INTRODUCTION

In September 2013, Outlier Research and Evaluation of the Center for Elementary Mathematics and Science Education (CEMSE) at the University of Chicago together with the University of Chicago Urban Education Institute (UEI) completed an unprecedented collaborative research and communication effort to establish a more comprehensive understanding of high school computer science (CS) education. The study, titled “Building an Operating System for Computer Science Education” (OS4CS) (http://cemse.uchicago.edu/computerscience/OS4CS), has five major components: (1) the Professional Development Landscape Study (a survey of high school CS professional development offerings); (2) the Teacher Capacity Study (a survey of current high school CS teachers, their experience, and the contexts in which they teach); (3) Stories from the Field (stories of computer science education growth efforts); (4) the CS in Schools Study (perspectives from computer science teachers and their school administrators); and (5) the Design Studio (a meeting of CS professional development providers). While each component of the study can be examined independently, when considered together they provide a broad view of the issues affecting CS education through the lenses of different stakeholders.

The OS4CS study was the first of its kind in the United States to examine the high school CS teaching population, CS teachers’ needs, the contexts and conditions under which they work and the resources available to them. And yet, it is only a beginning. Much more work is still to be done to provide a systematic and comprehensive understanding of computer science learning, teaching, leadership, and to develop shared goals for quality CS education.

The OS4CS study identifies five major challenges that repeatedly surfaced across the five study components (see http://cemse.uchicago.edu/computerscience/OS4CS/challenges/). This white paper highlights one of those challenges: “More Comprehensive, Quality Instructional Resources Are Needed.” The urgency of this challenge is most clear when contextualized by the intention to provide quality computer science education to dramatically many more learners, including those from historically underrepresented groups. There are many current and emerging summer camps, after-school programs, online environments and other educational resources; however a more direct and consistent way to reach to learners is through our nation’s public school system. There is little chance of universal access to robust computer science learning if it does not become part of the regular school instructional experience. A core element of that experience is comprehensive, quality instructional resources. When carefully developed and tested through collaborations between curriculum developers, teachers, and schools, instructional resources can help develop teachers’ content and pedagogical knowledge and increase teachers’ abilities to “achieve productive instructional ends.” Quality instructional resources are a key element of the systemic change that must happen if quality computer science education is to be accessible for all.

1 This paper uses the phrase “comprehensive, quality instructional resources” to refer to a collection of research-informed, designed instructional materials for teachers and students (that may include written materials, on-line materials, manipulatives, computer-based activities, and a variety of other resources) that reflect the best of what is known about pedagogy, disciplinary content sequencing and development and pedagogical content knowledge. They tend to have an internal coherence that connects ideas and lessons throughout, and be “educative” for both students and teachers.
THE RESEARCH AGENDA

A focus on comprehensive, quality instructional resources provides a framework for a series of cohesive, complementary studies. The framing research question is:

*What are the best designs and delivery systems for computer science instructional resources and how should they be developed in order to maximize student and teacher learning at scale?*

This question cannot easily be answered by a single researcher, study, or research group, and as such, emphasizes the importance of building a coherent, collaborative research community. It requires that investigators conduct a wide range of research efforts including those that examine learning processes, teaching strategies, content sequencing, and instructional resource usability and adaptability, to name only a few. With a focus on creating instructional resources that can be used at a large scale, the question highlights the importance of translating findings from these studies into actual instructional resources that can become tools for teachers and schools to use, as they become part of computer science education expansion in this country.

The research agenda represented by this broad question will necessarily leverage the work of others and require the range of study types outlined in the *Common Guidelines for Education Research and Development* (2013). Some researchers will undoubtedly pursue research streams that require foundational studies examining cognition and learning processes in computer science. Knowledge of CS learning, in combination with what is known from other disciplines, is an essential part of the work required to inform instructional resource development. Others will likely examine specific teaching strategies including the experience and background needed to execute those strategies and their effectiveness for particular populations and settings. Translating current and emerging knowledge of computer science teaching and learning to operational interventions (i.e. instructional resources) will necessarily be an iterative process requiring “Exploratory Research” that then will contribute to “Design and Development Research” and ultimately “Efficacy and Effectiveness” studies. This is an exceptional opportunity for the computer science education community to make a decision that educators and researchers in other disciplines have not had the opportunity to make given the long evolution of those disciplines in our nation’s schools: to work closely together, collaboratively, to build essential groundwork that will, in the longer term, lead to important strides in computer science teaching and learning.

Research Questions

For many, the term “instructional materials” conjures up negative images of textbooks that encompass passive learning approaches and rote memorization. Although these assumptions are well-grounded in experience with what has become known as “traditional instruction,” history also has another story to tell. Alongside the long-standing use of more traditional materials, our nation has also made investments in instructional resources that are student-centered; that focus on actively engaging students in a discipline through problem-solving and collaboration; and that help teachers make well-informed decisions about instructional strategies and communication of content (Salinger, 2007; DeBoer, 1997). The kinds of approaches embedded in what some refer to as “reform-based” or “standards-based” instructional materials are very compatible with the kinds of computational thinking, problem-solving, and collaboration learning targets articulated in the Computer Science Teachers Association’s (CSTA) K-12 Computer Science Standards (2011), the College Board’s Computer Science: Principles Computational Thinking Practices (2011), and others. The computer science education community is now well-positioned to leverage what is known about instructional materials in other disciplines, as well as new knowledge about computer science teaching and learning as it emerges. Building on this, researchers can conduct exploratory, development, and efficacy studies that will help support the highest quality computer science teaching and learning experiences for all teachers and students.
Instructional resource design
Looking at the over-arching research agenda, one clear research strand must focus on instructional resource design. In this case, design refers to the content, pedagogy, and organization of the teaching/learning experiences. More specifically, design questions may include:

1. **What disciplinary content should be included in instructional resources for primary/early elementary learners?** Upper elementary learners? Middle school learners? High school learners?
2. **How should that content be sequenced?**
3. **What is the appropriate balance of content type (e.g. concepts, processes, procedures, facts) in different contexts?**
4. **How might design differ based on teacher experience?**
5. **What are the most productive assessment system designs for informing instruction?**
6. **What pedagogical strategies should be embedded in the instructional resources?** How should lesson organization and flexibility reflect those strategies?
7. **What parts of the content, pedagogy and design are essential and which parts are optional?**

The last two research questions above touch on a particularly timely issue. Adaptability and flexibility is important for local teacher decision-making, instructional differentiation and customization. Relatedly, school districts may need to adapt a program in order to meet particular instructional requirements. However, more traditional instructional materials create static bodies of knowledge and structures. This is an issue confronting instructional materials developers in other disciplines, and is perhaps even more relevant to CS education. In a field that is rapidly evolving, research focused on the nature and extent of effective teacher adaptation and customization of instructional materials is especially important to curriculum development and instructional resource design and can create examples for instructional resources in other disciplines.

**Delivery systems**
The research agenda question also articulates the importance of delivery systems. This is referring to the media through which pedagogical and disciplinary content are communicated to teachers and students. While textbooks may historically be the most common, other quality comprehensive curricula have taken other forms including “modules” or “kits” that contain teacher and student written materials and manipulatives; on-line resources; and new media tools that support teacher and student collaboration. The computer science education community has an opportunity to capitalize on what is already known about instructional delivery resources to determine which of those approaches will work best for computer science, in combination or alone, with which groups under which conditions. This is where research questions related to the delivery system will enter the conversation. Delivery system questions may include:

1. **What are the best media to use for CS instructional resources?**
   a. Which media are best for different disciplinary content areas?
   b. Which lend themselves to the most desirable pedagogy?
2. **How adaptable can and should instructional resources be?** By whom? In which contexts?
3. **What features will make the materials as easy to use as possible?**
4. **Which aspects or components of the delivery system should be prioritized in which contexts?** (e.g. distribute media first, or PD first, or simultaneously)
5. **How can instructional resources be designed to help accumulate knowledge and inform a growing knowledge base about CS teaching and learning?**
Computer science education is on the brink of enormous possible growth. In order to realize this potential, computer science education advocates must have tools that will support the human and organizational capacities needed to advance computer science education in schools. In a review of science education reform, Powell and Anderson (2002) highlighted the importance of instructional resources, commenting that “curriculum materials can and should play a vital role in educational reform.” (p. 130). More specifically, at this time when computer science education demand and computer science teacher supply will almost certainly change in uncertain ways, quality comprehensive instructional resources will:

1) Support New Teachers: First, new computer science teachers don’t necessarily know where to look for coherent, clear guidance about computer science content and the best approaches for teaching it (http://cemse.uchicago.edu/computerscience/OS4CS/es-schools-study/teachers/). As computer science education expands in more locations and across multiple grade levels the nation will need more teachers. CSTA and other formal and informal networks provide some support for new CS teachers, but instructional resources can provide immediate, concrete guidance for teachers every day. The OS4CS study found that only 35% of high school computer science teachers who responded had degrees in computer science, and that over half of the respondents were the sole computer science teachers in their high schools. As demand grows, particularly at lower grade levels, the likelihood that teachers new to computer science instruction will have CS backgrounds diminishes, and they will have few immediately near them who can provide ongoing support. This is an opportunity to create instructional resources that Ball & Cohen (1996) suggest can become more “central to teacher learning.” (p. 7)

2) Support Experienced Teachers: Instructional resources are an excellent foundation for teachers with all ranges of experience. Instructional resources aren’t intended to dictate instruction; rather, they are intended to provide a strong, clear base for instruction that skilled teachers can then appropriately adapt. Quality instructional resources are most often developed through collaborations between content experts, curriculum development experts (who are often former teachers themselves) and master teachers with the intention of creating the most usable tools for the widest range of teachers. Teachers who participated in OS4CS studies noted that in recent years they have been able to find increasing numbers of lesson ideas online. But there is no knowing the quality or efficacy of those resources with regard to content and pedagogical fit for a particular teacher’s students. The OS4CS study noted, “without a variety of fully developed and coherently designed instructional resources to choose from, teachers are left on their own, which for even the most creative and persistent teacher can be stressful and time consuming.”

Quality comprehensive instructional resources provide teachers with foundational content and pedagogy knowledge and ensure that teachers don’t need to “reinvent the wheel” for each course, lesson and activity. Ball & Cohen (1996) acknowledge that instructional materials – particularly traditional ones – are viewed as constraining and limiting. However, quality instructional resources don’t create those boundaries. Rather, they become tools for supporting creativity and independence by relieving teachers of the need to find basic activities so they can customize, enhance, and most importantly, adapt them for their immediate students’ needs.

3) Support Spread and Access: As increasing numbers of schools and school districts seek to incorporate computer science education into their K-12 instruction, they can rely on quality comprehensive instructional resources to inform their implementation, scale-up and communication efforts. Instructional resources informed by a strong research agenda will provide clear descriptions of what computer science is (and is not), learning goals and outcomes for computer science education, sound assessments, and daily lessons/projects/activities that are carefully designed to help realize those goals and outcomes. Carefully designed and tested instructional resources are a necessary component of a support system for efficiently and coherently bringing changed practice to an educational setting.
4) **Support Equity:** Research-informed instructional resources will help bring consistency to computer science teaching and learning, ensuring that all students have opportunities to learn quality computer science. Research-informed instructional resources can be vehicles for defining what is most important for students to know and be able to do. Further, they will help communicate to teachers the best pedagogical strategies for teaching particular content with particular audiences. Instructional materials can help teachers organize instruction so that it appropriately addresses the range and sequence of content appropriately, but also allows for principled adaptation and flexibility based on students’ experience, needs and interests. Thus, instructional resources create a baseline, a guide for the content and experiences all students should have access to so that student experience is not completely dependent on the background, knowledge, and preferences of the teacher alone.

**IMPACT, REACH AND BENEFITS**

The computer science education community is already engaged in discussions about the best approaches to teach computer science. A research agenda focused on research-informed instructional resources shifts the discussion from personal experience and opinion to empirical investigation. As in other disciplines, there is likely no single best way to teach computer science, because there is no single group of computer science teachers and no single group of computer science learners. There should be a range of instructional resources that fit best with particular contexts and conditions. Instructional resources may take different approaches, but should all reflect the best of what is known about effective computer science teaching and learning and all point towards the same learning goals for students. Moreover, they should be clear about how that knowledge is operationalized within instructional resources. A research agenda focused on research-informed instructional materials provides the overarching framework that can bring consistency and coherence to that discussion.

Some CS instructional materials exist. But such a research program will lead to comprehensive instructional resources available to teachers nationally for all age groups PK-12. An essential part of providing access to computer science education for all students will be established. Just as important, it will have been established in a way that allows for continuous learning and growth. There will never be a single instructional resource that will be the ideal for all teachers and all students but there can be a coherent, collaborative and communicative process for developing knowledge about the best resources.

The computer science education research community has many unknowns and many unanswered questions. No single study will provide the answer to any question. This is the beginning of a process that will include foundational, exploratory, development, efficacy, effectiveness, and implementation studies that, as the field grows larger, can inform one another in an ambitious but achievable iterative cycle. As the Common Guidelines for Research and Development state, there is no single linear path. That necessitates the need for communication and collaboration around research agendas; clear articulation of where those research agendas do and don’t overlap and how they can inform one another. With this research agenda, computer science education has an opportunity to become a leader regarding the development of innovative research informed instructional resources.

**References**


