The Impact of Pen and Touch Technology on Education
Human-Computer Interaction Series

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HCI is a multidisciplinary field focused on human aspects of the development of computer technology. As computer-based technology becomes increasingly pervasive – not just in developed countries, but worldwide – the need to take a human-centered approach in the design and development of this technology becomes ever more important. For roughly 30 years now, researchers and practitioners in computational and behavioral sciences have worked to identify theory and practice that influences the direction of these technologies, and this diverse work makes up the field of human-computer interaction. Broadly speaking it includes the study of what technology might be able to do for people and how people might interact with the technology. The HCI series publishes books that advance the science and technology of developing systems which are both effective and satisfying for people in a wide variety of contexts. Titles focus on theoretical perspectives (such as formal approaches drawn from a variety of behavioral sciences), practical approaches (such as the techniques for effectively integrating user needs in system development), and social issues (such as the determinants of utility, usability and acceptability).

Titles published within the Human-Computer Interaction Series are included in Thomson Reuters’ Book Citation Index, The DBLP Computer Science Bibliography and The HCI Bibliography.

More information about this series at http://www.springer.com/series/6033
The Impact of Pen and Touch Technology on Education
We are in perhaps the most exciting and demanding era of education change. These changes include entirely new interfaces for expression and communication; pen and touch computing are among these new interfaces. This monograph features applications and research that are integral to realizing the promising and often extraordinary advances in technology and education. Applications of ink-based computing—such as those from current tablet and surface computing devices—have demonstrated compelling and often transformative advantages over traditional keyboard/mouse interfaces for promoting student learning and effective educational practice. These applications motivate a new landscape for such interfaces to alter the use of technology enabling effective collaboration and learning experiences.

In the four years since the last monograph, the presence of hand-held computing devices in education has significantly increased. Touch interfaces on Android and iPad tablets and phones have enabled them to join Windows-based Tablet PCs in the classroom and research lab. Microsoft is again focusing on digital ink across its product line, including their new Tablet PC hardware, and Windows has added touch as a primary interface method on tablets and other small devices.

The pedagogical benefits of sketching have been shown to be enormous. Students retain information better, students better internalize ideas, and students are better able to discuss their ideas with drawing. Many of the papers that follow reflect and demonstrate these benefits.

Purpose of the Monograph

This edited volume is inspired by the research presented at the Workshop on the Impact of Pen and Touch Technology (WIPTTE) over the last two years, a conference dedicated to providing and evaluating change. WIPTTE provides an excellent opportunity to present and share innovative applications and research. The conference is intended to leverage a shared passion for the potential educational use of pen and touch-based computing, such that educators and researchers alike may benefit from and contribute to new emerging interfaces.
The beauty of WIPTTE is in the multi-contextual diversity of the attendees. As opposed to standard conferences that focus on a single type of clientele, WIPTTE has a wide variety of participants who bring an array of different types of knowledge together. Past attendees hold a wide range of positions with academia and industry; from K-12 teachers and administrators to university deans; from sales directors to systems engineers. The participation list speaks well of the diverse group of individuals impacted by the WIPTTE conference. The papers included in this monograph include reflections from these various perspectives. WIPTTE 2014 had 150 attendees who had flown in from at least 8 different countries, highlighting the international impact the topic has.

This monograph represents selected papers from the 2013 and 2014 WIPTTE conferences which provide solid evaluation data and discuss new and existing applications of digital ink and touch and the proven impact they have on pedagogy across disciplines. At the same time, it reinforces the ongoing research interest in digital ink as a powerful tool for education with a promising future—six authors of a paper in this monograph are high school students themselves.

Combined papers from current and previous monographs have reported on studies involving many thousands of students and many hundreds of educators from Pre-K through higher education at institutions around the world and in a very broad spectrum of academic disciplines.

Monograph Organization

This book is organized into four sections. The first section presents a perspective by one of our keynote speakers. The second section presents emerging technologies for integrating pen and touch technologies in classrooms and early childhood development. Most of the technologies in this section were invented by the authors, and each paper identifies the success of these technologies in scientific deployments. The third section presents papers regarding technologies in practice. Papers in this section offer perspectives of classroom educators regarding the success of pen and touch technology integration in their own classrooms or schools. The final section contains papers that propose works in progress—systems that are not complete yet, but that hold great promise for pedagogical effectiveness.

WIPTTE Venue 2013

WIPTTE 2013 included a diverse set of enriching experiences including academic and practicum talks and tutorials, and hands-on workshops. WIPTTE 2013 was held at Pepperdine University in Los Angeles, California. In 2006 and 2007, the Princeton Review ranked Pepperdine first on the “Most Beautiful Campus” list, and highly on the “High Quality of Life” and “Dorms Like Palaces.” The Peace Corps
of America named Pepperdine University to be “One of the Top Producing Colleges and Universities.” US News and World Report Ranked Pepperdine University as the 53rd best national university for undergraduate education. Pepperdine University’s Dispute Resolution program in the School of Law is first in the nation. US News and World Report ranked The School of Law 54th across the nation’s law schools and the Graziadio School of Business and Management at 82 compared against the nation’s business schools. Forbes magazine ranked the Fully Employed MBA within the top 20 when examining return on investment.

**WIPTTE Venue 2014**

WIPTTE 2014 included a diverse set of enriching experiences including academic and practicum talks and tutorials, campus research tours, grant and networking breakout sessions, hands-on workshops, a high school contest, and social events, including a banquet at the local winery. WIPTTE 2014 took place March 12-15, 2014. WIPTTE 2014 was held in College Station, Texas on the Texas A&M University campus, *Home of the Fightin’ Texas Aggies.* The Dwight Look College of Engineering is consistently ranked in the top ten by US News and World Report. Texas A&M boasts the following:

- 1st in Texas in student retention and graduation rates – overall and for minorities
- 1st in nation in “payback ratio”—what graduates earn compared to the cost of their college educations, *Smart Money* magazine
- 1st in Texas and 8th among public universities in New York Times survey of business leaders worldwide based on the top institutions from which they recruit, 2011
- 1st in Texas and 17th nationally as “best value” among public universities, Kiplinger, 2013
- 2nd in nation for preparing graduates for the workforce, *The Wall Street Journal*
- Top 10 in nation for return on investment, or what graduates earn in their careers compared to their college costs, *PayScale*
- Top 10 in nation among public schools in earnings of alumni with 10–20 years of experience, *Forbes*
- 2nd in nation in a survey of top U.S. corporations, nonprofits and government agencies, based on graduates recruiters prefer to hire, *The Wall Street Journal*
- 4th among U.S. public universities and 10th overall with an endowment of more than $5 billion
- 4th nationally among public universities in affordability combined with high quality education and high return on investment, AffordableCollegesOnline.org, 2013
Talks were held at the Mays Business School. The opening reception on Wednesday was held at the Benjamin Knox Gallery, a rebuilt historic College Station train depot that draws inspirations of Texas A&M University and the city’s roots when the original location of the depot marked the main entrance to the campus in front of the University’s Academic Building. The surprisingly large gallery facility is the National Art Gallery Headquarters of Benjamin Knox, American Artist and Texas Aggie Class of ’90. Thursday night’s dinner consisted of music by Possessed by Paul James, great food from the Village Cafe, and a poster session and gallery tour at SEAD Gallery. SEAD Gallery offers exhibits juried by Arts Council of the Brazos Valley, while promoting cultural and heritage assets unique to the community. The gallery is housed in the Federal Building in Historic Downtown Bryan, which also houses the Innovation Underground, both community and economic development projects by Advent GX. Over the years, the building, which was built in 1915, served as the community post office and also housed the IRS and FBI. Village Cafe is a restaurant and art stage dedicated to the community. They promote local farms and serve farm fresh eggs, locally roasted coffee beans and local produce. Each month boasts art from a different artist, and different musicians play each week. Possessed by Paul James is a one-man band (Konrad Wert) from south Austin, Texas. The music is composed of string instruments including banjo, guitar, and fiddle with written roots within folk, blues, and punk. The banquet was held at the Messina Hof Winery. Messina Hof Winery & Resort, a Texas vineyard established in 1977 by Paul and Merrill Bonarrigo, is rooted in the union of two family heritages. Winemaker Paul Bonarrigo’s family dates back seven generations to Messina, Sicily. Merrill’s family is from Hof, Germany. Breakfasts and lunches were provided on site with catering from a different local restaurant each meal. All meals and rides were provided to ensure intense collaboration amongst the participants.

**Keynote Speakers 2013**

WIPTTE 2013 had three keynote speakers: Ken Hinckley, Principal Researcher at Microsoft Research, Andries van Dam, Professor of Technology, Education, & Computer Science at Brown University, and Ken Forbus, Professor of Electrical Engineering and Computer Science at Northwestern University.

**Ken Hinckley** is a Principal Researcher at Microsoft Research in Redmond, WA. His research on sensors, mobile devices, pen computing, and pen + touch interaction has been widely covered in the press and tech blogs (MIT Technology Review, The Wall Street Journal, Gizmodo, Engadget, Slashdot, and many others). Ken holds a PhD in computer science from the University of Virginia where he studied spatial interaction with Randy Pausch, now famous as the late author of “The Last Lecture.”

Ken’s research seeks to augment the capabilities of technologies and user experiences to match human abilities, skills, desires, and expectations. His work has often involved exploration of novel input devices and modalities, unusual sensors
and device form-factors, with a dash of panache and a well-lets-just-try-it-and-see-if-it-works sensibility about things. He has a firm belief that you can learn a great deal by observing the natural behaviors of users and an equally firm belief that users can’t tell you how to design an outstanding user experience. Sometimes you just have to put together a few insights, build something new that nobody has ever thought of the need to have before, and unleash it on the world to see what happens.

Ken Hinkley’s talk discussed “The Fractured Frontier of Reading, Writing, and E-Creation.” For students, knowledge workers, and creative professionals alike, the vast tectonic shifts now taking place in the world of publishing, electronic books, device form-factors, and emerging modalities of natural interaction create tremendous opportunity to sunder new realms of innovation from the fabled Pangaea of reading. These fault-lines are visible everywhere, if only one knows where to look. The moment a serious seeker of knowledge cracks open a book—electronic or otherwise—the fissures in the traditional monolithic view of reading begin to propagate. Multiple books and papers and yellow sticky-notes tile the tabletop like a riotous mosaic of stationary. Highlights emblazon the text and notations crowd the margins. These dedicated knowledge-seekers markup articles, tear out pages, and fill note-books with handwritten insights. And from this teeming jungle of information, they synthesize and create anew. Natural ways of interacting with texts—from simple and expressive multi-touch gestures to markup with electronic pens to sensing the subtle motions of devices and their context of use-together promise, with appropriate design, to transform our experience of reading—and thereby to transform our students and other knowledge-seekers into a newly empowered generation of creative professionals. The keynote flashed a few glimpses of this new world, this e-Creation, and demonstrated some concrete technologies and techniques that illuminate the way forward. It is a many-forked path fraught with design dilemmas and unknowns, but in Ken’s view the experience of reading and interacting with electronic information has only yet begun its incredible transformation.

Andries van Dam is the Thomas J. Watson Jr., University Professor of Technology and Education and Professor of Computer Science. He has been a member of Brown’s faculty since 1965, is a founder of Brown’s Computer Science Department, and was its first Chairman from 1979 to 1985. From 2002 to 2006 he was Brown’s first Vice President for Research. His research includes work on computer graphics, hypermedia systems, post-WIMP user interfaces (including pen-centric computing), and educational software. Over the last four decades he has worked on systems for creating and reading electronic books with interactive illustrations for use in education and research.

He is the co-author of nearly a dozen books, including “Computer Graphics: Principles and Practice”, with James D. Foley, Steven K. Feiner, and John F. Hughes (Addison-Wesley 1990). He received a B.S. degree (with Honors) in Engineering Sciences from Swarthmore College in 1960 and a Ph.D. in Electrical Engineering from the University of Pennsylvania in 1966. He is a Fellow of ACM, IEEE, the American Association for the Advancement of Science, and the American Academy of Arts & Sciences, and is a member of National Academy of Engineering. His awards include the ACM Steven A. Coons Award for Outstanding Creative Contributions to
Andy Van Dam’s talk discussed “Pen and Touch Computing: From Research to Resource.” The keynote furnished multiple demonstrations of scholarship-support research from the Pen and Touch Computing (PTC) Laboratory at Brown University. Effective digital scholarship tools can sharpen researchers’ focus, augment their capabilities, extend their reach, and multiply their impact. Two such tools from Brown University are Touch Art Gallery (TAG) and the WorkTop hypermedia framework. TAG is a walk-up application for museum visitors and curators. In kiosk mode, visitors can explore arbitrarily large 2D artworks, e.g., smoothly zoom in from an overview of the famous Garibaldi Panorama, which is the length of a football field, down to the detail of individual brushstrokes, or see a guided tour in the style of Ken Burns documentaries with its visual vocabulary of slow pan-zoom, auxiliary materials, and soundtrack for narration. Authoring mode enables curators to create exhibits and tours without need for programming aid. WorkTop is an IDE (Integrated Development Environment) for scholars that provides an unbounded 2D workspace and the ability to annotate and to link and between different types of media in a consistent fashion. Research tools can, of course, extend to a wider audience. One such example is FluidMath, a commercial package for tablet computers to be used in high school or low-level college math courses that evolved from their earlier pen-computing research project, MathPad, started more than a decade ago. TAG represents another such transfer from interactive, gesture-based museum and library support research, while the WorkTop framework contains both research-support tools and publication-support tools. All these projects are pen- and touch-centric and to varying degrees use both handwriting and gesture recognition as integral parts of the user experience.

Ken Forbus is the Walter P. Murphy Professor of Electrical Engineering and Computer Science at Northwestern University, where he carries out research on qualitative reasoning; spatial reasoning, analogical reasoning and learning, and learning from natural language. In his keynote comments he addressed the CogSketch tools developed in research on spatial learning in K-12 science, technology, engineering and mathematics (STEM) education fields.

Ken Forbus’ talk discussed “CogSketch: Using human-like sketch understanding to help students learn.” Sketching is a powerful way for people to think through ideas and to communicate with others. Sketch-based educational software offers tremendous potential for improving spatial learning. This talk described work on CogSketch, which uses models of human visual, spatial, and analogical reasoning to provide a new platform for sketch-based educational software. Two kinds of educational software built on CogSketch were described. Sketch Worksheets help students learn concepts expressed spatially, such as geological faults and how the circulatory system works. The Design Coach helps engineering students become more comfortable with using sketching to communicate design ideas. CogSketch is publicly available, and efforts underway to make it customizable by teachers were discussed.
Keynote Speakers—2014

WIPTTE 2014 had three keynote speakers: Barbara Tversky, Professor of Psychology and Education, at Columbia University; Randall Davis Professor of Computer Science and Engineering, Massachusetts Institute of Technology; and Olya Veselova, Program Manager, OneNote, Microsoft.

Barbara Tversky is a Professor Emerita of Psychology at Stanford University and a Professor of Psychology and Education at Teachers College, Columbia University. Tversky specializes in cognitive psychology, and is a leading authority in the areas of visual-spatial reasoning and collaborative cognition. Tversky’s additional research interests include language and communication, comprehension of events and narratives, and the mapping and modeling of cognitive processes. Tversky received a B.A. in Psychology from the University of Michigan in 1963 and a Ph.D. in Psychology from the University of Michigan in 1969. She has served on the faculty of Stanford University since 1977 and of Teachers College, Columbia University since 2005. Tversky has led an esteemed career as a research psychologist. She has published in leading academic journals prolifically for almost four decades. Many of her studies are among the most significant in both cognitive psychology and experimental psychology generally. Tversky was named a Fellow of the American Psychological Society in 1995, the Cognitive Science Society in 2002, and the Society of Experimental Psychology in 2004. In 1999, she received the Phi Beta Kappa Excellence in Teaching Award. Tversky is an active and well-regarded teacher of psychology courses at both the introductory and advanced level. In addition, Tversky has served on the editorial boards of multiple prominent academic journals, including Psychological Research (1976–1984), the Journal of Experimental Psychology: Learning, Memory and Cognition (1976–1982), the Journal of Experimental Psychology: General (1982–1988), Memory and Cognition (1989–2001), and Cognitive Psychology (1995–2002).

Barbara Tversky’s talk was entitled: “Thinking with Hands”. The content of thought can be regarded as internalized and intermixed perceptions of the world and the actions of thought as internalized and intermixed actions on the world. Reexternalizing the content of thought onto something perceptible and reexternalizing the actions of thinking as actions of the body can facilitate thinking. New technologies can do both. They can allow creation and revision of external representations and they can allow interaction with the hands and the body. This analysis is supported by several empirical studies. One shows that students learn more from creating visual explanations of STEM phenomena than from creating verbal ones. Another shows that conceptually congruent actions on an iPad promote arithmetic performance. A third shows that when reading spatial descriptions, students use their hands to create mental models.

In 1978, Randall Davis joined the faculty of the Electrical Engineering and Computer Science Department at MIT, where from 1979–1981 he held an Esther and Harold Edgerton Endowed Chair. He later served for 5 years as Associate Director
of the Artificial Intelligence Laboratory. He is currently a Full Professor in the Department, and a Research Director of CSAIL, the Computer Science and Artificial Intelligence Laboratory that resulted from the merger of the AI Lab and the Lab for Computer Science. He and his research group are developing advanced tools that permit natural, sketch-based interaction with software, particularly for computer-aided design and design rationale capture. Dr. Davis has been one of the seminal contributors to the field of knowledge-based systems, publishing some 50 articles and playing a central role in the development of several systems. He serves on several editorial boards, including Artificial Intelligence, AI in Engineering, and the MIT series in AI, and was selected in 1984 as one of America’s top 100 scientists under the age of 40 by Science Digest. In 1986, he received the AI Award from the Boston Computer Society for his contributions to the field. In 1990, he was named a Founding Fellow of the American Association for AI and in 1995 was elected to a two-year term as President of the Association. In 2003, he received MIT’s Frank E. Perkins Award for graduate advising. From 1995-1998, he served on the Scientific Advisory Board of the U.S. Air Force.

Randall Davis’ talk was about “Pen-Based Interaction in the Classroom and The Clinic.” His talk described three projects centered around pen-based interaction. PhysInk is a system that makes it easy to demonstrate 2D behavior by sketching and directly manipulating objects on a physics-enabled stage. Unlike previous tools that simply capture the user’s animation, PhysInk captures an understanding of the behavior in a timeline. This enables useful capabilities such as causality-aware editing and finding physically-correct equivalent behavior. PhysInk is envisioned as a physics teacher’s sketchpad or a WYSIWYG tool for game designers. We have all had the experience of drawing data structures on a blackboard to illustrate the steps of an algorithm. The process is tedious and error-prone, and even when done right the result is still a collection of seashell-dust on slate. Seeking something better, they have begun developing CodeInk, a system that provides a direct manipulation language for explaining algorithms and an algorithm animation tool embodying that language. CodeInk allows instructors and/or students to describe algorithm behavior by directly manipulating objects on the drawing surface. Objects on the surface behave appropriately, i.e., as data structures, rather than simply as drawings. Finally, ClockSketch is the first member of a family of applications that may revolutionize neuropsychological testing by capturing both the test result and the behavior that produced it. By capturing data with unprecedented spatial and temporal resolution, they have discovered very subtle behaviors that offer clinically interesting clues to mental status. This offers the possibility of detecting diseases like Alzheimer’s and other forms of dementia far earlier than currently possible.

Olya Veselova is a Senior Lead Program Manager on OneNote—Microsoft’s primary note-taking and inking application delivered as part of the Microsoft Office suite. Olya has worked on note-taking, inking, sketching, and the tablet experience for over twelve years. She started out at the MIT AI Lab working with Randall Davis on sketch understanding and shape recognition, where she developed a system for perceptually based learning of shape descriptions. She carried her passion for tablets
and ink into her work in the industry, when she joined the OneNote team and Microsoft. She has worked on OneNote for the past ten years, developing the design and experience for a large number of OneNote features, including touch and ink and optimizing OneNote for tablets. Olya is a passionate advocate for the potential of digital ink and natural expression in education, work, and personal life, and is continually promoting ink related investments in OneNote and other Microsoft initiatives.

Olya Veselova’s talk discussed “Perspectives on Microsoft OneNote and Education.” The talk covered interesting aspects of OneNote history, and particularly the highlights and challenges of productizing ink and tablet experiences in Microsoft applications with the goal of broad reach. It also covered the exciting uses of tablets and ink seen in education and beyond, and a perspective on the future potential of digital ink and corresponding developments at Microsoft.

**High School Contest 2014**

The High School Contest was inspired as part of the yearly high school contest organized by the Sketch Recognition Lab and the Department of Computer Science & Engineering at Texas A&M University. Eighteen high school and middle school students combined into four teams from three different schools: the North Houston Academy of Science and Mathematics, Young Women’s College Preparatory Academy, and North Crawley High School. The students first watched and commented on Dr. Tversky’s keynote. They were motivated through a presentation delivered by the contest organizer, Stephanie Valentine. Their goal: “Choose a topic commonly taught in elementary, middle, or high schools and design a ‘gamified’ tablet application. You should design your application such that it adequately teaches your chosen topic, makes explicit use of tablet touch & gesture functionality, and strategically attracts users for long-term use (over many months).” Their task was then to create a 7-minute presentation to pitch their game. The four ideas constructed were incredibly creative and unique. A regular attendee of the TAMU CSE high school contest remarked: “This is my favorite computer science contest I do with my students. I believe it does more to show students what computer science truly is than all the programming competitions do. I would like to bring more teams so I can expose more students to the terrific opportunity.”

**Festschrift 2014**

Many of the presenters over the years have been students of Randall Davis. Dr. Davis has advised and inspired many students to change the world of pen and touch computing. Four of them (Kimberle Koile, Tracy Hammond, Aaron Adler, and Olya Veselova) presented at the 2014 Festschrift, describing the research he advised as well as his overarching impact.