HOPE for Computing Education: Towards the Infrastructuring of Support for University-School Partnerships

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ABSTRACT

The state of computing education in the UK is described as "patchy and fragile" with universities tasked to provide further support to schools. However, little guidance exists towards the provision of this support. To explore the development of university-school partnerships, we present findings of an extended educational engagement coordinated by Newcastle University, as part of the national "Create, Learn and Inspire with the micro:bit and the BBC" initiative. Following an action research approach, we explore the experiences of undergraduate students, schoolteachers and an educational broker through the process, including recruitment, content development, and delivery of over 30 computing lessons by nine undergraduates. We identify a number of design considerations towards the development of High Opportunity Progression Ecosystems for the improvement of computing education, such as student identity, workload model, and process visibility. We then discuss the potential role of technology in infrastructuring support for university-school partnerships.

CCS CONCEPTS

• **Social and professional topics → Computer science education**; *K-12 education.*

KEYWORDS

Computing education, brokerage, university-school partnerships, learning ecologies

ACM ISBN 978-1-4503-5970-2/19/05…$15.00
https://doi.org/10.1145/3290605.3300729

ACM Reference Format:
Megan Venn-Wycherley and Ahmed Kharrufa. 2019. HOPE for Computing Education: Towards the Infrastructuring of Support for University-School Partnerships. In *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019), May 4–9, 2019, Glasgow, Scotland UK*. ACM, New York, NY, USA, 13 pages. https://doi.org/10.1145/3290605.3300729

1 INTRODUCTION

The inability to understand and appropriate computing technologies has the potential to isolate citizens from playing an active role in society [52], exacerbating and entrenching existing social exclusion [21, 56]. This contributed to the introduction of computing to the UK National Curriculum in 2014 [17, 18] as a method to provide young people with "digital citizenship skills" through active engagement, design and criticality of computing systems [3, 71, 72]. However, evidence indicates that the introduction of computing education (CSE) has only further contributed to ongoing social stratification [58, 61].

Higher Education has been encouraged to develop closer links with compulsory education institutions [58] to improve overall quality and engagement with CSE. However, there are few suggestions on how these links might be achieved and how these partnerships might be best framed for the benefit of learners. Universities are geographically and socio-culturally positioned to collaborate with communities [27, 28], yet educational outreach schemes can be met with skepticism by schools around usefulness, sincerity and sustainability [44, 59]. This is attributed to the fact that outreach often takes place with little input from the educational communities or pupils who are the recipients of this outreach [6] and that communities do not recognize the potential for university engagements [65].

Adrion et al. investigated how community college programs helped to provide economically, socially and academically disadvantaged populations with pathways to engage with CSE through careers fairs, seminars, workshops etc. [1]. In their evaluation, they summarized that the communities with which the were working were further disadvantaged due to their environment, and that family, community knowledge, role models and support would need to be considered for succesful oureach programs in thefuture.

McNall et al. [47] propose that university undergraduates (UGs) are ideally positioned to contribute towards these partnerships, with specialist knowledge and their need to develop professional skills. Currently, employers consider 39% of UK computing graduates to lack appropriate workplace skills [11, 13, 62] and 8% of UGs remained unemployed 6 months post-graduation [51].

Interestingly, extra-curricular enrichment is not a popular option for computing UGs [16, 42], despite evidence that it can develop the technical and social skills relevant to employment and wellbeing [10, 42].

This paper investigates methods for developing and sustaining educational partnerships between universities, undergraduate students and local secondary schools through the scope of an existing engagement. A team of nine UGs and one researcher from Newcastle university worked in partnership with nine local secondary schools and an after school code club, as part of the "Create, Learn and Inspire with micro:bit and the BBC" (CLIMB) initiative. This pilot project, coordinated by BBC Research and Development, encouraged STEM undergraduates to design and three computing lessons to Year 8 pupils (12-13 years old).

Following an action research approach and utilizing the Local Learning Ecology (LLE) model to examine the engagement, this study aims to understand the experiences of the participants in university-school partnerships for CSE. These include the absence of advocacy in the academic identity of computing UGs, the mismatch of expectations between UGs, teachers and the broker, and a need for school-driven lesson development.

Through the study of this engagement, we seek to contribute towards 1) an understanding of the barriers, motivations and opportunities for university-school partnerships in support of CSE, 2) a model for creating and sustaining partnerships in response to our findings, and we reflect upon these findings to 3) provide guidance on how technology can infrastructure the partnership process.

2 BACKGROUND

This section discusses the role of High Opportunity Progression Ecosystems (HOPEs), and the impact of action research and brokerage in developing an improved Local Learning Ecology.

The Local Learning Ecology

The multi-level Local Learning Ecology (LLE) model is proposed as a method for examining the wider ecological system of a community and its educational impact upon young people [34]. Its roots can be traced to Bronfenbrenner's model for understanding the impact of the ecological environment on human development [8], and Finegold's framework for creating and sustaining high-skill ecosystems [23]. The *exo 1 layer* focuses on how relationships between educational institutions have the ability to influence quality of education of an individual institution at the *macro* layer. The quality of the young person's school environment at the *macro* layer correlates to the development of their identity and disposition toward learning at the *micro* layer [34].

Developing a HOPE

An LLE can be conceptualized as a continuum, ranging from a low opportunity progression equilibrium (LOPE) with poor opportunities for learners, to a high progression opportunity ecosystem (HOPE) which focuses on providing young people with successful transition to further learning or employment [34]. To achieve sustained movement towards a HOPE, Hodgson and Spurs recommend each layer of an LLE is configured to prepare young people with the opportunities to succeed both academically and socially [20, 23]. One recommendation is the "development of partnerships between multiple educational institutions at the *exo 1* layer" [34]. In examining the experiences of those taking part in university-school partnerships [33, 34] we might begin to understand the requirements for a HOPE for CSE.

Action research and brokerage in education research

A "study of a social situation with a view to improving quality of action within it" [22], the action research (AR) approach is increasingly popular in the field of HCI [31]. Historically employed in classroom-based research to uncover the complexities of the teaching process and improve the learning experience for pupils [2], AR promotes systematic and collaborative research towards the practical resolution of community concerns, mindful of the social relations inherent to the space [32], making it an ideal approach when investigating the development of a HOPE.

Furthermore, when considering complex social relations, there must be an alignment of purpose to ensure interactions are purposeful and effective [22, 37]. This âĂIJalignment of purposeâĂİ can be achieved through brokerage, where an individual works within the space to understand the needs, desire and politics of disparate groups and bring about mutual understanding. Brokers can be positioned as a central proponent in educational change, acting as an intermediary to communicate academic research findings [55] and navigate logistical, cultural and communicative boundaries [41]. This approach to bridging existing communities lends itself strongly to integration with AR [37].

3 RELATED WORK

The following section investigates the current responses and shortcomings around CSE, and the role of brokerage in educational improvement.

The state of computing

HCI has begun to provide support for CSE through technologies to aid learners in developing computational skills [43, 57], assist teachers in delivering content [38], and encourage engagement through the use of tangible devices [54]. However, these studies are limited in scope, focusing on finite engagements to improve knowledge of concepts, rather than supporting the wider context of CSE.

Poor support for teachers. A predominant approach to support for computing teachers is continuous professional development (CPD), but is often defined by teachers' working hours [64], poor availability of support and limited access to resource in the school environment [30, 58, 61, 64].

UK teachers highlight Computing at School (CAS) as providing the most beneficial source of resource and CPD [53] in its ongoing role to support and guide the development of CSE [14]. Organizations which provide similar support can be found on the global stage, such as CSforALL in the USA [15]. However, these types of organizations do not address limitations around teachers' unsuccessful attempts to transfer CPD material into the classroom [30].

Skills of a computing graduate. University level courses offering computing UGs the opportunity to work on community projects are limited [60]. Known as "Service-learning", these opportunities also allow for the development of soft skills for future employment [66, 67], making it an interesting curricular omission in the face of poor employment opportunities for computing graduates [16, 48]. However, service-learning relationships do not exist without difficulties, as successful project outcomes involve complex logistical organization, management of expectations and development of structural processes [9].

Computing on the international stage. Problems with CSE are not limited to the UK context, and are a developing problem as countries attempt to develop rigurous CSE curricula. Issues surrounding teacher CPD are highlighted in Gal-Ezer et al's [25] analysis of CSE in the USA and Israel, where a lack of standardized teaching qualifications and difficulties in accessing relevant training courses were found to impact the quality of CSE. In a study of the K-12 CSE curricula of 12 countries, there were massive variations in definitions and delivery of CSE [36]. This lack of standardization echoes the "patchy and fragile" nature of CSE in the UK [58]. Without a clear, cohesive policy outlining "exemplary CSE teaching" there is little way to ensure the quality of CSE experieced by pupils [51]. In this paper, while conducted in the UK, has implications for CSE beyond the UK context.

Brokerage in education

Bouwma-Gearhart et al. investigated the role of brokers in the success of postsecondary STEM (science, technology, engineering and mathematics) collaborations in the USA [5] and found that brokers allowed for the translation of specialist content such that it was usable by other educators, and that through valuing the knowledge of participants, were able to make educational research and theory accessible.

The importance of brokers who can negotiate cultural, structural and logistical barriers towards the development of reciprocal university-school relationships [45, 46] is also found in Gu's investigation partnerships between Higher Education and schools in the UK [29]. The role of broker was adopted by a Vice Principal, who acted as an intermediary for teachers who were wary of working with academics, uncovering tensions between the typical approach to University-School partnerships [42].

4 THE CLIMB STUDY

The following research aims to understand participant experiences in the development and delivery of university-school partnerships for CSE, to inform the configuration of university-school partnerships in pursuit of a HOPE. This involved developing and delivering an engagement between university UGs and local secondary schools as part of a six-month pilot scheme from BBC R&D.

An action research (AR) approach was adopted [31, 32] to allow for iterative research and flexible integration of methods for data gathering, synthesis and analysis. AR's focus on encouraging place-based, collaborative research positioned the lead researcher as the educational broker in developing and coordinating partnerships between schools and UGs. Furthermore, as part of this approach, the lead researcher also delivered CLIMB lessons in two further schools to gain a deeper understanding of the UG and teacher experience in the process.

The CLIMB scheme invited STEM UGs at UK universities to apply for the opportunity to teach three lessons to a class of Year 8 pupils (12-13 years old) as part of their timetabled computing lessons, using BBC media content and BBC micro:bits. To participate, UGs were required to submit a two-page outline of their lesson plan and the BBC program content they used as inspiration. After judging by the BBC, each successful applicant would be partnered with a local secondary school to deliver these lessons and paid £250 taxable income (equivalent $460) upon completion. The BBC did not prescribe a process by which this outcome should be achieved, so the research team were free to create and evaluate their own process. To explore the experiences of

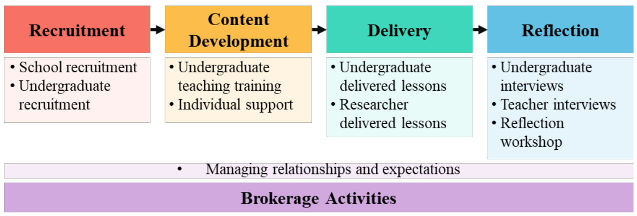

Figure 1: Schematic for the CLIMB process

the participants during CLIMB, this process has been split into five sections (see Figure 1): *recruitment, content development, delivery, reflection* and *brokerage activities*. These are expanded upon below and at the end of each section we outline the methods of data collection and analysis.

Recruitment

The following section outlines the process of participant recruitment.

Schools. Invitation emails were sent to 18 local secondary schools, and an additional 14 schools were contacted through the local Computing at School hub. When a school expressed interest, short informal chats were conducted with teachers to discuss their expectations of the scheme and relevant school policies. These teachers were identified by the school to participate, and were asked to select a class with a high percentage of pupils identified as being from disadvantaged background where possible. Ultimately, the schools had the final decision in which classes participated in CLIMB. The percentage of disadvantaged pupils ranged from 0% (an independent school) to 59.5% (an academy school).

Undergraduates. UGs from the School of Engineering and the School of Computing received a CLIMB invitation email through the School's administrative team. It was also promoted through an engineering professionalism module for first year computing UGs, where they were instructed to design a single computing lesson and were invited to submit responses to the lead researcher for feedback. A further recruitment workshop was attended by 18 UGs (3 female, 15 male), who were each compensated £10 in Amazon vouchers ($13) for attendance. Additional recruitment included leveraging existing relationships between the research lab and UGs involved in research projects or supervision arrangements

Data Collection. Conversations between teachers and the researcher were reinforced by observations and field notes, while data for the recruitment of UGs was collected through observation and informal chats. During the recruitment workshop, the researcher conducted short informal chats with the UGs to understand motivations for attending, and address questions and concerns.

Content Development

Successful UGs were partnered with a participating school dependent on availability in their schedule and the scheduled times of the Year 8 classes.

Teaching Training. UGs attended a half-day teaching training to transform their proposals into lessons. Eight UGs (7 male, 1 female) attended, with one UG unable to attend due to prior commitments (1 female). All training materials were made available for UGs to access after the session. The start of the session was coordinated by the Computing at School group, to discuss the micro:bit and classroom management techniques. The session finished with focus groups facilitated by three computing teachers from participating CLIMB schools, to support UGs in developing engaging and achievable lessons for Year 8s.

Individual Support. Engaging with UGs on an individual basis (e.g. requests for feedback) allowed the researcher to learn about challenges encountered when preparing for school engagements, and encourage UGs to contribute to the ongoing development of the engagement as part of the AR methodology.

Data Collection. UGs and teachers completed questionnaires to gauge how they felt the training had influenced their ability to deliver lessons in schools. Additional data was collected through the analysis of proposal content, and observation of the areas where UGs requested feedback.

Delivery

UGs delivered their lessons in their partnered schools and were responsible for liaising with teachers and arriving in good time to begin lessons.

Student Delivered Lessons. UGs delivered their lessons in schools, with the lead researcher observing the first and final lesson of two UGs. Teachers were expected to supervise the lessons and provide support to UGs through classroom management and post-lesson feedback.

Researcher Delivered Lessons. To better understand the experiences of the CLIMB UGs, the researcher designed and delivered three computing lessons in two further schools, following the AR approach. Lessons were delivered in timetabled slots for computing to minimize disruption to the schools.

Data Collection. Insight was gained through the analysis of prepared lesson materials, semi-structured interviews with UGs and teachers, and experiences recorded through researcher field notes. Additional insights were gained through an informal WhatsApp group between the researcher and participating UGs.

Reflection

Participants were invited to reflect on the process, and contribute suggestions for improvement.

Teacher Interviews: Semi-structured interviews were conducted with five participating teachers to gain insight into the school experience of taking part in the engagement. The interview began with questions about their general experiences of the CLIMB process, and subsequently explored the pertinent elements which arose from this line of questioning.

UG Interviews: 30-minute semi-structured interviews were conducted with each of the nine participating UGs. Questions were linked to the stages of the CLIMB process (see Figure 1), to explore their experiences and the development of skills throughout the process. Interviews ended with the UGs describing their thoughts around the timeframe of the project.

Reflection Workshop. Data from the UG questionnaires, interviews and researcher field notes were presented to UGs in a "back-talk" approach [24] through two repeated 40 minute workshops. The first was attended by three UGs (two male, one female), and the second was attended by two UGs (two male). The data was paired with a probing question to which the UGs had to respond, designed by the researcher to support meaningful engagement with the data (e.g.: *"How can we make content of the lessons suitable for Year 8s?"*). UGs converged ideas to create a collaborative response to the underlying issue prompted by the probing question through "dotmocracy" [19], a method of cooperatively establishing outcomes amongst limited choices by placing physical dots on desired outputs.

Data Collection. UG and teacher interviews were recorded and transcribed, with axial coding used to develop themes. Individual outcomes of the reflection workshops and list of proposed suggestions for the improvement of CLIMB were also analyzed sources of data.

Brokerage Activities

Due to previous experience in working in schools, the lead researcher adopted the role of broker between the university, UGs, teachers and the BBC. This included developing the CLIMB process (Figure 1) and continuously adapting the process in response to feedback, in the spirit of AR. Brokerage activities ran through the recruitment, content development, delivery and reflection stages.

Recruitment: This stage involved communicating expectations of the participants and ensuring that expectations were upheld, as well as general logistical organization of the UGs delivering lessons in schools.

Content development: To ensure that the developed lesson content was appropriate for Year 8 classrooms, the lead researcher assigned each successful CLIMB UG with a school-identified teacher at each partnered school. The pairs would then work collaboratively to develop appropriate lesson content, with the lead researcher offering advice and support when the teachers were unavailable (e.g. holidays).

Delivery: The lead researcher supported the delivery of the lessons by organizing the logistical elements of the process, with an understanding of delivering educational computing content in the classroom and academic context of UGs. This involved managing expectations of the two groups, to ensure that UGs were appropriately supported by teachers and that teachers had appropriate expectations of UGs.

Reflection: Towards the end of the engagement, the lead researcher consolidated and communicated the outcomes of the reflection stage of the process to participants. This was to provoke further reflection on the process, particularly around the experience of others and how this could prompt a more relational approach to the overall engagement. This also included making the developed resources available to participating schools, so they might benefit from the work of other CLIMB UGs and schools.

Data Collection. Data was primarily collected through the lead researcher's observations and field notes, including reflective entries examining their experiences as an educational broker.

5 FINDINGS

Collected data was analyzed using Thematic Analysis [7], and provided an outline of the experiences of the three main participating groups in the CLIMB process. The following findings are presented in sections relating to experiences of these groups: UGs, teachers and the broker.

Undergraduate Students

Hands on recruitment opportunities. Nine UGs were recruited in total. Five UGs recruited through existing relationships with the research lab, two through workshop participation and one through direct emails. UGs were unsure if they received an email, with one UG responding *"There were emails sent out to everyone at uni? I didn't see that, and I usually check my emails" (UG1).*

Two first-year CLIMB UGs who had taken part in the recruitment practical explained how the exercise was patronizing, saying *"it wasn't marked which didn't help" (UG2).* When asked about the introductory workshop, another UG had a more positive response, and that it had better communicated the expectations of participation in CLIMB, expressing *"That was quite good actually, that was what convinced me to actually apply at all" (UG3).*

When questioned as to why they felt that more UGs hadn't applied to CLIMB, UGs felt that many of their peers were reticent to engage due to the involvement of the micro:bit, as they are not a common feature in degree-level computing. *"Maybe if people haven't used the micro:bit and they think it's a completely new thing that's like a Raspberry Pi then like... that might turn them off from the start?" (UG4).* UGs proposed a response to this issue through "low-risk" engagement activities such as lecture talks and hackathons to help communicate the expectations of the scheme.

Developing Proposals. UGs had limited teaching experience so proposals often focused on concrete outputs, such as pupils completing a project across the course of the three lessons.

"There was no inspiration or anything to draw from in the first place, so I spent most of my time creating that idea (the proposal), refining it with my friends. Like 'could this be complicated for Year 8 children?"' (UG5)

One UG remarked that his proposal contained a creative idea, but he didn't know if it could be implemented using the micro:bit, expressing that he "kinda expected to be told 'OK, cool idea but here's the actual limitations of the micro:bit"' and was surprised when his proposal was accepted with no feedback, leaving him to wonder *"...is it possible? because I'm still not sure if I can even do what I put down" (UG3).*

Engaging Content. UGs remarked that the integration of BBC content *"seemed kind of forced from the beginning" (UG3)* and was a challenge to find appropriate media to fully utilize the Dr Who or Springwatch themes, going on so say the choice of programs came "ten years too late". UGs suggested future iterations of CLIMB should allow access to relevant media resources to provide a more engaging experience for pupils.

UGs expressed a desire that they should have interaction with the schools before developing proposals, so that they could ask pupils *"...what they want, what they would like to see, what they already know as well" (UG1)*, so that developed lessons could be crafted to respond to pupils' interests. UGs also proposed that schools should be involved in judging proposals and providing pedagogical feedback to support content development.

Balancing Motivations and Barriers. All UGs expressed concern towards the impact of CLIMB on their academic life, with deadlines and revision cited as main conflicts.

When asked how they might redesign the CLIMB timeline to better fit their academic life, one UG said *"Releasing something in September time would be more helpful because... I have like, a lot of deadlines..." (UG6).* Similarly, another UG felt that it was difficult to juggle CLIMB and academic commitments: *"it's a bit stressful... to manage it around revision, coursework and this." (UG7).*

When asked about motivations for participation, UGs felt financial incentives were appealing *"I won't lie, the money was a pretty big motivator" (UG2)*, but there were academic benefits *"the initiative did prompt me to do a lot of research for the (final year) dissertation" (UG1).*

UGs also felt that taking part in CLIMB helped to build *"a lot of confidence in speaking to the class" (UG6)*, with teachers noting improvement in UGs classroom management and content delivery in a short period of time: *'in three lessons it's great progress!" (T1).* However, UGs often had to be prompted to reflect on skills gained through CLIMB. As such, skill development was not considered a primary motivation for participation.

Disruptions to Delivery. Lessons were planned for consecutive delivery, but this was not always possible. Timetabling and personal illness meant delivery of some lessons was disrupted. This was difficult for UGs as they felt interrupted in the flow of delivery: *"It didn't help that I missed- that it wasn't three consecutive weeks, when I went back some of them had forgotten who I was..." (UG1).* This also impacted teachers, who had to deliver a single lesson to bridge the gap in teaching.

Teachers

Importance of UG-Teacher Partnerships. Teachers expressed that they felt unsure of how to best support the UG in lesson delivery, especially when providing feedback at the end of sessions, with one teacher remarking that she felt her feedback was too negative, and that it was *"the sort of feedback I would give to a teacher who's been training" (T1).* In situations where teachers worked more collaboratively, UGs reported the experience to be more enjoyable *"The middle lesson was good because there was three teachers in there with me." (UG2)*, and were able to learn new approaches to computing concepts in the classroom, for example *"you could take your shoes on or take your shoes off" (UG5)* to explain Boolean logic. However, in situations where teachers were not as engaged with the project, UGs felt unsupported and less resilient in the face of challenges. *"Interestingly I actually semi-struggled more teaching the technical stuff to the IT teacher... Once people really decide that they don't care then it (teaching) becomes impossible" (UG3).*

When UGs were prompted in questionnaires to reflect on the most "successful part of the teaching training session" responses were focused on the teacher feedback, with a UG expressing that they felt *"a lot more confident and prepared about this now" (UG1)*, as this support had been missing during the recruitment stage of CLIMB.

During the post-delivery interviews, a UG felt that the training session had also helped them to prepare them for lesson delivery by developing their classroom management skills, stating: *"I think the stuff we did on that day was incredibly helpful because... had I gone in, without any... Kind of... I think I would have been torn apart." (UG5).*

Teachers at the training session contributed to UGs understanding of the computing capabilities of Year 8 pupils and strategies to overcome this challenge. Many UGs expressed that their next steps would involve contacting their partnered schools to learn more about pupil ability and talk to their partnered teachers about their experiences of teaching, to help better prepare their lessons.

Macro Layer Restrictions. When teachers were questioned about their thoughts towards the CLIMB process, and how we might begin to broker more sustainable university-school partnerships, teachers were keen to ensure future ventures were considerate of the limitations of the school environment.

"The trouble is, where outside agencies fall down in schools, is they want to be helpful and participate, and have their own ideas of what they want to happen, but school life can't change too much." (T2).

The concept of the process needing to fit the existing context of school life, within the *macro* layer, was echoed frequently by teachers. Citing a need to ensure developed resources were appropriate and meaningful for the classroom, teachers were interested in developing an improved process to support future UGs to develop content for their partnered schools.

Broker

Workload. The amount of work incurred by the broker was considerable, as they felt as if they were *"on-call 24/7, preparing for emergencies"*, and had to continue to manage the engagement outside of typical working hours, as UGs encountered problems with equipment, travel and timetabling. This amounted to a full-time role for the broker across the span of three weeks and the broker felt that the current workload would be unsustainable for a single person to coordinate in addition to existing responsibilities.

Communicating Expectations. A shared electronic document with anticipated problems and solutions was created by the broker, with the view that UGs could collaboratively contribute to the document and create a well-rounded support document. However, this document was rarely accessed, and UGs preferred to contact the broker via private instant messaging. When asked how the UGs experienced the logistics of CLIMB process, one UG remarked that the relying on the broker *"worked good for us, not having that responsibility" (UG8).* When prompted to consider how a future process might be designed, so that UGs had more responsibility for their involvement in the engagement process, another UG expressed: *"You're putting more responsibility on the peopleâĂę which shouldn't be a problem, it's only if you start having issues, then you blame a person and then what happens? I guess at the moment if a school starts to complain you'd take responsibility..?" (UG9)*

This lack of a clear expectations towards the role of UGs in the engagement meant that they often felt unsure how to approach issues, leading to over-reliance on the broker to resolve these problems.

Exo 1 Layer Restrictions. Across all participating schools, it was observed that each had their own individual method of accessing external resource and sharing resources within their institution. . In response, the broker distributed the lesson materials to schools through email, but this approach left no opportunity for ongoing dialogue and development of these resources between the university, UGs and schools themselves.

Schools are unlikely to share best-practice, resource and outputs beyond the confines of their own institutions, with one teacher remarking that *"schools don't interact with each other" (T5, Teacher).*

Frustration towards these limitations were expressed by several teachers, with one summarizing *"You'll find a lot of school networks won't even allow shared Google Docs for security reasons" (T5).* This *macro* layer limitation around the sharing and development of educational resources is currently preventing the more nuanced relationships at the *exo 1* expected of a HOPE.

6 DISCUSSION

Through this study, we seek to contribute towards the development of process by which university-school partnerships can be created and sustained. In response to the findings above, we present the beginnings of an infrastructure to support university-school partnerships for CSE. These include an improved process for recruitment, delivery and sustainability of partnerships, and the role technology may play in support of the process and brokerage (Figure 2).

The proposed process responds to challenges experienced by UGs, teachers and the broker through the CLIMB process. These include a mismatch in expectations, anxiety towards participation, issues surrounding the sharing of resource and challenging workloads. The process also builds upon identified opportunities.

A technological infrastructure can further mitigate these challenges, by providing an opportunity to navigate engagements at the *exo 1* layer (relationships between multiple educational institutions), provide improved infrastructure of the university-school partnership, manage and share generated knowledge and learning artifacts, and allow for improved coordination amongst a distributed group of people. These suggestions are influenced by Wenger's research on

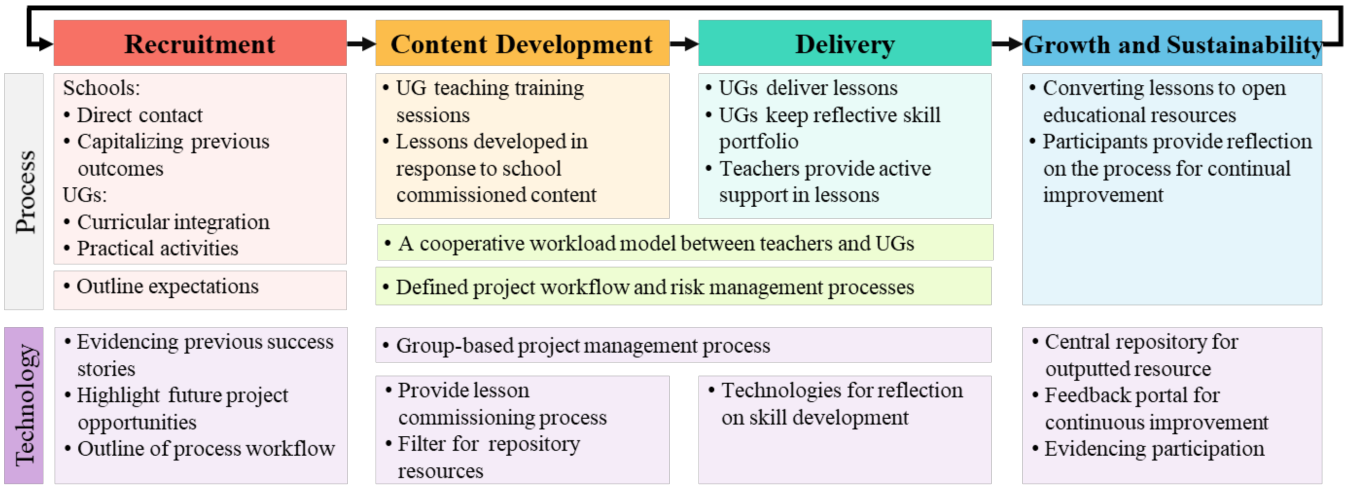

Figure 2: Schematic for proposed university-school partnerships.

platforms in support of communities of practices[70], particularly for their ability to 1) act as repositories for good practice 2) assert the existence and aims of a community and 3) allow for an improved management of expectations and workflow.

The following sections discuss our findings and outline suggested improvements towards university-school partnerships. Each contains a subsection to discuss the potential role of technology.

Recruitment

The recruitment of schools was primarily conducted through email contact from the broker or built upon existing relationships, showing the importance of direct contact in the recruitment of school partners.

This allowed for a discussion surrounding expectations of the process and what the school seek to gain from a partnership. However, not all schools responded - which could partially be attributed to schools being unaware of the benefits of engaging in university partnerships [65].

In making generated resources and previous success stories available to schools who don't currently participate in partnerships, we address schools lack of access to computing resource [53, 61] and communicate the benefits of university partnerships. This begins to move the LLE towards a HOPE through varied partnerships between multiple educational institutions at the *exo 1* layer.

It became apparent that UGs were motivated by factors beyond financial compensation. UGs valued academic achievement before extracurricular activities, despite computing students more widely critiquing the lack of opportunities to develop social and employability skills [10, 16]. This may be explained in terms of a disconnect between academic endeavors and civic engagement activities. That is, *civic engagement activities are not intrinsically linked to their identities as students, and future computing science professionals.* With no concrete definition of student identity, we adopt Kinnunen et al's definition of student identity as the "student perception of CS and how they relate to and participate in the field" [39].

STEM education has been criticized for not typically supporting the development of students' identity [35], and that this has led to the one dimensional perspectives of CSE UG students who believe that their undergraduate career involves "programming and sitting in a dark room and not having any interaction with the outside world" [16] and that being a computing professional means they "sit in front of a monitor for the rest of (their) life, hammering on the keyboard" [50]. This highlights a need to integrate participation in
university-school partnerships into the wider university computing curriculum, providing diverse opportunities to apply CSE to real-world problems and societal issues. This might provide a stronger framing of the identity of UGs as computing science advocates and motivating UGs through academic credit.

This curricular integration can also include academically meaningful practical activities, allowing UGs hands-on experience on working with new hardware, responding to the issues highlighted by the UGs around curriculum-based activities with no academic benefit and anxieties towards learning and utilizing new technologies.

Throughout the process, it became clear that there was a mismatch of expectations between BBC R&D, the UGs, and the teachers in schools. As challenge commissioners BBC provided limited feedback and little further benefit from their partnership to the UGs, despite UGs expecting active feedback or access to resources.

Furthermore, some teachers expected that UGs should take charge of classroom management, as well design and delivery of lessons, despite having limited training and experience. In practice, the researcher acted as an intermediary to communicate expectations to stakeholders, which was often a difficult and time-consuming task. These mismatched expectations permeated the CLIMB process and made clear the need to improve visibility of the future partnership process to all, clearly communicating expectations of those involved.

Technology. Technology can play a major role in providing visibility of previous engagements and workflow, supporting participant recruitment. This can be achieved by the creation a central repository of previous successes, generated lesson resources, a catalogue of current projects and recommended process workflows. This addresses reported barriers to participation and improve recruitment of schools and UGs, who are able to see examples of the opportunities and benefits, becoming aware of the expectations of participation in a university-school partnership.

Content Development

Key challenges focused on UGs struggle to develop content for their target classroom and their concern that the imposed topics of lessons were neither meaningful nor engaging.

There was a clear need to ensure that the content developed by the UGs was relevant to the needs of the teacher, interesting to the wants of the pupils and achievable by UGs with limited prior experience of developing lesson content. In adopting a commissioning approach to lesson development, teachers could outline curricular requirements of a lesson and pupils define their interests so that UGs can be better supported to develop lessons.

Positioning the school as reciprocal partners can address the skepticism held by schools towards educational engagements with universities [6, 44, 59]. The development of a commissioning process links back to a HOPE, encouraging links between educational institutions at the *exo 1* layer.

Technology. Existing digital tools for the commissioning of social change (e.g. change.org) and community support [12, 26] provide us with insight as to the role of technology in community-commissioned content.

A typical commissioning scenario, as used in AppMovement [26], involves 1) proposing an idea, 2) gathering support, 3) collaboratively developing popular ideas and then 4) submitting the developed proposal to be actioned.

In the partnership process, pupils and teachers commission lessons through a defined steps on shared platform, outlining a "lesson proposal" of the schools needs and wants - improving the agency of the school and providing UGs with a concrete starting point for lesson development.

In developing this technological platform, we might bring about a sense of uniformity to the commissions, so that they might be more easily managed and interpreted. This commissioning approach would also help to better address the criticisms that university-school partnerships are often not meaningful to the contexts in which educational content is delivered.

A further benefit to a platform acting as a resource repository is the possibility of providing filtering. This would allow UGs to access relevant previously developed resources, commissions and media when developing their content, mitigating the "cold-start" issues experienced in CLIMB, and provide schools with resources and inspiration when taking part in the lesson commissioning process.

Delivery

UGs delivering content in the classroom, supported by teachers, is a vitally important element to the process. UGs have the opportunity to develop confidence through interactions with a class, and the partnership and feedback process allows teacher to upskill in situ.

There are also benefits to the *micro* layer (the pupil themselves), through interaction with a UG that may raise aspirations towards higher education progression, continuing towards the development of a HOPE.

However, our findings convey the precarity of UGs in the position of "students-as-teachers" while not being "Student Teachers" (e.g. those undertaking a form of training to gain teaching qualifications), and that there is need for UGs to improve awareness and evidence of skill development.

Academically assessed portfolios would help UGs to reflect on the benefits of participation and address the issues surrounding the underdeveloped skills of computing UGs [11, 13, 62].

Technology. E-portfolios are already used to evidence and promote skill development [63]], though they receive mixed response [69] Creative portfolios might better engage UGs for whom a written account would not be cause for personal reflection. By providing access to a range of digital tools, UGs could create digital artifacts (e.g. vlogs and podcasts), and be positioned to reflect on the skills gained through participation.

Content Development and Delivery

Our findings demonstrate how the challenges of disruption and both teacher and UG workload have the ability to influence the content development and delivery stages of the process. The following section outlines suggestions for a cooperative workload model between teachers and UGs, as well as project workflow and risk management processes.

The current format of CLIMB requires considerable commitment from UGs, who work individually to propose, design and deliver their lessons. In promoting a cooperative workload model between UGs, with tasks assigned to individuals to develop lesson content and others deliver to classes, we might begin to mitigate the issues of workload and allow UGs to develop specific desired skills.

Additionally, positioning the teacher as an active member of this cooperative group has the potential to provide CPD within and beyond the classroom environment as they contribute to the development of lesson content. This addresses the issue of teachers access to high quality resource and training [30, 40, 61] as well as providing UGs with an understanding of the classroom environment and pupil skill level.

In moving towards this cooperative workload model, there is need to define a concrete workflow which will outline the roles of participants, key deliverables and dates by which these should be achieved. This sets expectations of participants, allows for a better management of these partnerships by a key member of the university, and provides the beginnings of risk management.

For example, consecutive participation in the scheme was not always possible in the face of timetabling issues or illness. The current format is untenable, due to the pressures of developing and delivering lessons between a single teacher and UG, and there is need for the definition of a risk management process to mitigate the impact on the school and the partnered teacher.

Technology. With roots in Wenger's view of platforms as a method of coordinating distributed groups of people, implementing a digital, group-based project management process would provide coordination within these cooperative groups through the provision of a defined project workflow and required deliverables (e.g. Basecamp which allows for group management, scheduling and task assignment etc. [4]). This could allow UGs to self-organize lesson delivery with schools and agree on "backup measures" to reduce the impact of disruptions.

Growth and Sustainability

To ensure a sustainable approach to partnerships, with the potential for future growth, we suggest how the outcomes of a partnership can support the ongoing process.

Positioning developed content as Open Educational Resource [68] allows teachers free, open access to use, adapt and redistribute resource. Content can have impact beyond the macro of partnered school, to multiple institutions which exist at the *exo 1*, contributing towards the development of a HOPE for computing, and addressing the issue of access to computing resources. In addition, these resources provide future UGs with inspiration for their own lesson development when fed back to the recruitment and delivery stages.

Including a feedback process for continual improvement can empower participants to influence the future of the process, as they design future iterations in a similar approach to reflection workshops in CLIMB. This continual adaption of process ensures partnerships are appropriate for their context and provides participants with a sense of ownership. *Technology.* In providing an online feedback process, we respond to difficulties in gaining feedback from UGs and teachers in a face-to-face format and future-proof for scale by providing asynchronous feedback mechanisms. This reduces the barriers for participation, addressing the wariness felt by teachers when entering partnerships with university over fears that their feedback and knowledge will not be valued [29].

To provide most educational benefit, HOPEs must focus on making educational engagements visible to current and future participants, as well as other communities who might want to infrastructure their own HOPE engagements for computing on a global scale.

UGs expressed anxiety in participating in CLIMB as they struggled to find inspiration and support. Teachers were unlikely to discover the work occurring at other schools in their community. These problems could be resolved through the creation of a digitally accessible central hub, storing resources, lessons and participant experiences, such that participants might benefit from the increased visibility.

This would help computing teachers access a growing central repository of resources to appropriate content without the need for direct university engagement and allow for wider participation of schools who are unable to support partnerships in the long-term, but can still access the outputs of other partnerships.

Furthering the concept of evidencing participant experiences, technologies have the ability to demonstrate partnership outcomes. For example, Open Badges [49] are used to evidence learning and act as verifiable records of achievement. The potential to implement digital credentials, could permit UGs to signpost created materials and developed skills, providing further credibility and motivation in participation, and evidencing their developed skills in a way accessible to future employers. This concept could also be extended to schools, as they are required to demonstrate educational outcomes for their students as part of school policy.

Technology-mediated Brokerage

Throughout each stage of the process, there were activities required of the broker. These included communicating expectations, partnering schools and UGs, resolving issues with scheduling and equipment, as well as organizing opportunities for participants to reflect and redesign the CLIMB process. In the sections above, we have detailed how technologies like Basecamp could support the coordination of participants and provide processes for management of risk, and the role of a platform in brokering new partnerships between schools, universities and UGs through externalizing participant experiences and developed resources. These technologies either support, or completely automate the activities conducted by the broker, yet we do not recommend that the role of the broker is completely eliminated from the process. The need for a human element in the process was demonstrated by the brokerâĂŹs informal chats with teachers at the start of the process when setting expectations and encouraging dialogue, and in the UGs preference to contact the broker when they encountered issues. Instead, technologies should be considered as methods of supporting a broker to work within the *exo 1* context, bridging cultural divides schools and universities education and infrastructuring partnerships for the benefit of CSE.

HOPE beyond CSE

A key strength of the proposed model for university-school partnerships is its potential to be re-purposed for wider STEM education. The only necessary changes would be to the commissioned topic and targeted UG population with specialist subject knowledge [47]. As such, this model can be applied beyond CSE and the UK context, dependent on the commissioning environment, UG population and school curriculum and resource needs.

7 CONCLUSION

We presented our work toward the formation of a HOPE for computing, within the context of university-school partnerships. The process entailed university students working with schools to deliver computing in local schools.

Overall, the project helped to outline the tensions and challenges in creating and sustaining educational relationships between universities and schools, and in response, our findings point to a series of elements to be considered when developing an infrastructure for HOPEs for computing education.

In addition to an updated process, we propose the development of a technological platform to better support school and university partnerships. This can be the beginnings of a formation of a HOPE for computing.

ACKNOWLEDGMENTS

We would like to thank all participants for their time and input. This work was funded under the EPSRC Centre for Doctoral Training in Digital Civics at Newcastle University (EP/L016176/1). Data supporting this publication is openly available under an 'Open Data Commons Open Database License'. Additional metadata are available at: http://dx.doi.org/10.17634/154300-101. Contact Newcastle Research Data Service at rdm@ncl.ac.uk for access instruction

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