An evaluation of a professional learning network for computer science teachers

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Abstract

This paper describes and evaluates aspects of a professional development programme for existing CS teachers in secondary schools (PLAN C) which was designed to support teachers at a time of substantial curricular change. The paper's particular focus is on the formation of a teacher professional development network across several hundred teachers and a wide geographical area. Evidence from a series of observations and teacher surveys over a two-year period is analysed with respect to the project's programme theory in order to illustrate not only *whether* it worked as intended, by *why*. Results indicate that the PLAN C design has been successful in increasing teachers' professional confidence and appears to have catalysed powerful change in attitudes to learning. Presentation of challenging pedagogical content knowledge and conceptual frameworks, high-quality teacher-led professional dialogue, along with the space for reflection and classroom trials, triggered examination of the teachers' own current practices.

Keywords

Computer science education

teacher education

professional learning

Introduction

Many countries in the world are moving towards, or have already adopted, Computer Science (CS) as a compulsory secondary school subject, for example England, Australia, New Zealand, and Finland. This shift from optional to required school subject necessitates the education of a vastly increased body of CS teachers. The U.S., for example, has the CS10K initiative which aims to train 10,000 CS teachers by the end of the decade. There is also a requirement for existing CS teachers to embrace the inevitable increased breadth of student motivation and ability as they shift to teaching all school pupils rather than only those who self-select to take the subject.

Existing CS teachers identify two key areas that would improve their practice. First, they report that the vast majority of CS teachers are *singletons* in their school, with no other immediate CS teachers with whom they can share experiences and practice (Yadav, Gretter, & Hambrusch, 2015). Those who have experienced regular connection with other CS teachers recognise the huge value of a teacher network (Ni, Guzdial, Tew, Morrison, & Galanos, 2011). This focus on teacher networks is being modelled in larger programmes, such as the Exploring Computer Science programme in the U.S. (Goode, Margolis, & Chapman, 2014) and the Computing At Schools hub network in the U.K. (Sentance, Humphreys, & Dorling, 2014). Second, teachers note a general lack of subject-specific teacher preparation (Yadav et al., 2015). They are often teachers from another subject, e.g. mathematics or business studies, who are self-taught in CS content, and/or who have learned how to teach the subject by trial and error in the classroom. Alternatively, they may have been teaching CS for many years and due to the paucity of subject-specific professional development opportunities, they may not be aware of advances in methods of teaching CS. In both cases, existing teachers lack the opportunity to pick up crucial pedagogical content knowledge (PCK) (Shulman, 1986) to enhance their practice over time.

This paper evaluates aspects of a professional development programme for existing CS teachers in secondary schools that attempts to address these problematic issues. The paper's particular focus is on the formation of a teacher professional development network across several hundred teachers and a wide geographical area. The programme, Professional Learning and Networking in Computing (PLAN C) has been running in Scotland since 2014, with the aim of providing professional development for teachers across the whole country.

The paper is structured as follows: the next section presents themes in teacher professional development that underpin the PLAN C design. This is followed by an overview of the Scottish CS

educational context within which PLAN C is embedded, and then an outline of the structure of the PLAN C programme. The paper principally presents an evaluation of the PLAN C design's ability to support the creation of a teacher network to promote professional dialogue and reflection. Hence, a logic model capturing the intended set-up, operation and outcome of the network is presented next, followed by the evaluation methods, results and discussion.

Professional learning for teachers

The design of the PLAN C professional development programme draws on three themes, developed below, concerning successful teacher professional development. Meta-reviews that have looked at hundreds of studies into teacher professional development are reporting remarkably similar findings that concentrate on the importance of these themes, e.g. (Cordingley, 2015; Guskey & Yoon, 2009). All three aim to deliver on the central purpose of professional development, that is, to positively influence the practice, attitudes and understanding of teachers with the ultimate goal of improving student learning outcomes.

(1)

Early experience of improved classroom outcomes. Guskey (2002) argues that the desirable long-term professional development goal of changing teachers' attitudes and methods begins with teachers trying out new teaching methods embodying the new understanding about learning. If these trials produce improved classroom outcomes, then teachers' attitudes begin to shift, and a dialogue can ensue about the detail and underpinning of the new methods. This approach draws on the realisation that teachers are *pragmatically* motivated to undertake professional development – they are looking for practical ideas that will improve student learning, a key marker of teacher success (Harootunian & Yargar, 1980 as referenced in Guskey, 2002). In Guskey's model, longitudinal professional development over repeated sessions is essential, since the change in attitudes does not happen on first exposure to the new ideas, but only after successful experiences in the classroom and subsequent reflection.

(2)

Providing a catalyst to promote change in teaching philosophy. Richardson (1990) notes the problem of externally driven professional development activities, suggesting that the externality causes a level of resistance to change among teachers. Nonetheless, professional development typically intends to promote a specific change in practice, usually driven by research results, that is viewed as beneficial to the profession. This external agenda for driving change can conflict with teachers' experience of relative autonomy and reflective practice within their classrooms. A teacher's classroom experience gives a level of practical knowledge, or PCK, against which any new teaching situation can be assessed and action chosen. This PCK is more generally useful than any specific new behaviour that a traditional professional development programme might intend to instil. However, both Schon and Shulman indicate that such experience on its own is not enough: *reflection* on experience is required in order to generate improvement (Schon, 1982; Shulman, 1986). Richardson's specific point is that professional development, the external agenda, can provide the catalyst for that reflection. The teachers have their personal PCK and their philosophy of teaching and learning; the empirical findings underpinning the research being presented in the professional development form a "warranted

practice" that demands to be considered. With appropriate facilitation, reflective conversation is then possible, evaluating personal philosophy and knowledge against the warranted practice, which can provide sufficient impetus to initiate the desired change in attitudes. This model incorporates the recurring finding in studies of professional development that *expert input* is required (Cordingley, 2015).

(3)

Professional learning via *teacher-led groups*. The provision of professional learning in small teacher-led groups that meet regularly, as opposed to one-off full-day or multi-day professional development events, is recognised as best practice (Wilson & Berne, 1999). For example, a national report into teacher development in Scotland recommended this approach (Donaldson, 2011), as well as a study into CS teacher professional development needs (Yadav, Gretter, Hambrusch, & Sands, 2016). One existing model for developing these groups is the *Disciplinary Commons*, which promotes learning through rich dialogue between a group of practitioners, based on their teaching experience and artefacts brought from classrooms (Tenenberg & Fincher, 2007). While the Commons model was initially trialled with university academics, Morrison, Ni and Guzdial (2012) have set up a series of Commons groups of school CS teachers, meeting 8–9 times at monthly intervals during an academic year. The teachers involved reported a wide range of benefits including increased levels of confidence as CS teachers, the promotion of reflection on their teaching practice, sharing and adoption of new ideas and materials from peers, heightened motivation to improve practice and increased student enrolments in their classes.

These three themes can be combined into an approach to teacher professional development in a subject such as CS, where there are numerous research results emerging in the CS education literature that the majority of CS teachers will never have encountered. Furthermore, the research may represent a challenge to their practice and philosophy. One example is a focus on code comprehension (Schulte, Clear, Taherkhani, Busjahn, & Paterson, 2010) and notional machine understanding (du Boulay, 1986), which requires a teacher to rethink their approach to developing programming skills in learners. Within a small teacher professional development group such topics could form the catalyst advocated by Richardson, as a form of the essential expert input highlighted by Cordingley, which is discussed in the group in light of personal experience, thereby providing sufficient motivation for teachers to try out provided classroom-ready materials, as advocated by Guskey. The success or otherwise of these materials in practice would be a topic for deeper reflective discussion in one or more subsequent meetings of the group.

This combined approach lies at the heart of the PLAN C programme to set up a national network of teacher professional development groups in Scotland.

The Scottish CS educational context

While around 70% of Scotland's 5.5 million inhabitants are concentrated in a 100 by 50-mile belt, much of the remainder is very spread out, representing a challenge for building face-to-face teacher communities. CS has been taught in Scottish secondary schools for around 30 years, initially focussing

on programming and computer architecture, before a shift in emphasis towards teaching general ICT skills in the 1990s. Many early CS teachers transferred over from other subjects, with limited retraining. There are now around 640 practising CS teachers across 420 secondary schools.

A minimum requirement for content knowledge for applicants who wish to study computer science teaching is the equivalent of one-third of the content of the first two years of a CS degree. This means that there is a wide variation in levels of content knowledge between those teachers with a full CS degree, those with only the minimum qualifications, and those whose experience may have come from industry or retraining many years ago. Strikingly, by comparison with other subjects, new teachers have typically received very little training in *subject-specific* pedagogy.

The impetus for the PLAN C project forming the focus of this paper is a redesign of the three national qualifications for 16–18 year olds, named National 5, Higher, and Advanced Higher. This redesign was initiated in 2010 with the first running of the National 5 course in academic year 2013/2014. The qualifications focus more firmly than their predecessors on the development of sound computational thinking skills using programming languages and database/web systems. The increased difficulty of the courses represented a challenge to teachers' content knowledge and PCK in order to deliver the courses successfully, resulting in the Scottish Government's decision to fund the PLAN C project.

PLAN C – the professional learning and networking in computing project

The original goal of the PLAN C project was to provide ongoing professional learning for practising CS teachers across the whole of Scotland, significantly enhancing practice and consequently learning outcomes. The project was led by two of the authors as project officers who were employed part-time, alongside their existing jobs as university academic (QC) and school teacher (PD). As outlined above, the steady state was planned to be a network of local teacher communities, or hubs, meeting regularly, with research-oriented input and associated teaching materials acting as a focus for reflective discussion, both before and after their use in classrooms. Getting to this steady state was achieved in a number of stages, as follows.

(1)

Asking teachers what they wanted in the programme. Using an online questionnaire, teachers were asked to identify the most pressing development needs. The strongest response was for improvements in teaching methods appropriate for CS, rather than the more typical CS professional development training in the use of particular technologies, e.g. a new language. In this questionnaire, teachers were also invited to be a lead teacher. Appropriate ethical procedures for collecting data were followed at this point and throughout the programme, including explaining how their data would be handled, how care would be taken to ensure no individual would be identifiable in any write-up, and how they could withdraw from the study. This enabled them to give informed consent for their data to be used.

(2)

Identification of lead teachers. Fifty lead teachers were recruited from most areas of Scotland. These teachers were self-selecting, with no formal assessment/interview. The lead teachers, usually in pairs, set up a local teacher hub in their area and then led the meetings of the group, by introducing the local teachers to the research and related teaching materials, and facilitating high-quality discussion around the topics and the teachers' experiences.

(3)

Lead teacher training. The format of this training aimed to give the lead teachers an experience of a Disciplinary Commons-like environment it was hoped they would set up in their local teacher hubs, although in necessarily rather accelerated form. To do this, a sequence of the Richardson-inspired research-led catalysts were developed, along with associated classroom-ready materials as advocated by Guskey. These were delivered in a sequence of four sessions held across a 6–9 week period, consisting of a 1.5-day session at the start and end and two single days in the middle, each session separated by 2–3 week intervals. The longer sessions included a meal in the evening to implicitly underline the importance of developing strong connections between the participants. In-line with one of the author's prior experience of providing successful teacher professional development (Cutts, Brown, Kemp, & Matheson, 2007), a new topic was introduced with only brief exposition at the front of the group, immediately followed by the lead teachers acting as a classroom of pupils, trying out the classroom-ready materials. This hands-on experience, while not the same as trialling in an actual classroom, did at least give teachers an immediate insight into the materials and how they might be used, and provided a foundation for discussion of the concepts involved, and a comparison with teachers' existing practice. Such trialling is noted as a stand-out characteristic of effective workshop-based professional development (Guskey & Yoon, 2009). The extended duration of the training gave teachers an opportunity to try out the materials in between sessions and to report on their experience in later sessions. Lead teachers were also given research papers to read and/or activities to undertake prior to each session. The four-session sequence was run three times in different parts of the country, staggered over a period of around six months, allowing the project officers to incrementally improve the materials.

(4)

Preparation of local hub materials. The project officers further developed the presentations and classroom-ready materials used in the lead teacher training so that they could be used by the lead teachers in their local hubs. These teaching materials, along with copies of the research papers, were provided via a Moodle VLE site to which the lead teachers had access.

(5)

Promoting the local hubs. Promotional materials were developed and with the aid of Scottish Government were sent to the director of education in each of the 32 local authority areas in Scotland as well as to the CS department in every secondary school, and also posted on a widely read CS teacher on-line forum. These materials identified the locations of 25 local teacher hubs that were set up across the country. Teachers could register online to indicate their interest in attending a particular hub.

(6)

Running the local hubs. In most cases, pairs of lead teachers led local hub sessions, modelling the leadership they had experienced in the lead teacher training sessions. The lead teachers typically met some days prior to a session to familiarise themselves with the materials

provided online by the project officers, to decide who would lead which session. Attendance at the sessions was recorded for evaluation purposes and also to be able to award certificates to teachers attending at least a given proportion of all the sessions offered. The project officers were available online to answer queries about the materials or running the local hubs, and set the intention to speak to all lead teachers in between their local hub meetings, although in practice this was hard to achieve.

(7)

Recall days. The project officers ran annual recall days for the lead teachers, bringing them together to both reflect on the operation of their local hubs, and to provide additional material for use in the local hub sessions.

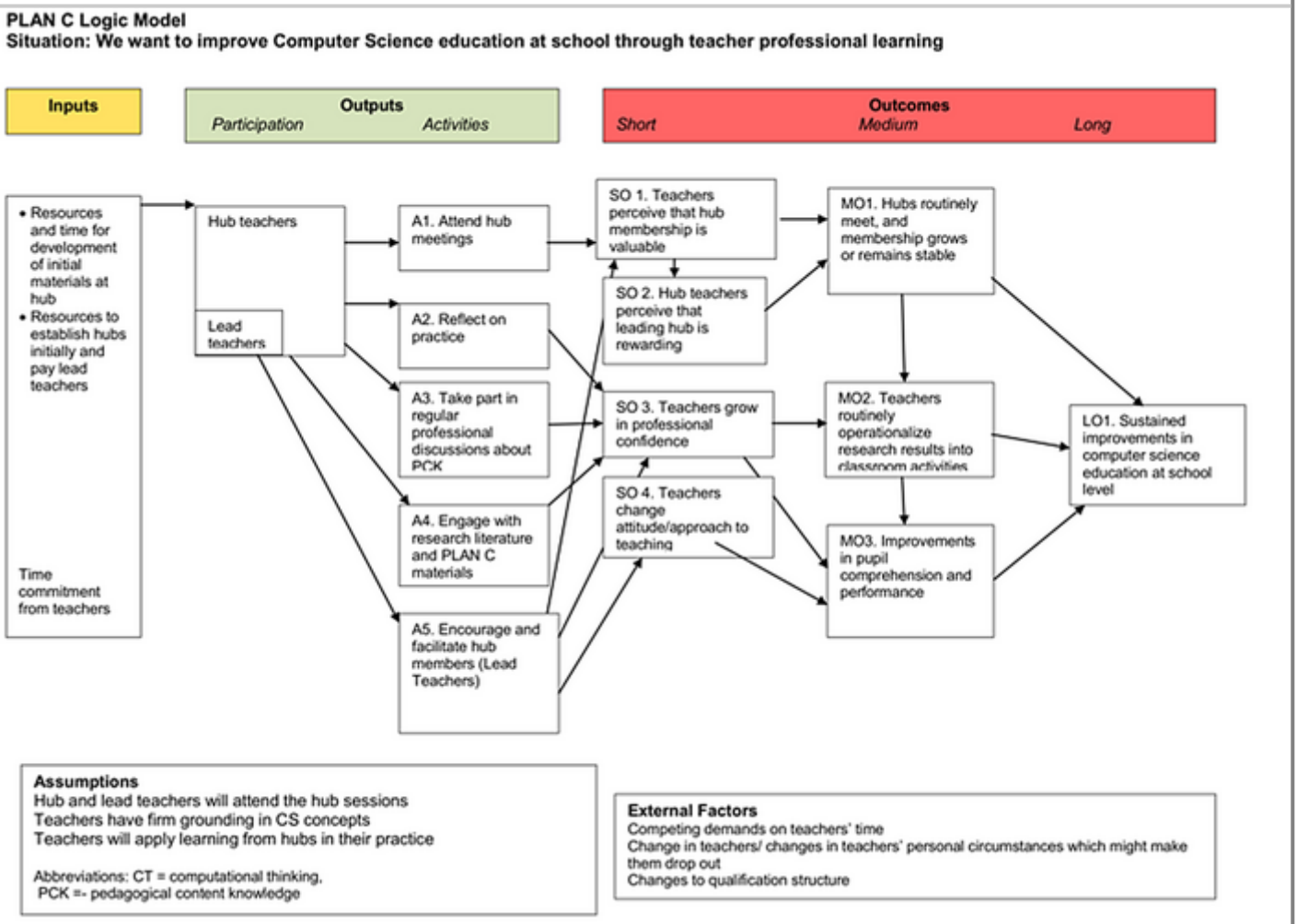
The sequence of topics covered in the lead teacher training and local hub sessions focussed particularly on: the various dimensions of the Block Model of code comprehension (Schulte, 2008), including surface characteristics and notional machine understanding (du Boulay, 1986); attitudes to success in learning CS (Cutts, Cutts, Draper, O'Donnell, & Saffrey, 2010); on increasing the opportunities for learners to articulate their understanding of CS concepts particularly via Peer Instruction (Crouch & Mazur, 2001; Simon & Cutts, 2012); on the importance of eliciting PCK for CS (Shinners-Kennedy & Fincher, 2013; Shulman, 1986); on the identification of alternative conceptions in CS (Pea, 1986; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013); and on the use of variable roles (Sajaniemi & Kuittinen, 2005), worked examples (Song, 2015; Sweller, 2006) and sub-goal labelling (Margulieux, Guzdial, & Catrambone, 2012) to develop pupils' problem-solving skills. While programming was the primary vehicle for delivering these topics, the topics themselves are relevant to the learning of any computer system involving a language of instruction and an underlying computing engine, such as database and web systems. These connections were regularly made and specific materials sometimes provided for teaching in these alternate contexts.

Logic model for the PLAN C design

In evaluating the formation of the PLAN C CS teacher professional development network, we have drawn on the programme theory approach which characterises social interventions by their underlying theory of change, and evaluates the proposed causal links in the intervention against the observed impacts (Funnell & Rogers, 2011). This paradigm is commonly used for evaluation research in complex social settings including education and professional development. The purpose is not merely to determine *whether* an intervention works, but *how* and *why*. The programme theory for PLAN C is that sustained improvements in computer science education can be brought about by a carefully designed model for professional learning which emphasises the importance of (a) applying research findings to practice as a catalyst for professional change, (b) reflective practice and (c) peer support through high-quality professional dialogue in teacher-led groups. The proposed mechanisms for change are represented as causal links in the logic model shown in Figure 1. Having clearly described the

pathways by which we expect PLAN C to promote change, in the next section we evaluate these pathways to establish which aspects of the programme theory worked as intended and why.

Figure 1. Logic model for PLAN C project.



The inputs to PLAN C were funding to give the project officers time to develop initial materials and lead workshops with the lead teachers. Lead teachers were also paid for their time to run their hubs. The activities for teachers which were intended to lead to improvements in CSE were attending hubs – with the support and encouragement of the lead teachers – at which they would engage with research literature, participate in high-quality professional dialogue, and reflect on how the new materials they tried would change their practice. Short-term indicators of the success of the project would be that the teachers would value the hub sessions (because of early experiences of improved classroom outcomes and the supportive atmosphere of the hub) and that lead teachers would find their role rewarding. Taken together, these would lead to the medium-term outcome of a set of sustainable hubs. Participating in the hub activities would lead to the short-term outcomes of a growth in professional confidence and changes to teaching attitudes and approaches. After a period of trying new teaching approaches, and the increase in confidence from reflection on these new approaches with the support of the hub members, in the medium-term (after a period of around 2 years) teachers would be expected to be routinely incorporating research results (and other resources developed through their hubs) into their classroom

activities. Changes in teacher attitudes to learning, increases in teacher self-efficacy and positive outcome expectations and new classroom activities should lead to improvements in pupil comprehension and performance. The medium-term outcomes are intended to lead to sustained improvements in CSE at school level in the longer term (i.e. over a period of several years).

Evaluation

The purpose of the evaluation was to establish whether the causal links in the programme theory worked as anticipated, and why. As changing the educational outcomes for a discipline across a nation is a process which necessarily takes time, we are not yet in a position to evaluate the long-term outcomes, and data is limited for the medium-term outcomes. In particular, we have focussed on teachers' perceptions of improvements to learners' comprehension and performance rather than using assessment data. This is appropriate to the present analysis because the teachers' evaluation of their learners is part of the causal model. However, we intend to collect learner performance data for future analysis.

Data collection

Table 1 shows the data sources used in this paper, including information about when the data was collected, the format, the number of respondents and the purpose of collecting it. The aspect of the logic model which each data source was intended to address is documented. Data were gathered to evaluate each activity, and short- and medium-term outcome proposed in the logic model. The data are primarily qualitative, in the form of written survey responses from lead teachers, reflections and observations from one of the authors who is an experienced evaluator of learning and teaching in schools (LO'D), and online survey responses from hub and lead teachers. Quantitative attendance records were also gathered. The questions for the surveys, and further information about the observations and reflections can be found in the supplementary materials.

Table 1. Data collection summary.

Source	Dates	Event	Data collection	Respondents	Purpose	Logic Model
1	Feb 2014	Lead teacher hub training	Survey (paper, completed at event)	20	Record lead teachers' perceptions of: (a) effectiveness of PLAN -C	SO2
						SO3
					(b) changes to their approach to teaching CS	MO2
						MO3
2	March 2014	Lead teacher hub training	As above	4	As above	As above
3	May/June 2014	Lead teacher hub training	As above	15	As above	As above

Source	Dates	Event	Data collection	Respondents	Purpose	Logic Model
4	September 2014–January 2015	Observations from hub meetings	Notes written by expert evaluator of learning and teaching	Observations of 18 sessions in 10 different hubs	To evaluate the quality of the professional discussion at hub meetings	A2, A3, A4, A5
5	November 2014	Reflections on observations	Reflections from expert evaluator of learning and teaching	1	To gain perceptions of an experienced teacher educator about the hub meetings	A2, A3, A5, SO3
6	June 2015	Online survey	Online survey to 257 hub participants across 23 hubs. Survey open for 10 days	65 (25% response rate)	To gather teachers' feedback on particular PLAN C activities and research papers	A4 SO1
7	June 2015	Recall day for lead teachers	Paper survey	35 teachers from 23 hubs	Evaluate the quality of professional learning at PLAN C	SO2 A5
8	October 2015	Final report to funder	Secondary data source	1	To gain perceptions of an experienced teacher educator about the project overall	MO1, MO2, MO3
9	May 2016	Recall days for lead teachers	Paper survey	20	To gather teachers' perceptions of impact on pupils, and on own teaching practice	SO3 MO3 MO2
10	Annual	Hub attendance records	Supplied to project administrator by lead teachers	Records from all hubs	To gather data on attendance at hub sessions and how this changes over time	A1, MO1

The paper surveys were completed on paper at the end of training and recall days for lead teachers. This was administered by QC (CSE researcher) and PD (computing teacher), who delivered the training. The online survey was administered by LO'D. He also wrote the observation notes and reflective reports.

Qualitative data analysis was performed by JR (CSE researcher), who was not involved in the project delivery or data collection. Thematic analysis (Hayes, 2000) was used to analyse the data sources under the headings of each activity, short- and medium-term outcomes in the logic model. Care was taken to look for negative evidence as well as positive and include this in the reporting of results. To facilitate this, each coded statement in the data-set was also coded with "positive" or "negative" and the proportions of positive to negative statements are reported in each section. Each quote in the results presented before is identified with the number of the data source form which it was taken (see Table 1).

Results

Activities

A1 and MO1: hub attendance

PLAN C began in academic year 2013/2014. There are approximately 640 computing teachers in Scotland. Of those, 430 registered interest in PLAN C online. At the end of academic year 2015/2016, 320 teachers had attended at least one session and 163 teachers have been certified (by attending at least 10 sessions). Hub membership figures are shown in Table 2.

Table 2. PLAN C membership and attendance figures.

	AY 2014/15			AY 2015/16			
Hub ID	Current status	Sessions held	Participants attending	Teachers attending >30% of sessions	Sessions held	Participants attending	Teachers attending >30% of sessions
LH1 (Rural)	Inactive	6	13	7	0	0	0
LH 2 (Rural)	Active	6	7	7	10	7	6
LH 3	Dormant	9	18	12	0	0	0
LH 5 (Rural)	Inactive	0	0	0	0	0	0
LH 6	Active	9	16	10	8	15	11
LH 7(Rural)	Inactive	1	5	5	0	0	0
LH 8 (City)	Active	10	6	6	6	6	6
LH 9	Active	9	15	6	10	8	7
LH 10	Active	10	18	8	9	6	6
LH 11	Active	10	17	11	9	13	7
LH 12	Inactive	2	4	4	0	0	0
LH 13	Active	9	13	12	9	–	–
LH 14	Active	10	13	8	8	14	9
LH 15	Dormant	4	13	7	0	0	0
LH 16 (City)	Active	8	15	11	3	–	–
LH 17 (City)	Active	4	12	5	4	4	4
LH 18	Inactive	3	14	6	0	0	0
LH 19	Inactive	9	7	5	0	0	0
LH 20	Active	8	11	6	7	7	4

	AY 2014/15			AY 2015/16			
LH 21 (City)	Active	9	28	16	7	–	12
LH 22 (City)	Active	7	14	7	9	11	11
LH 23	Active	9	19	10	9	–	–
LH 24	Active	7	14	11	9	11	10
LH 26 Borders	Active	7	6	5	8	7	–
LH 27 (Rural)	Active	7	9	6	8	13	8
LH 28	Dormant	7	5	4	0	0	0
LH 29 (City)	Active	3	8	7	3	11	9
Average per hub		7	12	7	5	6	5
Totals	18 Active	183	320	202	136	143+	110+
	4 Dormant						
	5 Inactive						

Note: “dormant” refers to hubs where the lead teacher has indicated to the PLAN C administrator that the hub will resume in the future.

In June of the second academic year of the project, around two-thirds of the hubs were still active. Nine are either dormant (the lead teacher intends to resume them in the next academic year) or inactive. LH1 became inactive when the lead teacher left his school, and LH7 was intended to be a video conference hub but encountered technical difficulties. The average number of sessions reduced from 7 in the first academic year to 5 in the second. The average hub attendance figures halved between the first and second years (although less complete data on attendance was provided by hub leaders in the second year). Interestingly, the proportion of teachers attending at least 30% of the sessions increased in the second year from 63 to 75%. This suggests that the hubs have stabilised into a more stable core membership.

A2. Reflection on practice

Evidence from the observation notes [Source 4] indicates that the professional discussions during hub sessions engaged the teachers in reflective practice. Forty-two statements were coded as positive examples of reflection on practice, and five were negative. Comments which were critical of the PLAN C materials but which indicated reflection on teaching were coded as positive, whereas comments

which suggested the mechanisms for reflection on the course were lacking, or which were critical of the project in general were coded as negative. For some teachers, PLAN C appears to have triggered profound reflection and changes to their practice. Experienced teachers welcomed the introduction of new ways of thinking to prevent them from "getting set in their ways", writing of the enthusiasm and motivation this provoked. A long serving teacher wrote "It has made me think more about my practice than anything else I have done in my career" [Source 7].

The materials about more controversial topics prompted some critical reflection to attempt to resolve research recommendations with classroom experience, e.g. the session on variable roles "seemed to add an extra layer of complication and restricts the view of what variables can do. … if teachers find it confusing, pupils may be even more confused". [Source 6]. This kind of comment, which is not uncommon in the wider teacher survey, is encouraging because it indicates that teachers are not unquestioningly adopting the new materials in their own practice. However, the reflections on the observation sessions note that PLAN C is "building a respect for research evidence that is grounded in the kind of authentic classroom practice that teachers can relate directly to their own experience" [Source 8].

A3. Professional discussion

According to the reflections on observations, there was a high standard of professional conversation with "teachers reflecting on their classroom practice, questioning how their students' learning could be improved and sharing ideas with each other" [Source 5]. There were 44 statements coded as indicating positive instances of professional discussion, and 4 negative. Those which were coded as negative included examples where the observer or participant noted that the discussion was irrelevant or poorly managed. Examples of discussion topics at the observed hub meetings included: laying the proper foundations from the beginning; how to share resources to avoid "reinventing the wheel"; what makes a good Peer Instruction session and when best to use it; what we expect pupils to be able to understand before they can start to code meaningfully; and question design and difficulty in constructing wrong answers that provide meaning feedback on student understanding/conceptions [Source 4].

The teachers welcomed the professional discussions and the opportunity to learn from others' experiences. One teacher described how it was useful to "discuss your thoughts with others to clarify different aspects of a particular area rather than muddle through" [Source 1]. Echoing Guskey, another felt that reflection on practice would enable him to get more from the discussion sessions: "I would like to be able to use some of the activities and accompanying forms used in the hub sessions to be able to discuss PCK topics at a deeper level than at present". It was considered by several participants that the format of discussion structured around particular topics and activities enabled "less room for 'subject moan' without solutions" [Source 7], an issue also highlighted by Richardson (1990).

A4. Engagement with research

The online survey posted to all teachers in June 2015 [Source 6] specifically asked whether the respondents had read the research papers: 54% of them had done so. The lead teachers often commented that they felt it was their responsibility to read all of the recommended papers, although some ordinary hub members had also done so. There were 30 statements about engagement with research which were coded as positive and 6 coded as negative. Positive statements were related to individuals' positive perspective on how the research they learned about at the hubs related to their teaching, or observations in which research material was successfully incorporated into hub meetings. The negative comments were from individuals about the research not being of value or unsuitable in some way for classroom use.

The comments from lead teachers indicate that in the main, the teachers welcomed the emphasis on research informed practice, e.g. "I am now more aware of recent research evidence in Computing Science Education". [Source 1]. Indeed, one teacher pointed out that it is difficult to gain access to research papers in the normal course of his job. The perceived benefits of engaging with research included "insight into barriers that could prevent learning as well as teaching methods that could aid understanding". [Source 2] And the opportunity to "allow me to evaluate my practice in light of academic research" [Source 7], exactly as predicted by Richardson. Research was seen as something AQ2 "which can confirm our 'instincts' and also prompt reflection and change" [Source 9], again echoing Richardson. The knowledge that the new approaches they were trying were based on research appeared to give some teachers confidence.

However, it should be noted that not all of the teachers valued research. One lead teacher reported that "Academic research was of no interest to my hub members" [Source 7]. Another teacher wrote "some members felt that too much of the content was high-level theory and not enough materials to be readily used in lessons" [Source 7].

A5. Hub facilitation

According to the reflections on observations, the "vast majority" of the sessions were "led effectively and met the aims of PLAN C" [Source 8]. There was a variation in the skills of the lead teachers from those whose delivery was similar in quality to the expert teacher in the PLAN C team to those who needed "quite a lot of support to get across the key messages behind PLAN C" [Source 8]. The small number of sessions which in the view of the expert evaluator of teaching and learning fell short of the expected standard could have been improved with more confidence from the lead teachers, and more time for them to prepare the session.

The lead teachers considered that there is much "commitment … required to run our hubs" [Source 7]. Of the statements coded as relating to encouraging and facilitating hubs, 17 were positive and 16 were negative. The teachers perceived their roles and responsibilities to include building confidence in

their colleagues and encouraging them to try new things, assisting them to find resources and sharing their own deep knowledge from courses with other teachers.

The delay in materials being made available to lead teachers by the PLAN C project team was mentioned by a number of participants, and is the main type of negatively coded statements in the data. This is important because, as identified in the reflections on observations, the materials on more complex topics worked best when the leader teachers found the time to use them in their own classes first and "could therefore speak authoritatively from direct experience rather than relying on research" [Source 8].

It was common for the lead teachers to comment on the value of sharing the running of a hub with a colleague. Observations confirmed this as a single teacher leading a hub found it difficult to sustain a regular pattern of meetings because of workload [Source 3].

The lead teachers also spoke of the barriers they encountered. One said that he encountered difficulties in "dealing with group members who are very opinionated. This concerns me that other group members are being put off coming along to the hub or sharing ideas for fear of being criticised" [Source 7]. The same teacher also described the time pressures faced by his hub members who were "struggling to get their heads around the new qualifications" [Source 7]. Another teacher noted that "the big issue we've had is attendance, or lack of it". [Source 7], and wondered how to resolve the issue of multiple commitments of hub members. Similarly, a lead teacher struggled with how to "maintain a high level of pedagogical discussion" in the hubs when faced with the "demands of subject development and colleague exhaustion" [Source 7].

Short-term outcomes

SO1. Perceptions of the value of the hubs

On the whole, the teachers spoke highly of PLAN C, valuing the opportunities for deep discussion, subject-specific content and material tailored to the Scottish qualifications. There were 85 statements relating to the value of the hub which were coded positively and 17 coded negatively. Teachers described it as having "vision", "intellectually challenging" [Source 6] and "inspirational and motivational". [Source 9]. The "network of pioneering teachers" [Source 1] and peer interaction was frequently mentioned as a strength of the project, e.g. "This hub has shown how valuable interaction, exchanging ideas and sharing information for your own development and peace of mind is" [Source 6]. Several teachers mentioned that they valued the exchange of pedagogy as well as content. These discussions were seen as "far more valuable than a single resource" [Source 1]. Several survey answers indicated that the sessions encouraged teachers to understand the perspective and challenges faced by pupils when they initially learn programming. Negative comments, although infrequent, were more likely to come from hub members than lead teachers. As examples, one teacher said that they had not

found anything they would use in their classroom, another said the topics were too theoretical, and another mentioned that the "people delivering don't know more than I do already".

SO2. Rewards of hub leadership

This was a relatively infrequently used category; five statements relating to the rewards of hub leadership were coded positively, and one negatively. The reflection on observations noted that "The lead teachers appeared to relish the opportunity to grapple with a challenging course that took them well out of their comfort zones". [Source 8]. Some lead teachers commented on the increase in their "zest" for teaching, and their renewed hope about the future of CS teaching in the country. One lead teacher identified the part she hoped to play in this: "No one likes change and although it [the changes to the qualification structure] is a huge change I can see the benefits clearer than before and hope to make others enthusiastic about teaching new ideas". [Source 1].

Another lead teacher explained that he volunteered because he immediately saw the value in what was on offer. He had

been waiting a long time for something of this quality to come along. It needed the right level of central support – needed a mechanism in place to ensure that it would work. You only get one shot at starting something like this. [Source 4]

Although hub leadership was perceived as rewarding, it was also challenging: "As we have bought into this 'PLAN C' we have a greater responsibility to get it to work. In some sense I feel an additional level of difficulty has been added to my work" [Source 1].

SO3. Growth in professional confidence

The expert teacher educator commented that the shift towards computational thinking in PLAN C "helped to renew confidence in the subject discipline and provide teachers with a clear rationale why computing science should be an important aspect of every child's formal curriculum at all stages" [Source 8]. In the survey answers, the teachers wrote about their increase in confidence (particularly in teaching programming and code comprehension) which came from the discussion and sharing with colleagues e.g. "More confident in my approaches to delivering CS materials especially with programming" [Source 9]. Another teacher linked confidence to trying approaches which had "scientific backing" from research [Source 9]. Of the statements coded as relating to growth in professional confidence, 37 were positive and 1 was negative.

SO4. Changes in attitudes/approaches to teaching

Statements were coded positively in this category if they indicated that teachers were changing their attitudes or practice in a way which was consistent with the aims of the course. Statements in which the teachers indicated that they considered an aspect of the PLANC materials or concepts flawed and so would not incorporate them into practice were coded negatively. There were 149 positively coded

statements and 25 negatively coded. In the opinion of the expert evaluator of learning and teaching, there is “some emerging evidence that they [teachers] are beginning to make changes to their classroom practice and these changes are directly attributable to the project” [Source 8]. At the observation sessions, he particularly noted professional discussion about the change in approach from focussing on code writing to code comprehension. This involved perspective-taking and empathising about “how much we expect from novice programmers and how difficult it is” [Source 4]. Similarly, a teacher wrote that

> From the very start of PLAN C I have made big changes in the way I have taught … I now teach in a way that pupils are shown how to understand code. I now start by getting pupils to read code before they can write code. [Source 1]

For some teachers, PLAN C catalysed a major change in their perceptions of how to teach the subject. Some noted that their previous approaches to teaching programming had been “flawed” [Source 2] or “that the methods and mechanisms I had used for years in teaching were not actually benefitting my pupils’ understanding” [Source 3]. While recognising the shortcomings of one’s practice can be uncomfortable (“I cannot pretend that everything is fine any longer” [Source 1]), the survey answers indicated an enthusiasm and motivation to try new approaches. For example:

> I am always keen to take on new ideas and approaches to my practice and have done this for most of my 25 years in teaching: however, I have never been as enthused to do so as now, since the techniques I am going to use will not only result in improved motivation due to their engaging nature [but also offer] the prospect that my pupils will perhaps gain a deeper understanding of key concepts. [Source 3]

Of course, not all teachers experienced such a major change in their perceptions or practices: “many of the sessions incorporated ideas already used in my teaching practice. I am now just much more able to understand the root pedagogy behind these” [Source 1].

Teachers reported a shift in their teaching towards developing a “deeper understanding of the underlying mechanisms of Computing Science concepts” [Source 1] including an emphasis in computational thinking, e.g.

> I now want to start with first year pupils and embed the techniques we’ve been learning about to get them thinking computationally and breaking problems down to smaller steps to get a deeper knowledge and understand the mechanisms behind computing rather than just using applications or having surface knowledge. [Source 1]

The survey answers documented specific changes which teachers had made to the way they teach the new National 4, 5 and Higher qualifications, such as using tools for visualising mechanisms, and sub-goal labelling. Peer instruction was mentioned as a particularly helpful change. It was seen as a way to “force confrontation of surface level learning” [Source 1], encouraging explanation and was

described by a lead teacher in a hub session as “the most important thing he had done with his classes over the last year” [Source 4].

Negatively coded statements occurred when teachers either lacked time to make changes, or were sceptical about the merits of a course topic (such as pseudocode or an approach to code tracing) and had decided not to adopt it in their own practice.

Initial evidence for medium-term outcomes

At the time of writing, the hubs had completed two academic years of operation. Source 9 contains the reflections of lead teachers from three of the hubs about their experiences to date. In terms of whether the teachers were routinely operationalising research results into their classroom practice (MO2), one teacher commented “I have enhanced my research in the area of support for coding and this has impacted on my practice”. Another mentioned that working in the hub “continues to allow me to evaluate my practice in light of academic research” and another noted that “TRACS in particular has been awesome and revolutionised the approach to programming in our school”. To evaluate this outcome more fully, further data should be collected on the content which particular teachers cover with their classes and how it relates to research.

The teachers were asked to comment on the impact that they believe PLAN C has had on their pupils (MO3). The teachers wrote about their higher expectations of pupils: “[I am] no longer willing to accept that some pupils just don’t understand” and commented that “The raised expectations in itself improves classroom practice”. Another noted that “I expect and am getting improved problem solving skills, resulting in greater independent work in all aspects of programming”. In terms of the impact on attainment, some teachers noted it was too early to say because the relevant exam results had not been published or that it was currently difficult to measure. However, one teacher did write about performance on portfolio assessments for national qualifications which were marked in school: “more of them are passing assessment and first time round and uptake in subject has increased”.

Teachers were, however, able to clearly articulate the improvements they had seen in pupils’ confidence and learning behaviours, particularly with respect to programming. They considered that programming comprehension had improved, that pupils were better at explaining code verbally, discussing their code with peers and were “more aware of what specifically their lack of understanding is”. This led to greater opportunities for dialogue with the teacher and specific support. Teachers also reported that pupils were more “resilient in fixing errors” and were more confident. Although these are encouraging signs, further research is required to examine the impact of PLAN C on pupils’ attainment scores.

Across the statements coded under the medium-term outcome categories (hubs meet routinely, teachers routinely operationalise PLAN C material and impact on pupils), 87 were coded as positive and

17 as negative. The negative comments were mostly related to difficulties in sustaining the hubs once the central funding for the project workers ended.

Limitations

The survey results primarily come from the lead teachers, as they attended face-to-face events with the researchers and so it was possible to get their completed responses directly. It is possible that there was a bias in participants' answers given that the project team were present in the room as they completed the surveys. However, the positive responses in the surveys did triangulate with the observational data and negative opinions were recorded. The survey of all teachers, which was presented online to overcome practical difficulties relating to the geographical spread of participants, had a 25% response rate. Although low, this is not uncommon for online surveys and it returned data from 65 individuals.

The focus of this evaluation has been on the mechanisms by which PLAN C intends to change teachers' practice and their perceptions of the impact of these changes on their learners. The next step is therefore to gather evidence of the impact of changes to teaching on pupil attainment.

Discussion

PLAN-C has engaged with a large number of computing teachers in Scotland. By the end of the project, of 640 teachers in total, half had attended one PLAN C session and a quarter were certified. Qualitative evidence indicates that the pathways to change proposed in the logic model are plausible. In all categories in the logic model, there were a higher proportion of statements indicating positive evidence to support the proposed pathway than negative evidence suggesting that the pathway did not occur. Clearly not every teacher had the same experiences, attitudes or values relating to the course, but the weight of the qualitative evidence is currently in favour of the pathways. There is evidence that the activities took place as intended, and the short-term outcomes were achieved. Preliminary evidence indicates that the medium-term outcomes may also be achieved. It is too early to have gathered much data on routine integration of research so far, but many of the teachers believe that PLAN C is having a positive impact on pupils' confidence and learning behaviours.

The PLAN C project has been successful in increasing many of the teachers' professional confidence and appears to have catalysed powerful change in attitudes to learning. Presentation of challenging PCK and conceptual frameworks, along with the space for reflection and classroom trials, often triggered examination of the teachers' own current practices, which in some cases led to transformational change. This broadly validates the Guskey, Richardson, Disciplinary Commons triad around which the project was designed.

Important pathways to achieving change appear in the form of intellectually challenging professional dialogue and reflection with peers on experiences of how the new materials work with

classes. The induction and recall days for the lead teachers appear to have played an important role in illustrating how to conduct professional dialogue, as modelled by the PLAN C project officers. The engagement of ordinary hub members in professional development varies according to the skills of the lead teacher, and some comments from hub members suggest that they feel less ownership and responsibility for building on the original PLAN C teaching materials. Subsequent work has shown the particular value of strong members in a teacher network (Reding et al., 2016). Future work should explicitly develop leadership and facilitation skills among the lead teachers, and provide videos of experienced educators explaining the core research concepts to ensure the accuracy of the presentation at hub sessions.

Another successful aspect of PLAN C is the focus on CS pedagogy. Teachers indicated that all previous CPD has related to technology vehicles used in teaching CS, or general pedagogies, rather than specific pedagogy for CS, and that they value the subject-specific pedagogical knowledge more. This chimes with the best-practice findings of Guskey and Yoon (2009) that practitioners value highly pedagogical techniques that relate directly to their subject. The project has created a group of subject leaders, who can offer content and pedagogical expertise nationally.

Some teachers, more the local hub rather than the lead teachers, appeared to expect to receive more materials in a ready to use state. For them, professional development appears to be about acquisition of materials *only*, whereas the provision of materials in the programme design is a vehicle to support the core aim of changing attitudes. Once that aim is met, the expectation is that teachers would themselves enter into large-scale production of materials. Indeed this issue was discussed often, and echoes findings from other CS teacher studies (Yadav et al., 2016).

Whether the underlying rationale for the programme design should have been more explicitly conveyed to the local hub teachers is a moot point. As noted, lead teachers were concerned about attendance at their hub at a time when CS teachers were under huge pressures to bring in new qualifications. Given the desires of teachers in times of stress to acquire materials that will directly help with the job at hand, explaining up front that only limited materials will be provided may have further damaged attendance. While in the best case, professional learning can act as a catalyst for change in teaching philosophy in Richardson's sense, anxiety and time pressure is likely to act as an inhibitor to change. It is to be hoped that with time, teachers who originally hoped only for materials to help them cope with new assessment regimes might come to value the professional dialogue for its own sake once the immediate anxiety and work load decreases. This is a point for policy-makers in the future to consider: in the interests of supporting teachers' well-being it would be beneficial to put in place professional learning support networks to establish a safe space for discussion and professional learning *before* implementing large-scale changes to national qualifications.

The design of the programme assumes that teachers will be able to try out new teaching materials between sessions. For a general technique such as Peer Instruction, this is a reasonable assumption, since it can be applied in almost any context. By comparison a topic-specific technique, such as a code comprehension method, can only be trialled when teaching that topic. Ownership of some of the techniques by the lead teachers will have been hampered by this issue, as they were unable to trial materials even with a long lead time; a local hub teacher may be put off from attending again if they have no opportunity to try out a proposed technique straight away. This relates to Guskey's insight that teachers should have early experiences of improved classroom outcomes. While this is clearly desirable, there are some logistical issues to be resolved in facilitating this.

Recommendations

Based on the findings and experiences of the PLAN C project, we offer the following recommendations for colleagues in other countries who have an interest in the continued professional development of the CS teacher workforce.

- •Educate leaders and policy-makers that CS, in common with other scientific disciplines, requires the understanding of deep concepts and subject-specific pedagogy as well as practical skills with the various technologies used to develop that understanding.
- •Provide contexts where teachers are regularly able to engage in high-quality professional dialogue with peers in their subject.
- •Create an expectation that teachers will try out new teaching techniques regularly and reflect on these with their peers.
- •Encourage teachers to engage with pedagogical theories and emerging evidence from the current research literature.
- •Enable teachers to address gaps in their conceptual CS understanding.
- •Invest in the development of a network of subject-specific teacher leaders with expertise in PCK and conceptual frameworks for the subject and leadership and facilitation skills.
- •Where possible, synchronise the delivery of specific topics in the schools involved in a teacher network, as well as with topic-specific professional development input, to enable the whole group to trial new techniques, leading to deeper subsequent reflection.

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Supplemental data

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