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Education

# Design exploration through interactive prototypes using sensors and microcontrollers ☆

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ABSTRACT

Smart products, adaptive designs, and intelligent spaces are in the forefront of current artistic discourse. Regardless of one's field – design or science – interaction design projects often benefit from efficient production methods for prototypes for beginners. This paper presents an educational case study and its pedagogical lessons from a project-based course for beginning design students to produce interactive prototypes using sensors, actuators, and microcontrollers. A series of short project-based modules using scaffolding of code templates in conjunction with toolkits for physical prototypes were introduced in order to learn fundamental technical knowledge and skills in the first half; then more open-ended investigation of project-based individual creative final projects followed. Each module can be completed in one day with instructions on prototyping and programming in pairs, allowing students to build and see abstract logic in programming through the physical behaviors of prototypes without overpowering student creativity and motivation. Students can reinterpret given materials and modify them to produce custom tools that can realize their original project goals. This strategy allows students to acquire extensible knowledge that does not rely on higher-level software functions or specialized but inflexible plug-ins. This paper is an extended and revised version of a paper presented at the EUROGRAPHICS 2014 conference [30].

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## 1. Introduction

There are newly emerging demands to make our products more adaptable and responsive in order to create smarter products that can sense users' needs more interactively. These demands require design students to acquire new skills to communicate their ideas more interactively through new technologies such as sensors, actuators, and microcontrollers. Smart products, adaptive designs, and intelligent spaces are critical components in sustainable designs where products monitor their own performance and respond to consumers' real-time needs and environmental factors. These components have a potential to enrich our ways of interacting with our living environments. The paper presents an educational case study and its pedagogical lessons from a project-based course for beginning design students to produce interactive prototypes and discuss some potential crossovers of this approach to computer science students.

Traditionally in design fields, including industrial design and architecture, one of the primary roles for designers is to find a formal solution based on aesthetics, ergonomics, formal styles, and functionality [29]; these aims have come to be supported by the use of CAD applications for drawings and digital fabrication tools such as laser cutters and 3-D printers for physical models. As Baskinger and Gross [6] have pointed out, additional knowledge of computing allows designers to be able to add input and output to an inert form through sensors and effectors, and the integration of form and computing provides an opportunity to design adaptive and responsive products which have a capability to sense, evaluate, and demonstrate varying conditions interactively. For example, a variable shading system can have light sensors to sense solar radiation, motors to control shades from the sun, and microcontrollers to provide a control feedback system, providing superior energy-saving performance with novel aesthetic qualities. Movable interior partitions can create more flexible solutions for spatial organization without requiring new construction.

There are examples of successful educational results using interaction technologies such as Arduino Microcontrollers with students in science and technology [3,14,17,36]. While the idea of using technology, programming, and microcontrollers in design education is a relatively recent development, there is a growing interest in interdisciplinary models of education [9,13,21,25,38]. Interaction design programs at schools, such as the MIT Media Lab, Carnegie Mellon University's tangible interaction design program [6], ID-StudioLab at the Delft University of Technology [4], and others, have adopted such concepts in their curricula since the

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1990s, primarily at the graduate or advanced level of studies [12]. As an example from Eindhoven University of Technology [1] shows, there is a growing need for teaching such concepts even to beginning undergraduate design students who are neither directly majoring in nor familiar with interaction design in order to prepare them for new paradigms, and this paper presents one such case study at the New Jersey Institute of Technology (NJIT).

## 2. Course structure and framework

### 2.1. Course framework and objectives

At the School of Art +Design (SoA+D) at NJIT, the author has taught an elective course on interaction design to beginning designers in various fields – digital design, interior design, industrial design, and architecture – for the past four years. The course is a 3-credit undergraduate course (typical credit hours for non-studio-based lecture and workshop courses at the institute) out of at least total 12 credits per semester, which is required for students to be considered as full-time. The course was usually offered in the second (spring) semester of the academic year. The majority of the students were third-year undergraduate students from the SoA+D, which provides an opportunity to incorporate their learning about microcontroller technologies into their senior year final studio project using a longer duration. However, there were some second and fourth year and a very few from the information technology department registered for the course. The prerequisites include completion of courses for a design-based introduction to 3-D modeling and basic digital fabrication or an instructor-approved equivalent for those who register from outside the school. Although students were expected to use hours outside of the class for their productions, it was an elective course that met only once per week for three hours and was not funded for costs of materials. An average enrollment of 12–18 students allowed for providing project-based individual instruction to each student.

The intended learning outcomes for the course include many objectives inherited from the previously proposed approaches and curricula from computer science education [9,18] that promote use of science, engineering, and technology through project-based work and provide students exposure to tools, techniques, and ideas for human–computer interaction. To learn how to make something interactive was the essential goal and was a new addition to the SoA+D's program. The installment of the interaction design course in the art and design context introduced several different emphases from those in other technical fields. The course is still considered as an art course, which involves production of physically, visually, and aesthetically pleasing outcomes. To bolster this objective, the course introduces techniques that always use microcontrollers in pairs with physically oriented prototyping techniques, which is not typically practiced in computer science education. However, it can also be implemented in any other discipline in order to enhance visual aspects and physical productivity of students' projects. As a consequence, reviews by expert artists and design instructors have become necessary to evaluate quality of outcomes since value and performance of art projects cannot be easily quantified.

In the course, the instructor encourages students to seek unique project goals as artists rather than replicating what is likely to be accomplished as a typical contribution by scientists and engineers. As Do and Gross point out [12], designers and engineers approach toward their creative goals differently. Many projects from science courses can be directed from explicitly defined problem statements or specifications by instructors, for example "*Design, construct and program a factory assembly line to simulate the sorting and packaging using image processing* [9]", while development processes of projects from art courses tend to be more open-ended and spontaneous [12]. Projects by artists often have emphasis on conveying a certain message or emotion through experience (and perception) of users by integrating different media that work coherently together, regardless of whether their projects possess a specific practical purpose or functionality. For example, a media artist, A. Sayegh of INVIVIA, referred to his public media installation as "*highly evolved useless things with strong evocative powers* [27]." The author sees this as an opportunity for design students to establish their unique identities within the larger paradigm of creative interaction design (by clarifying their areas of contributions) through the development of projects.

Another important objective is to prepare design students to be able to collaborate with professionals from technical fields in the future. Today, it is common among designers to work with programmers and engineers – for example, in the gaming industry. In order to accomplish this, students need to be able to clearly identify the areas of contributions that artists can make with the help of engineers and their technologies. Although interdisciplinary approaches have been addressed by many curricula for human–computer interaction [18], the course has a particular focus on investigating types of interaction media work by artists and designers, which might have a potential to expand the contribution areas, even of scientists, beyond what is currently recognized as mainstream work in science. The author does not believe it is necessary to draw a line between contributions from art and technology disciplines. However, differences in outcomes and the talents that deliver them currently exist. For computers and graphics communities, it would be a mutual benefit to identify and find a way to incorporate the evocative power found in some interaction projects by artists. For example, in the near future, the comfort level and natural likeliness of a subject's aesthetic acceptance of robots, often referred as the uncanny valley [28], can be improved through the use of artists' ability to evoke particular sensations, perceptions, and cognitions of users from their art work to help break down the limitations in current research. What is regarded as work and skills by artists today could be integrated into means to pursue what are currently called 'scientific' goals by taking advantage of synergy among different types of talents; specializations based on disciplines may diminish in the near future. Highlighting uniqueness in approach by designers and promoting interdisciplinary collaboration are the (as yet speculative) potential long-term contributions for the advancement of the states-of-the-art among computers and graphics communities.

### 2.2. A unique target group

The SoA+D is a relatively new school in its sixth year, with a small number of students, and there was no interaction design course using microcontrollers offered before. Unlike more advanced graduate students focusing on interaction design at established schools such as the MIT Media Lab, most students had had neither sufficient exposure to current paradigms in interaction design nor technical knowledge of microcontrollers. Furthermore, some students from the digital design program simply registered for the course due to the lack of other available elective courses, and had displayed an antipathy to doing anything other than digital 3-D modeling – for example, learning physical prototyping using digital fabrication tools was not their priority. With such a target group – some of the students potentially being hostile – the instructor needed to create a curriculum that could motivate students and introduce the fascinating world of interaction design within relatively short contact hours.

### 2.3. Overcoming technical materials

Another challenge was to introduce adequate technical knowledge to design students without overpowering their creativity and

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