SENSOR AND ELECTRONICS EDUCATIONAL DATABASE: USING TECHNOLOGY TO TEACH TECHNOLOGY

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Abstract

This paper provides an overview of SEED - the Sensor and Electronics Educational Database – a system designed to support independent student learning by using technology to teach technology. The SEED system is a resource designed to help students identify, learn, and access a wider range of electronic components and sensor technologies than what is feasible in a structured classroom or lab scenario.

New technologies are continually changing the way we learn, work, and play. The availability of new tools and resources is growing rapidly, particularly with regards to the increasing range of electronic components and sensing devices that provide us with the ability to interact with one another and the world around us. This widespread trend is readily evident by the response in advanced education to create a range of new courses in diverse disciplines that include electrical engineering, digital media, interactive art, physical computing, human-computer interaction and industrial design.

Typically, there is a course in each of these programs that provides an introduction and instruction on capabilities of new electronic and sensor-based technologies along with an overview of how to use them. However, even though the classrooms, prototyping labs, and makerspaces associated with these courses all have an extensive range of electronic components for those learning to work with the technology, a typical course only provides instruction and core prototyping support for a small number of these components. As a result, students may not be familiar with the most appropriate parts for a new product concept they may have in mind. Often they don't know what to look for, where to find parts, or how they might be used. The SEED system was created to connect these students with the available parts and the information they need to extend their design and prototyping capabilities – all on their own.

In the first fully operable implementation of the system, each tool or component is represented by an RFID card placed in a wall mounted sleeve along with other component cards. The cards are topically categorized to facilitate quick and easy visual browsing. When a user wishes to learn more about a specific component, they simply pick up a card and place it on an RFID enabled "hot spot" on a lab table connected to a computer running SEED software. The program will then display a variety of interactive resources including links to vendor specifications and internet tutorials, as well as sample projects and the related wiring diagrams and computer code. The system will also tell the user where to find the part in the Lab.

We have been running the SEED System in our Lab for the past two years. The system continues to draw significant interest from educators and industry representatives who tour our lab. As part of an effort to build a more robust system that we can share with others, we have conducted a series of studies in order to: 1) validate user priorities and preferences of the existing system; and 2) collate strengths and weaknesses of similar lab teaching/learning methods from around the world.

In this presentation, we will review our findings, share our list of pros, cons, and best practices to enhance independent learning, as well as an overview of our efforts to refine our SEED system.

Keywords: sensors, electronics, interactive product design, STEM, personalized learning, technology-enhanced learning, digital resources.

1 INTRODUCTION

The growth and evolution of wireless technologies combined with the rapid introduction of low-cost miniaturized sensor technologies has fostered an opportunity for exploration and development of an entirely new field of interactive products and technology. Stanford professor Paulo Bilkstein [1] provides a summative history of the maker movement and its ties to education. He indicates that at the

turn of the millennium there was a shift of learning emphasis from technical skills to technological fluency. The new field initially drew interest from electronics engineers, who were interested in development and optimization of the hardware technology, and computer scientists who were interested in the programming challenges of the new wireless systems. At the same time, we began to see the emergence of a diverse range of new combined academic disciplines interested to optimize the application of smart technologies for their own specific needs. Some of the more popular hybrid programs include: Human Computer Interaction, Computational Media, Digital Media, Media Arts, Interactive Arts, Physical Computing and Industrial Design. These new developments have given students who do not have engineering or computer science backgrounds the capability of embedding working technology into their own concepts for interactive products and technology.

University labs and makerspaces provide access to hardware and basic tutorials, but the ability to design and develop new innovative ideas for electronic prototypes often goes beyond the scope of those tutorials and information about appropriate hardware is often difficult to find. There are now an incredibly large number of affordable electronic components and sensors as well as a significant number of internet resources available to support the development of interactive products based on microcontroller platforms such as Arduino and Raspberry Pi. However, a typical introductory class will only provide students with an overview of a limited number of components and sensors based on predefined sample tutorials. The challenge is then how to help students scaffold learning beyond the classroom.

The Sensor and Electronics Educational Database (SEED) was designed to provide both novice and experienced design students with structured access to browse and navigate to the resources appropriate for their applications. One of the primary goals in creating the initial SEED system was to "use technology to teach technology" and leverage existing resources wherever possible and to avoid replicating materials that were already publicly accessible.

After two years of operation the first study was conducted to evaluate the performance of the SEED system and to identify opportunities for improvements [2]. A further study was initiated this past year to 1) validate user priorities and preferences of the existing system; and 2) collate strengths and weaknesses of similar lab teaching/learning methods from around the world. This paper presents the findings and recommendations of the combined results.

1.1 User insights

The idea for this project originated from observations of students who utilize the Interactive Product Design Lab (IPDL) "Fig.1" in the School of Industrial Design at the Georgia Institute of Technology. The IPDL is a state of the art facility custom built to host multiple design courses that teach students how to incorporate physical computing into their own design projects. Outside of class time it also serves as a general resource for students who want to work with electronics. The IPDL contains hundreds of distinct electronic components and tools which are stored in cabinets and tool chests within the space.

Figure 1. Interactive Product Design Lab, Georgia Tech

From the observations of students in the lab space and discussions with instructors and teaching assistants, it was apparent that novice students had major problems getting started with their own interactive product design concepts. Although they were aware there were hundreds of components available to them they had no idea how or where to begin to look. The questions they asked could be categorized into two main themes: how to find parts in the lab inventory and how to find learning resources. In addition, there were complications in managing the rapidly growing inventory of electronic components as well as the rapidly growing archive of student projects.

1.1.1 Access to Lab Inventory

Most students who use the lab were not familiar with the catalog of components available for them to use in the space. Some students expressed that they would like to explore components that they have not heard of before but don't know where to start, while others often asked whether or not a specific part is included in the lab's inventory. Students sometimes knew the name of the component they were looking for, but did not know how to visually identify it. On a higher level, students would know what interaction they wanted to enable in their project, but did not know which available sensors, outputs, or microcontrollers they needed to make the interaction functional. The best source of information in these cases was to consult a lab assistant or instructor, and they were out of luck when such resources were not present.

Some students knew that the component or tool they were interested in was available in the lab, but often did not know where that component or tool was stored. There were too many containers and drawers for students to efficiently browse for parts. Again, they heavily depended on human assistance.

1.1.2 Access to Learning Resources

When a student had identified an appropriate component or tool in the lab he or she often did not know where to access learning information about the item on their own even though they may have been aware that there were a substantial number of tutorials and walkthroughs online that correspond to the components in the lab space. Many students were also interested in learning the context in which a component could be used, but were not always able to find the existing example projects that could fuel their brainstorming process. When a student was curious about an unidentified electronic component they found in the lab, he or she relied on a lab assistant to identify it. In these instances, the student often lacked self-sufficiency to explore for answers on their own.

1.1.3 Management of Lab Inventory and Project Archive

Lab assistants and instructors did not have a method to keep track of available components themselves, and sometimes could not respond to catalog questions with certainty. Additionally, no part checkout system was in place to maintain inventory and keep track of borrowed parts.

Completed student projects are documented as posters and hung on the wall in the lab. Due to limited wall space, these posters are taken down after a period of time and are no longer accessible. Properly archived these projects would serve as a valuable resource to provide the component context for future projects.

1.2 Existing Resources

Our preliminary research identified two types of current web-based solutions: tutorial libraries and part managers "Fig. 2". There are a many tutorial sites and blogs that focus on DIY electronics and microcontroller circuitry, but there are a couple that stand out in terms of accessibility and design. Adafruit Industries [3] and Sparkfun Electronics [4] each provide detailed information on the parts that they sell. Resources on these sites include datasheets, tutorials, product reviews, example projects and community comments. When using one of their parts those are the sites to go to. Not surprisingly, that wealth of information is limited to the components each company is selling. This means that a student with a non-Adafruit or non-Sparkfun part would likely be unable to find a guide to its use. Hence these commercial sites lack prowess as a universal database for student discovery, but would be important to include in such a database.

Though Adafruit [3} and Sparkfun[4] are not designed to maintain a custom, personalized part database for an individual or lab, such applications do exist. The open source web app Electronics Component Database, or ecDB [5], is a basic electronics library manager that you can use to track part inventories, record price information, and save datasheets. One feature of note is the ability to create a "project" and attribute parts in your database to it. This allows a user to see where resources are going and get a glimpse of project progress. A mobile application called PartSeeker (IERO) [6] has somewhat similar functionality and has access to the Octopart library. The app allows users to search among many existing components, create lists and view datasheets. The app has a professional bent to it, and advertises itself to practicing engineers. Hence the technical information may seem inaccessible to beginners. Additionally, these tools are tailored to people who know what components they are looking for and can search accordingly. Those beginners who wish to explore or discover will

likely not be able to find what they are looking for or know how and where to start especially when they are interacting with all kinds of tangible electronics in a physical makerspace.

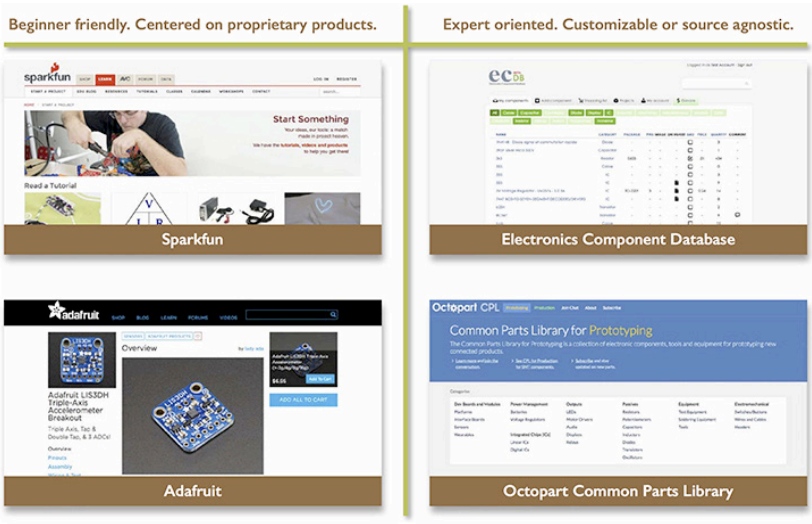

Figure 2. Existing Resources

1.3 Initial System Implementation

As previously stated one of the primary goals in creating the initial SEED system was to "use technology to teach technology" and leverage existing resources wherever possible and to avoid replicating materials that were already publicly accessible. Based on previous work with RFID technology we felt we could take advantage of the inherent discreet identification code in each RFID tag to develop an interactive identification system consisting of a wall based card catalogue, a table based RFID patch and a screen based information portal.

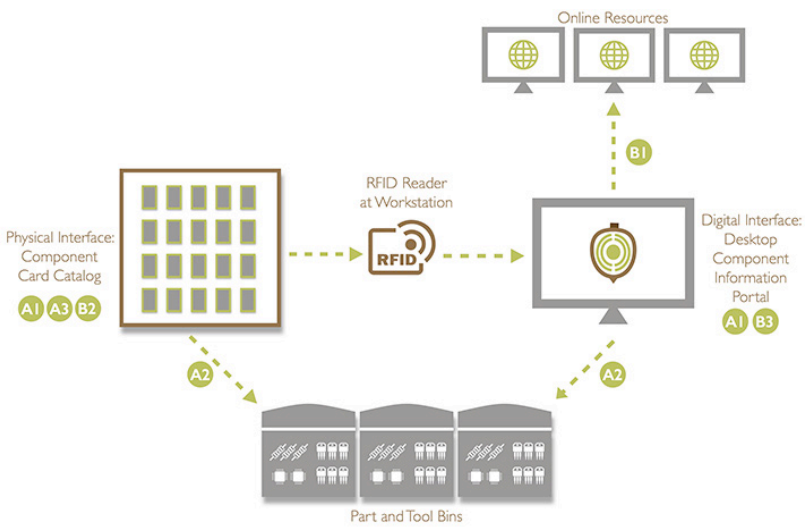

Figure 3. System Architecture

In this system "Fig. 3", all of the components in the lab are represented by a physical RFID card that contains visual reference information about the component printed on it. The goals of the printed visual material on the card are to facilitate component browsing (A1), describe component function (A3), help visually identify parts (B2), and direct students to where they can find a part in the lab (A2). These cards are RFID enabled so that when they are placed on an RFID reader at a computer station in the lab, the system is capable of identifying the card and bringing up further information about the corresponding part. To facilitate immediate access all cards are displayed on a wall in the lab space to provide a clearly visible starting point for interaction with the system.

The goal of the connected digital interface is to provide more in depth information about component function (A3) and lab location (A2) as well as access to online resources (B1) and sample projects (B3). This digital interface draws from a premade database of components that belong to the lab.

1.3.1 SEED Card Catalogue

The SEED card wall “Fig. 4” is comprised of all the individual cards that correspond to the various tools and electronic components that are in the Interactive Product Design Lab (where the system was installed for testing). Clear trading card sleeves were mounted to a trifold board, which was mounted to a wall in the lab. In this iteration, the board could hold and display 84 cards. To help achieve design criterion A1, the cards needed to be highly visible and easy to browse. The clear sleeves and broad layout were chosen to meet this criterion.

Figure 4. SEED Card Catalogue

To add to the organization and presentation of the cards and help users compare the different parts (criterion A3), the cards were classified and sorted under six major type categories:

- Logic: this section contains electronics such as microcontrollers, Arduino shields, and other smart peripherals.
- Input: The largest category, this contains sensors and other electronic components that detect and translate effectors into process signals. Examples include temperature sensors, buttons, Leap Motion controllers, and RFID readers.
- Output: This category contains electronic parts that give feedback to the user. Examples include LCD screens, vibration and servo motors, and audio output devices.
- Power: This section contains cards that correspond to some of the ways of providing electricity to projects. Examples include wall wart supplies, batteries, and relay switches.
- Components: This generalized section is meant to catch the parts that are used in electronics prototyping but do not fall under the previous categories. Examples include various types of wire, breadboards, and resistors.
- Tools: The last category contains cards with information on the various prototyping tools available in the lab space, such as wire strippers, soldering equipment, and more.

1.3.2 Component Card

The component card “Fig. 5” was designed to both stand alone as a source of information and be a key to deeper exploration (via the RFID reader and digital interface). Each card prominently displays a photo of the tool or electronic part to help users visually identify unfamiliar components (B2). Each card also has a colored box and number to indicate which bin the part can be found in (A2), a list of icons that describe the categories the part belongs to (A3), as well as a link to more information (B1) and a short description to help users compare parts at a glance (A1). There are approximately 100 cards in the current system. The cards were generated in InDesign from an Excel database file and

printed on sheets of sticker labels. Each label was placed onto a blank RFID card. The back of each card contains a generic branded SEED label to indicate that it is part of the system.

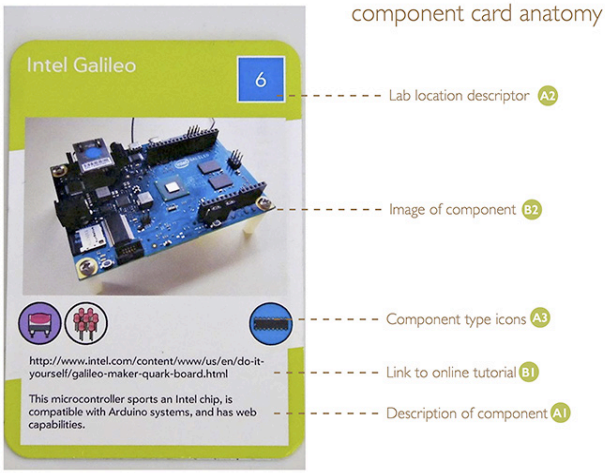

Figure 5. Component Card

1.3.3 RFID Patch

The RFID "patch" connects the physical component cards to the onscreen information portal of the SEED system. An Arduino Uno was connected to a Parallax 125kHz RFID card reader and to a computer station via USB. The assembly was affixed underneath the computer workstation table, which is thin enough to read cards through. This allowed there to be an unobtrusive interface on the top side of the table. The tabletop patch displays the SEED logo (so users can recognize it is part of the system) as well as a bounding box in which cards can be read. The placement of the patch was intended to allow users to integrate the system and card reader into their workspace as they prototype.

1.3.4 Component Portal

The screen based information portal was designed to provide more depth of information than the cards could provide, and address the criteria of linking to curated resources and sample projects (B1, B3). A program was written in Processing that is able to generate a component specific information portal "Fig. 6" for each part in the database spreadsheet. The onscreen information contains all of the information that was on a component's card, as well as a wiring diagram or schematic, clickable links to up to four additional online resources, and clickable links to up to three sample projects. The content of these sections varied between components, but were curated to be the most relevant to novice users who would want to learn to use the part.

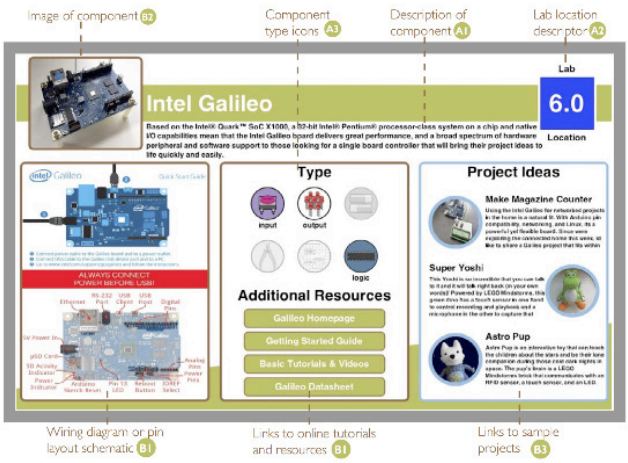

Figure 6. Component Portal

2 METHODOLOGY

After the initial SEED system had been operating for two years we felt there was significant room for improvement and we undertook a multipart study to assess the pros and cons of the existing system with the goal of identifying priorities for redesign.

2.1 Preliminary System Evaluation

Initially we conducted user research and user testing to help us begin to understand the benefits of tools like SEED and how we might better target our research to address the priority issues reported by the lab users.

A small group of volunteers were recruited for the study and were asked to complete a questionnaire regarding their background in electronics; complete a task assignment after viewing a demonstration and participate in an unstructured interview. One third of the participants identified themselves as novice while the other two thirds identified themselves as having intermediate skills and knowledge.

There were two main goals in this study: 1) To obtain qualitative feedback on whether the system was successful in increasing users' perceived self-sufficiency when interacting with lab inventory and efficiency when finding relevant learning resources; and 2) To obtain qualitative feedback on the information architecture of the system and the completeness of the information presented. As part of the project we conducted a System Usability Scale (SUS) Analysis [7] that indicated the prototype of the SEED system generated a significant benefit to users in three primary areas:

- Convenient access to lab inventory by linking with visual identity and location information
- Easy access to digital learning resources and references
- Better lab management

The study also revealed potential opportunities for improvement in several areas including:

- Better searching capabilities to improve the information architecture system
- The potential to benefit from a crowd source model where lab patrons can add their knowledge to the database
- An open source web version and corresponding classroom curriculum.
- A proper inventory management interface to facilitate a part checkout system.

These findings let us explore the theme using technology to teach technology for our design students.

2.2 More Extensive User Studies

There were two parts to the second phase of the system assessment including: 1) A global survey of similar or related initiatives in other educational settings and 2) more extensive user research and interviews with students and researchers engaged in classes and research activities related to the lab to better understand their concerns and requirements.

2.2.1 Comparable Programs

The 'Comparable Programs' section of the study involved surveys and interviews with both undergraduate and graduate programs focused on the use of sensor-based technologies at schools in countries around the world. Our objective was to identify any new initiatives in the application of sensor-based technology, any new techniques/teaching methods and/or technical support tools that other schools may have developed. Where possible information was obtained through direct contact with faculty regarding programs within their respective universities.

In order to establish a broad-based perspective of schools with programs focused on interactive technologies we conducted and extensive search by the keywords associated with all of the hybrid-type programs related to interactive or sensor-based technologies including: Human Computer Interaction, Computational Media, Digital Media, Media Arts, Interactive Arts, Physical Computing and Industrial Design. The university programs who specifically agreed to participate in the interview process include: New York University's Tisch College of the Arts, Interactive Telecommunication two year graduate program (Tisch); Parson's, The New School, Master of Fine Arts program; Simon Fraser University's School of Interactive Arts and Technology undergraduate and graduate programs in Media Arts (SIAT); Hong Kong Polytechnical University's Master of Design program (PolyU); Hunan

University's School of Design programs; Queen Mary University London's (QMUL)undergraduate and graduate programs in Media Arts; and Rhode Island School of Design's undergraduate and graduate programs in design (RISD).

Table 1. *School Programs participating in interviews.*

School Name	*Program*	*Location*
Georgia Tech, College of Design	Industrial Design	Atlanta, USA
New York University, Tisch College of the Arts	Physical Computing	New York, USA
Parson's, The New School	Fine Arts	New York, USA
Rhode Island School of Design	Design	Rhode Island, USA
Simon Fraser University, School of Interactive Arts & Technology	Interactive Arts	Vancouver, Canada
Queen Mary University London	Media Arts	London, UK
Hunan University	Industrial Design	Shenzhen, China
Hong Kong Polytechnical University	Design	Hong Kong

The surveys obtained information such as course lists, software and equipment used, and faculty and student numbers. Interviewees were also asked to identify issues they believed were strengths and weaknesses of their program and to suggest potential opportunities for improvements.

2.2.2 User Priorities

The 'User Priorities' section of the study focused on a detailed assessment of our own Lab users. The research team prepared a structured interview with an extensive set of 40 question covering familiarity with the lab facilities, use of the lab (during class/after-hours), familiarity with relevant technologies, access to in-person support, familiarity with the SEED system, strengths and weaknesses of the technical support resources and suggestions for improvements. The interviews included a random sample of ten students from various levels in the program with different levels of familiarity with sensor-based technologies ranging from beginner (Category 1) to expert (Category4). Each interview took approximately one hour.

3 RESULTS

The results of this research have been categorized in two primary sections including a summary of the key findings from the interviews with faculty from comparable programs from around the world and a summary of the detailed interviews with students who are currently in our industrial design program here at Georgia Tech.

3.1 Comparable Programs

Data collected regarding other programs is valuable in helping to understand trends – we now have a better understanding of where the field is headed as well as issues we may need to consider in the future. It also provides insight as to where our program is positioned relative to other leading schools in the field. There is significant pedagogical bias from program to program based on disciplinary strengths of each School's curriculum that has a substantive impact on the skill and knowledge students develop but despite these differences all programs appear to face the same challenges in developing and maintaining the technical resources to support rapid changes in the field.

3.1.1 Pedagogical Bias

Each institution's curriculum focuses on varying aspects of sensor technology and interactive design depending on the disciplinary bias of the program. NYU's curriculum, for instance, placed a particular emphasis on technical computing skills. This was evident in their use of sensor technologies in their physical computing and their micro-computers and sensors courses. This program has a very hands-on approach. In comparison, Parson's, The New School Master of Fine Arts program and Rhode Island College of Design's four year program have a design-focused curriculum. Each of these programs places an emphasis on user interaction with a focus on problem solving. Evidence of this is exhibited in the heavy weighting they place on studio based classes.

Other surveyed schools in the broad group associated as "Interactive Design" took a somewhat similar approach with a stronger emphasis on lecture based instruction. Queen Mary's courses, Creating Interactive Objects and Interactive Digital Multimedia Techniques, have a project-based lecture

module introducing physical computing and media programming using Arduino, while Hunan University's courses in Interactive Hardware Basics(Arduino) and Human Computer Interaction in Cars, take a similar lecture-based approach.

3.1.2 Strengths & Weaknesses

The programs participating in the interviews were also surveyed on the characteristics they identified as best practices and/or strengths of their programs. As previously noted NYU faculty indicted that their program was particularly strong on technical computing skills. Queen Mary University faculty identified the project based approach of their program together with first year introduction to programming in the form of visual coding as a particular strength of their program. In addition, they indicated that their faculty of practicing designers who were available to mentor students as needed was another strong feature of their program.

On the flip-side several programs identified areas in their programs that could use improvement as well as suggestions for potential solutions to these shortcomings. New York University faculty indicated a desire to see more instruction on how to learn new software rather than simply learning how to use software. They felt this would better prepare students for new technologies so that they are never left behind in a world of constant innovation. Simon Fraser University faculty expressed concern that their program is too much of what they call 'hands on, brain off.' From their assessment the program did not emphasize enough general discursive skills (e.g. reading, writing, research methodologies, applying research to the production of new artifacts or R&D generally), and was not interdisciplinary enough. They felt their students would particularly benefit from more collaboration with engineering and business students. Queen Mary University faculty indicated many of their students were not yet happy with the engineering modules and that they would like to introduce additional multimedia and creative modules in the final year of their program. Hunan University expressed concern with the lack of a programming coding tools aimed at designers generally. They indicated most coding tools were created with developers in mind and as such are harder to teach to students with an art and design background. They also voiced concern with the continuous rapid change in coding tools and felt much of the software would be outdated in 3 to 5 years.

3.2 User Priorities

The most valuable results we can share from this research are those we have learned from our in-depth interviews with our immediate student user group. This material contains useful suggestions for incremental improvements for the facilities management, an overview of major concerns for students and insight into the often overlooked challenge for novice users to get started.

3.2.1 Prior Knowledge

User feedback helps validate many of the changes we are seeing in student perception, understanding and experience in working with new interactive technologies. It is apparent from this most recent survey data that there have been significant changes over the past few years. Every student in our recent survey had previous exposure to electronics (particularly Arduino) as well as an introductory exposure to coding coming into our classes versus almost no students with any prior exposure five years ago. This change has profound implications for what we teach and the resources we require. Many of our initial technical resources are now redundant due to the rapid adoption of new technologies by pre-college students.

3.2.2 Guidance and Mentoring

All participants in the student survey indicated a strong preference for hands-on support from an expert and the majority report that they learn better through some form of kinesthetic learning – by doing the task themselves and getting hands-on experience and learning through trial and error. As a back-up strategy, they also refer to their peers. At the same time, all participants indicated they regularly use internet-based resources for technical support. In particular, they use the Arduino Playground [8] for tutorials or to 'grab' code from the database.

3.2.3 Existing Lab Facilities

The survey data indicates that overall students appreciate and value the existing lab facilities and resources and point out that the lab has "a decent amount of tables and screens", "the really big monitor is really nice (for instruction purposes)", "the soldering machines are great" and "having those

(SparkFun) kits was cool because we need them for our projects." One student summarized their overall impression of the lab when they indicated, "I think they have a lot of stuff to use and people there know how to use it."

3.2.4 Additional Resources

The majority of survey participants (9/10) would support enhanced access to electronic resources. "Yes, definitely something like that would help. It would be great to schedule time to meet with an expert through a website. If you are not in a specific class, your teachers might not have the expertise." In addition, most participants (8/10) would also like to have access to more project examples. "I definitely would. I'd rather see process than the final (result), especially when it comes to electronics. It's such a new topic, so there are still a lot of questions as to how we do stuff. In showing process, you answer that."

4 CONCLUSIONS

The results provide valuable insight and suggestions for the next generations of tools to help us 'use technology to teach technology'. The following summary identifies the primary issues we have learned from this research in priority order based on the frequency that issues were mentioned in the combined interviews with faculty in comparable programs and student users: 1) It is difficult to keep pace with the rapid change in both software and hardware technology; 2) There is a constant need for expert technical support; 3) Students will benefit from better coding skills; 4) Students are familiar with and regularly use online resources for technical support; 4) Students would benefit from access to more project examples – particularly those that show process.

Based on this feedback there are several suggestions we plan to implement to extend the framework for the next generation of the Sensor and Electronic Educational Database (SEED). These include the development of an internet-based version of the system that would be remotely accessible 24 hours a day; additional software coding support; and a much more extensive archive of past projects for reference. In addition, we plan to investigate the potential to develop a mechanism to 'crowd source' additional resources for the reference database. We will also continue to link to existing public resources wherever possible to minimize development and maintenance overhead to help ensure the system will remain relevant as the technology continues to evolve.

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