[25] Jean Lave and Etienne Wenger. 1991. *Situated learning: Legitimate peripheral participation*. Cambridge university press.
[26] Jane Margolis, Jean Ryoo, and Joanna Goode. 2017. Seeing Myself through Someone Else's Eyes: The Value of In-Classroom Coaching for Computer Science Teaching and Learning. *ACM Transactions on Computing Education (TOCE)* 17, 2 (2017), 6.
[27] Philip Mayring. 2000. Qualitative Content Analysis. *Forum of Qualitative Social Research* 1, 2 (Jun 2000).
[28] Jean McNiff. 2002. *Action research for professional development : Concise advice for new action researchers*.
[29] Muhsin Menekse. 2015. Computer science teacher professional development in the United States: a review of studies published between 2004 and 2014. *Computer Science Education* 25, 4 (Oct. 2015), 325–350. https://doi.org/10.1080/08993408.2015.1111645
[30] Briana B. Morrison, Lijun Ni, and Mark Guzdial. 2012. Adapting the Disciplinary Commons Model for High School Teachers: Improving Recruitment, Creating Community. In *Proceedings of the Ninth Annual International Conference on International Computing Education Research (ICER '12)*. ACM, New York, NY, USA, 47–54. https://doi.org/10.1145/2361276.2361287
[31] Lijun Ni and Mark Guzdial. 2012. Who Am I?: Understanding High School Computer Science Teachers' Professional Identity. (2012), 499–504. https://doi.org/10.1145/2157136.2157283
[32] Lijun Ni, Mark Guzdial, Allison Elliott Tew, Briana Morrison, and Ria Galanos. 2011. Building a Community to Support HS CS Teachers: The Disciplinary Commons for Computing Educators. In *Proceedings of the 42Nd ACM Technical Symposium on Computer Science Education (SIGCSE '11)*. ACM, New York, NY, USA, 553–558. https://doi.org/10.1145/1953163.1953319
[33] Gerald Pine. 2009. *Teacher Action Research*. Sage Publications.
[34] Jean Ryoo, Joanna Goode, and Jane Margolis. 2015. It takes a village: supporting inquiry- and equity-oriented computer science pedagogy through a professional learning community. *Computer Science Education* 25, 4 (Oct. 2015), 351–370. https://doi.org/10.1080/08993408.2015.1130952
[35] Sue Sentance and Andrew Csizmadia. 2017. Professional Recognition Matters: Certification for In-service Computer Science Teachers. In *The 48th ACM Technical Symposium on Computing Science Education*. Association for Computing Machinery. DOI: 10.1145/3017680.3017752.
[36] Sue Sentance, Simon Humphreys, and Mark Dorling. 2014. The Network of Teaching Excellence in Computer Science and Master Teachers. ACM.
[37] Norman A Sprinthall, Alan J Reiman, and Lois Thies-Sprinthall. 1996. Teacher professional development. *Handbook of research on teacher education* 2 (1996), 666–703.

[38] Josh Tenenberg and Maria Knobelsdorf. 2014. Out of our minds: a review of sociocultural cognition theory. *Computer Science Education* 24, 1 (Jan. 2014), 1–24. https://doi.org/10.1080/08993408.2013.869396

[39] David Thompson and Tim Bell. 2013. Adoption of new Computer Science High School Standards by New Zealand teachers. In *Proceedings of the 44th SIGCSE technical symposium on Computer science education (SIGCSE '13)*. ACM.

[40] Helen S. Timperley, Judy M. Parr, and Cherry Bertanees. 2009. Promoting professional inquiry for improved outcomes for students in New Zealand. *Professional Development in Education* 35, 2 (Jan. 2009), 227–245. https://doi.org/10.1080/13674580802550094

[41] Joke Voogt, Susan McKenney, Fred Janssen, Amanda Berry, Wendy Kicken, and Fer Coenders. 2012. A framework for studying teacher learning by design. (2012).

[42] Richard Winter. 1989. *Learning from experience: Principles and practice in action-research.* Falmer, New York.