2006-1515: BUILDING AND ASSESSING CAPACITY IN ENGINEERING EDUCATION RESEARCH: THE BOOTSTRAPPING MODEL

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Building and Assessing Capacity in Engineering Education Research: The Bootstrapping Model

Abstract

Improvements in engineering education will depend to a great extent on the availability of sound engineering education research. But how does a researcher, trained in engineering, begin to carry out *education* research, relying as it does upon non-engineering methodologies "borrowed" from the learning sciences? In response to these concerns, there have recently been initiatives in developing educational research expertise among engineering educators. In this paper we describe a multi-institutional, multi-national model (which we call *Bootstrapping*) designed to support education practitioners in Computer Science in undertaking high quality educational research. The *Bootstrapping* model comprises a set of integrated activities focused on specific acts of collaborative research called *experiment kits.* An experiment kit is embedded in a one-week workshop, in which particpants learn and practice appropriate research methods. Participants gather data over the course of a year and twelve months later, join a second one-week workshop where they share results, analyze data, plan for reporting and dissemination, and design additional studies. We have run two of these projects in the United State, funded by the National Science Foundation. We also discuss measures by which we might gauge the success of these capacity-building endeavors, anchored in Wenger's concept of *communities of practice.* Using participant responses to email questionnaires, we apply these measures to the two instantiations of the *Bootstrapping* model. This qualitative analysis indicates a dense network of continuing research collaborations, and provides strong evidence for the "shared histories of learning" that characterize communities of practice which extend over time.

Introduction

Computer Science Education (CSEd) research is a hybrid field that requires interdisciplinary knowledge. Although most of CSEd research is now based within Computer Science departments, disciplines on which the speciality draws include Computer Science, Psychology and Education. There is no clear entry point — or entry process — for researchers new to the field, whether graduate students or faculty seeking new directions; their enthusiasm may be dissipated in searches for relevant material, paradigms, and support — they need a 'way in'.

Because of the peculiar nature of the requirements for the subject, it is often the case that there are at most one or two staff members in any given department with the necessary knowledge and expertise. This isolation has meant that CSEd research itself has developed in a number of diverse ways, making it difficult to consolidate results from different studies in a meaningful way. Because there is not yet a visible hub, CSEd researchers tend to remain isolated within their departments — they need a community.

This paper has two goals. The first goal, addressed in the first half of the paper, is to describe our model for research-capacity building that responds to the lack of entry points and the isolation of the novice CSEd researcher. We call this model *Bootstrapping Research in Computer Science Education* (hereafter *Bootstrapping*). We describe the sequence of designed activities that comprise the model, arguing that these designed activities can be understood as enabling the emergence of a *communiy of practice.*[7] The second goal, addressed in the second half of the paper, is to develop measures of success for this model. These measures include not only the

visible indicators of success, such as resulting publications and replications of the model, but also *invisible* (but no less important) *indicators*, such as ongoing research collaborations among project participants, and increased activity of project participants within the wider discipline-based education research community. We apply these measures to the two instantiations of the *Bootstrapping* model that we have undertaken to date. Finally, we end with four open questions for our project and others like it: Where is the locus of a community of practice? Who are the core members? Do capacity-building models transfer to other disciplines? Can our theoretically-motivated measures of success apply to other projects of the same nature?

The Bootstrapping Metaphor

The term *bootstrapping* is short for "pulling oneself up by the bootstraps" and has a specific meaning within computing. "In computers, this term refers to … processes whereby a complex system emerges by starting simply and, bit by bit, developing more complex capabilities on top of the simpler ones." [9]

In naming our project, we used the metaphor in three distinct senses, reflecting our goals to impact three distinct, though interacting, levels:

- *bootstrapping the novice CSEd researcher* by providing entry points into the theory and methods of carrying out CSEd research;
- *bootstrapping a community of practice* of CSEd research practitioners with similar skills, practices, and language for engaging in shared research endeavours; and
- *bootstrapping the wider CSEd research community* by establishing a critical mass of researchers with rigorous practices and standards for carrying out and evaluating CSEd research.

We viewed the community of practice, the second of these three levels, as the most important, a bridge from the individual to the emergent discipline as a whole. But how does one create a community of practice when none exists?

In *Communities of Practice: Learning, Meaning & Identity,* Wenger[1] identifies "three dimensions of the relation by which practice is the source of coherence of a community" (p72/3). We used these as key design principles. These dimensions are:

1. *mutual engagement*: membership in communities of practice is enacted through the dynamic and continuous interactions on issues of shared interest and meaning.
2. *joint enterprise*: community is sustained through emergent projects and plans that the members themselves negotiate and hold one another accountable to.
3. *shared repertoire*: through mutual engagement on shared enterprises, members develop a shared set of "routines, words, tools, ways of doing things, stories, gestures, symbols, genres, actions or concepts that the community has produced or adopted in the course of its existence and which have become part of its practice" (p83).

In the *Bootstrapping*-model we addressed these as practical issues and created a sequence of designed activities to create the "shared histories of learning" that Wenger claims characterize communities of practice that extend over time. Though these activities were focussed on the bootstrapping of a community of practice, they were intended to simultaneously bootstrap at the individual and at the wider CSEd research community levels.

Project Design & Structure

The *Bootstrapping* model has the following major constituents:

- *Workshops*: Intensive four-day workshops attended by approximately 20 international CS educators in two successive years.
- *Experiment Kit*: A shared empirical research study in CSEd, carried out by each participant in the intervening year between the workshops.
- *Individual Scaffolding*: The scaffolding for participants to undertake new research studies in CSEd.

This model secured NSF funding and was instantiated with two consecutive cohorts, the first beginning in 2002, with 21 participants recruited from 6 countries, and the second beginning in 2003 with 18 participants recruited from 4 countries. Participants were selected from submission of a position statement and all workshop expenses were met for US participants (who were primarily from comprehensive four-year and liberal arts universities), international attendees were self-funding. This paper reports on both experiences.

Workshops

Workshop one was topic-oriented. The intention was to provide an overview of CSEd research and to enable participants to think about how to do research in CSEd. Participants came to the workshop with considerable depth in the field of Computer Science, experience in teaching Computer Science being a requirement for entry. They had insight into the CSEd issues that are interesting to investigate, but without the skills and experience in educational research to allow them to undertake such investigations. Each workshop day was themed (day one "Putting research methods in context", day two "How to ask questions and how to seek answers", day three "Working from purpose to technique" and day four "Introduction to, and practice with, the experiment kit") and contained a combination of delivered material, guided discussions, and practical exercises. Additionally, each day, there was time for participants to consider their own research questions as a way of reflecting on the material to date.

In the year between the two workshops, participants undertook the research study defined in the experiment kit, designed so that each participant undertook the *same* study in their own classrooms and institutional contexts. Execution of the experiment kit was one of the ways in which we fostered the experience of *joint enterprise*. Community meaning for the experiment kit was mutually negotiated by the participants in their separate, although co-ordinated, acts of conducting the research it prescribed. Attendance at the second workshop was conditional on completing the experiment kit work, on contributing data to the collective.

Workshop two was task-oriented, focussed on two tasks. Firstly, the group worked to analyse the aggregated data from the experiment kit, and jointly write a paper to report it. Secondly, each participant worked on a design for their own research study. In contrast to workshop one, most of the input in this workshop was from the participants, presenting and discussing their experiences of using the experiment kit to completion, and reflecting on research in general. The tasks of the workshop leaders were in structuring interventions to maximise the effectiveness of the analysis and writing, and in working with participants on their new study designs.

The Experiment Kit

What we have called an "experiment kit" is a research problem defined by a principal investigator (in this case the workshop leaders). It details the design of a relevant study from methodology to analysis, and situates the study in its theoretical context (readings, case studies and further references). An experiment kit should contain everything an individual researcher needs to understand and undertake their portion of the study. This includes all material to be given to the study participants, model applications and consent forms for human subjects review the individual data collection and analysis protocol, and copies of papers which are core reference material for the investigation.,

The experiment kit used with the first cohort was focused on the conceptual foundations of programming skills in first- and second-year undergraduate students, that used with second concerned understanding characteristics of student-generated software designs. Both experiment kits, and details of the publications arising from them, are available at: http://www.cs.kent.ac.uk/~saf/experiment-kits.

The ultimate aim of the *Bootstrapping*-model was that it would graduate people who could design and work on their own small-scale studies, but that was an impossible goal for the intervening year. Not only is that precisely the kind of activity that suffers from "post-workshop" isolation, but also the participants were not research-mature enough to act as constructive support for each other (in a design-critique-iterate model). The shared study provided experience of what doing disciplinary-education research means, and entails, in its specifics. In this way, although geographically distributed, the participants started to develop a *shared repertoire*. As importantly, the experiment kit (and its execution) became a "boundary object"[1] (p105) to which everyone had an interface; it gave common vocabulary, common experience and common identity.

Scaffolding Research Skills

In the *Bootstrapping*-model, we scaffolded the development of the skills and knowledge required to undertake independent research in several ways. First, during both workshops, participants were provided with "theoretical pitons" for conceptualizing the major steps of an entire piece of research, from conception through design and enactment to publication. These principles were drawn from the "Six Guiding Principles of Scientific Research" detailed in *Scientific Research in Education*[2]. This provided a transferable vocabulary, and could serve as a transition between the workshop presentations and experiences and emergent research work in the individual's local context.

A second scaffold was to actively engage participants in each of the identified research steps, only undertaking their own study designs after first "walking through" many of these steps in the context of the experiment kit.

Third, we did not regard individual study design as a private process. In our view research takes place within a community of researchers. Particular research communities determine the range of questions that its members pursue, the kind of evidence that is accepted to adjudicate truth claims, and the methods that are used for acquiring evidence. Our aim would not be fulfilled if participants grappled with their research questions (and the operationalisation of them into studies) silently and alone. We facilitated this with frequent public presentations and critiques of participants' evolving study designs. Throughout the workshops each study author used a "study

display", a public representation of their study around which all other participants could interact throughout the workshops. a further instantiation of *mutual engagement* between the participants. Because these "living documents" were always there and always available, many discussions became physically located with the record of the ideas.

These were very specific and situated aspects of our designing for a community of practice. As Edwin Hutchins notes

> "limits on observation of the activities of others have consequences for the knowledge acquisition process. This is so because they define the portion of the task environment available as a learning context to each task performer. Let us refer to the outer boundary of the portion of the task that can be seen or heard by each team member as that person's horizon of observation"[3] p.52

By our use of these public displays, we brought community practices within the horizon of observation of every participant and in this way concretely modelled scholarly—and community—discourse in disciplinary-specific pedagogic research.

Other Models Of Capacity Building In Disciplinary-Specific Pedagogic Enquiry

The *Bootstrapping*-model is only one in a number of recent programs to build disciplinary-specific educational research communities. Other programs include the *Carnegie Scholars Program*[4] (CASTL) , *Conducting Rigorous Research in Engineering Education*[5] (CRRE) and the *CAEE Institute for Scholarship on Engineering Education*[6]. Although there are similarities (and differences) in the model of delivery, these initiatives share common aims.

CASTL describes itself as "Neither an award for teaching excellence, nor a teaching-improvement workshop, the Carnegie Scholars Program has as its purpose the creation of a community of scholars"; RREE series has the twin goals to: "Create and present workshops for engineering faculty on conducting rigorous research in engineering education", and to "Sustain the development of this project through establishing a community of practice." For the CAEE Institutes "The main goal is to foster a diverse cadre of leaders and change-agents in engineering education who can conduct high impact research." So, in seeking criteria for success in *Bootstrapping* it seems likely that such measures could apply to these other *Bootstrapping*-like endeavours which share similar aims and so, presumably, seek similar outcomes.

It is striking that each of these projects brings people together for a "workshop" (most often more than one) during which time the participants will not only learn about methods and techniques of discipline-specific educational investigation, but also achieve the wider aim of forming a *community*. How then do we measure the success of these endeavours?

Measures of Success

"Can they do it?": Visible indicators

If one of the aims of a project is to help participants undertake discipline-specific educational research, then whether they are able to do that might be measured by what we term "visible" indicators, those overt signs of participation in the discourse *via* normal academic routes: workshops, panels, posters and papers at conferences, papers in journals, and grants awarded. The CSEd research publications – 31 to date – resulting from the *Bootstrapping* experiment kits and subsequent CSEd research collaborations by participants cover the spectrum of type of

publication (extended abstract, panel at a conference, workshop, conference paper, journal paper) and have appeared in a range of venues, all of them peer-reviewed.

Another category of visible indicator of success is replication and adaptation. The *Bootstrapping*-model was instantiated a third time in Australasia (as Building Research in Australasian Computing Education: BRACE) organised by two co-ordinators (one a participant of the first *Bootstrapping* cohort, one a participant of the second) and engaging the original workshop leaders. *Bootstrapping* participants have also adapted the model (or aspects of it) in two new, large-scale multi-institutional research studies involving both graduates of the Bootstrapping workshops combined with new recruits. These overt signs provide clear evidence that participants have been mutually engaged in joint enterprises.

"Are they doing it?": Invisible indicators

If accepted publications represent research activity, then we may assume that they don't represent the whole of that activity. On enquiry, we also found several other indicators that leave less public traces. Data reported in the rest of this section was gathered by email solicitation from both *Bootstrapping* cohorts. Quotations have been anonymised as to identity, but gender in the names has been preserved, and forename is used only where the respondent used forename only, forename and family name where they used forename and family name. The data that resulted from our solicitations were many and varied, but some common categories emerged. We discuss three of these: Professional Activity, Further Collaborations and Local Effect.

Professional Activity: many participants talked of engagement with the broader research community as mediated by their *Bootstrapping* contacts. Reviewing for conferences, and especially journals, was mentioned as valuable in this context:

> "I helped Neville review some papers for his CCSC conference last year. I'm an external evaluator for a CCLI grant run by Hermione, one of Ron's colleagues. Ron recommended me for the position because of our bootscaf [sic] connections, and Hermione considered me qualified as a result of my participation."

Further Collaborations: Active collaborations generate the visible indicators of participation and also build the mutual relationships which result in further engagement. In addition to the collaborations that have already matured to produce visible indicators of publications and grants, other collaborations exist and are developing work products that can be shared.

> "Another large group is meeting weekly online, doing a literature review on debugging and related topics. It is currently lead by Fiona Ackley and includes from west to east, Edmond, me, Sarah Perkins, Jane Roberts, Grant Chen, Victoria Kaupe, John Kacerowski, and Claudia LaFarge."

It is worthwhile noting that this collaboration represents five time zones on three continents. In another report, the "can-do" collaborative project described by one respondent demonstrates appropriating the opportunity offered by existing events such as conference attendance to organise face-to-face collaborations:

> "**Can-do" project**: **Participants**: Susan Hunt, Sarah Broadleaf, Thomas Silverstone, Harry Shumway, Syd Green, Darlene Capulet. **Description**: Trying to understand what students know … before they start taking CS courses. … **Status**: Outlined the project in July, 2005 (at NSF CCLI panel reviews in DC), initial data collected early

in the fall semester/quarter, discussion of initial data in September, 2005 (day before ICER in Seattle), more data being collected to be discussed within next few months (hopefully).

Local Effect: sometimes instead of, sometimes as well as, activities of Professional Activity and Further Collaboration a number of participants reported working in their local context to extend and support their CSEd research interests:

> "Following *Bootstrapping*, I started a local CSEd research group with faculty in my department at Poppleton University. I would not have had the confidence to do this without the *Bootstrapping* background."

Taken as a whole, these invisible indicators indicate the kind of mutual engagement and generation of shared repertoire characteristic of communities of practice.

Open Questions

Whilst we have identified several indicators of success aligned with Wenger's three dimensions of coherence for a community of practice there nevertheless remain open questions:

1. Where is the locus of *Bootstrapping*? It is clear that, at one time, *Bootstrapping* existed in a time and place. Subsequently, as the community members disperse, it is increasingly hard to say "where" *Bootstrapping* exists. It may be concentrated in the various activities of community members; it may coalesce in the observed opportunistic appropriation of other professional events to support face to face encounters; or it may be dispersed through expansion as an increasing number of "outsiders" are recruited as collaborators.
2. Who are the core members of the *Bootstrapping* community of practice? Wenger [7] describes a feature of communities as having central and peripheral members. For *Bootstrapping*, however, this model is problematic. It would be hard to define criteria to judge who were the central members of the *Bootstrapping* community – those who have the most publications? Those with the most collaborations? The most unique collaborations? Those who have initiated the most subsequent replicative or adaptive projects? Any one of these candidate criteria might describe a centre, or central participant, and in doing so would put some participants there and others further away. Which one might be more accurate, or useful, is unclear.
3. Does this model transfer to other disciplines? Bootstrapping as we did at three levels (individual, community of practice, and broader research community) was in response to the sociological and historical context in which CSEd currently exists. But might the pragmatic approach that we used be more strongly resisted if the participants had come from a discipline with more rigid paradigmatic practices for investigating social and behavioural truth claims? Or would these *disciplinary ways of knowing*[8] serve as a head start to doing disciplinary *education* research, serving as an advantage rather than a hindrance?
4. Can our theoretically-motivated measures of success apply to other projects of the same nature? Whilst it is our intention that they do, our measures can only be applied to projects that are suitably mature and have sufficient public accounting to populate the framework and allow meaningful comparison along these dimensions. But we see two distinct advantages of attempting to generalize these measures beyond the bounds of any

single capacity-building endeavour. First is to work towards the development of transferable principles to provide heuristic guidance in the deliberate creation of research communities; uncovering the relationship between specific characteristics of an intervention and subsequent outcomes will certainly be a necessary prerequisite for defining such principles. Secondly, we are hopeful that for those brokers of communities of practice with goals consonant to *Bootstrapping,* foreknowledge of measures of success, even in the absence of theoretical principles linking intervention to outcome, will help in the design of such capacity-building efforts. At the least it might sensitise such brokers to the non-obvious indicators of a vital community which might otherwise go unlooked for and unnoticed.

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