CRSN 151C: Sustainability Lab tools, techniques & applications

The goal of this 5 unit course is to introduce students to and bolster concepts, skills, and strategies fundamental to the successful development of sustainability-related projects appropriate to the “Sustainability Lab” (S-lab). S-lab is situated at the nexus between a dedicated Makerspace and supported research into community-level sustainability. The “maker movement” has increased accessibility to STEM technology, igniting a do-it-yourself mindset among students and community members alike.

The S-lab strives to reinforce this mindset. In order to produce truly impactful innovation, students must have general knowledge and interaction with the different areas that encompass sustainability. This means getting hands dirty and delving into the iterative process of design and prototyping. Whether a student’s work at UCSC has been in the Humanities, Social Sciences, Arts, or STEM fields, hands-on experience and the ability to rapidly create will accelerate innovation and provide a basis for flexibility when it comes to optimization.

The S-Lab is a maker space and incubator for student led projects related to sustainability and community development; functional laboratory with customized mentorship supporting multidisciplinary collaboration from project conception to deployment. Students have access to functional and living laboratory space, equipment, professional development and technical training with the explicit goal to foster entrepreneurship and ensure project continuity after graduation. Through this inquiry-based learning class, students will learn to safely use S-lab tools and equipment and apply their skills to creating a useful end product.

Course modules are comprised of a suite of preparatory online content and 2-3 hour workshops through which students gain involved, hands-on experience. Each module covers a different relevant topic. Each module has its own prelab that must be completed before attending the relevant session and a postlab that must be completed on your own time before attending the next session.

This suite of modules is designed as an entry point into the creative environment of the maker movement; when combined with the other resources offered by S-lab, learners can be supported beyond tinkering and into practices that solve real problems. In many cases, satisfactory completion of the modules are required before access to equipment is even an option.

Students are required to complete the EH&S Lab Safety Fundamentals; Hazardous Waste Management; Electrical Safety in Research; and possibly Hand and Power Tool Safety certifications before beginning any work in the lab.

Course learning objectives are listed within each class module, below.

Course requirements & grading
Students will spend 2 hours per week in class, 3 hours on project development in the lab and 10 hours on homework.

Attendance & completion of modules & assignments: 50%
Safety certification: 15%
Final project: 25%

**Required texts**
The lab manual is available for viewing and download on the course website; in it are the details of each day with instructions and important terminology, as well as the equipment list with links for purchase if you would like to attempt these tutorials at home.

A key component of the course is the use of a lab notebook. Make sure to bring the notebook with any questions you may have on the relevant prelab content to each session; it is important that you understand these concepts.

**Course & module learning objectives are listed below under each module description.**

**Class schedule**

**Week 1: Introduction to the S Lab**
Students in the class are introduced to the procedures and practices required in the S-lab and to the tools and safety issues associated with them. Tools will be demonstrated and students will be required to successfully complete a safety and use questionnaire. Students will organize into project groups and identify projects to be designed and completed during the class.

**Weeks 2-3: Module 1--Prototyping & fabrication**
Computer Aided Design (CAD) is a powerful tool used to create detailed prototypes in a 3D environment, before making a design a reality. This module provides directed guidance through many of the tools available in Autodesk’s Fusion 360, a modern and accessible CAD (and CAM) program that makes it possible to quickly iterate on design ideas, test fit and motion, perform simulations, create assemblies, collaborate, and make photorealistic renderings and animations. The class then utilizes 3D printing workflow capabilities to 3D print a design with the Kubo Titan2 Resin printer. At the end of the module, students will be able to effectively use and explore Fusion 360 as a prototyping tool and be cleared to operate the S-lab’s suite of 3D printers.

**Learning Outcomes:** By the end of the 3D prototyping module, students will have demonstrated familiarity and ability in:

- Good laboratory Environment, Health and Safety practice
- Autodesk Fusion 360 work environment:
• Tools: Model, Render, Animation, Simulation, Drawing
• Design Environments: Sculpt, Model, Mesh, Patch
• 2D sketching and 3D modeling
• Creating assemblies
  • Collaborative development in the cloud
  • Direct vs Parametric Design
  • CAD and CAM

After completing the session, students will be cleared to use the Kubo Titan2 resin printer.

**Session 1: Introduction to Autodesk Fusion 360**

• Tour the Fusion 360 Virtual Environment
• Review sketch techniques

**Session 2: Create your prototype**

• Review: Go over take-home design
• Create Assembly and Drawings

**Session 3: 3D print your design!**

• Complete your design and export into .stl format
• Understanding benefits and limitations of 3D resin printers

Autodesk offers many hands-on tutorials to get familiarized with Fusion 360’s different work environments. Check some out at: [http://fusion360.autodesk.com/learning/learning.html?guid=GUID-2AABB91A-0E9E-4D28-8D3C-EAFEE93B32A0](http://fusion360.autodesk.com/learning/learning.html?guid=GUID-2AABB91A-0E9E-4D28-8D3C-EAFEE93B32A0)

**Weeks 4-5: Module 2—Sustainable power systems: Energy generation & storage**

In this module, students learn the basics of renewable energy generation, electron flow and storage in DC systems. The first workshop will introduce basic terminology and concepts related to electricity. In the second workshop, participants will expand on this knowledge by designing, building and testing real-life circuits to manage USB charging/discharging. Finally, students will be challenged to construct a functional solar powered lantern and charger. By the end of the module, students are given a firm understanding of how to utilize, optimize, and balance energy distribution for sustainability research and projects.

**Learning Outcomes:** The Energy Generation and Storage module will give students an introduction to circuits and how energy management works. Students will have demonstrated familiarity and ability in:

• Good laboratory Environment, Health and Safety practice
- Appropriate selection of electronic components and the use of data sheets
- Analysis, design and testing of real-life circuits: series vs parallel, current and voltage dividers
- Creation of a power budget for multicomponent systems
- The application of basic physical principles of electrical flow and analysis (Ohm’s Law, resistance, AC vs DC voltage and current)
- Design of charging systems and battery management
- Incorporation of sustainable generation (solar) into power systems.
- Understanding of power converters and their efficiencies: DC to DC (Buck, Boost, Buck-Boost), AC transformers

After you’ve completed your session, you should have a basic understanding of how to utilize, balance, and optimize the use of energy for basic systems.

Session 1: Rechargeable Battery System

- Review:
  - Basic circuit design & power budgets
  - Energy collection, storage and distribution
- Build a solar charging system with an LED output

Session 2: Energy Management and Output

- Review:
  - AC vs. DC currents
  - Charge & discharge controlling
  - Step up & down conversions
- Build a charge controlled battery to USB output system
- Begin designing a solar charged battery to LED/USB outputs

Session 3: Energy Storage

- Complete your design and build the solar charging station with LED/USB outputs

Weeks 6-7: Module 3—Embedded Systems: Remote monitoring & control systems
This module details the process of designing and implementing a system that can remotely monitor and control environmental conditions. It provides the foundation for intelligently automating tasks that would be needed in a greenhouse such as humidity & temperature control. Participants will go through the process of remotely connecting to an embedded system, programming it to collect data and perform tasks through feedback control, and configure it to wirelessly transmit data and commands without the need to be physically present. By the end of the module, students are trained in operating and managing simple remote monitoring systems for both long and short-term projects.
Learning Outcomes: By the end of this module, students will have demonstrated familiarity and ability in:

- Good laboratory Environment, Health and Safety practice
- Appropriate selection and use of microcontrollers (Arduino UNO) vs single board computers (Raspberry Pi)
- Basic control structures, Types, and Boolean Operators for general programming
- Arduino IDE, Python, XCTU programming environments
- Analysis, design and testing of circuit diagrams and circuits: series vs parallel, current and voltage dividers
- General understanding of communication and networking protocols, both wired (serial and ethernet) and wireless
- Articulation of data flow and feedback control through the use of finite state machines
- Data storage with SQLite database
- Appropriate selection of electronic components and the use of data sheets
- Application of tools for project management (engineering notebook, GitHub)

The example use-case used throughout this Embedded Systems Module is a connected greenhouse. By the end of the three sessions, you will have a foundation for remotely monitoring and controlling elements such as humidity and temperature, storing data, and selecting electronic components.

Session 1: Introduction to IoT Hardware and Software: In this workshop, you will learn introductory programming and basic electronic circuitry while utilizing an Arduino UNO microcontroller for temperature and light sensing. We will discuss different electronic components, explore the microcontroller hardware, and write basic control structures to perform indicator tasks. Students will gain a basic understanding of electric circuits and circuit design, and be able to test and calibrate their systems. This session assumes little to no previous experience, and can be skipped by demonstrating the circuit to S-lab staff.

Session 2: Wireless Communication: This session introduces students to the use of short range wireless communication to connect discrete embedded systems. Participants will learn the simplest form of wirelessly transmitting data using Xbee radios in point to point configuration. By the end of this module, you will be able to wirelessly communicate sensor data to a host computer for processing and display.

Session 3: Introduction to Embedded Systems with Feedback Control: In this workshop, you will setup and configure a single board computer, the Raspberry Pi, as your master computer. This includes installing the OS, enabling networking, and communicating with each sensor using a Python script in order to deploy a fully functioning remote monitoring and control system. Students will be taught to program at a more advanced level for flow control and to facilitate data logging.
Weeks 8-9: Module 4—Rainwater harvesting: Water resource management
In this module, students are introduced to water resource management by constructing a mini-hydro pumping station in workshop 1 and a rainwater catchment system to be used in the arboretum greenhouse in workshop 2. After learning basic plumbing skills and concepts, we will explore the potential for water to provide energy as participants design and configure their pumps. In the second session, we will get outside and apply our newfound knowledge and skill at the arboretum where students perform a site inspection for potential rainwater catchment and design and build a system to be used by S-lab at the location. By the end of the module, students will have a better understanding of water as a commodity in an agricultural area and gain insight into approaches to use the resource more sustainably both in their projects and everyday life.

Learning Outcomes: In these Water Management workshops, students will demonstrate familiarity and ability in:

- Basic plumbing skills and familiarity with fittings, materials, valves, and gauges typically used in residential and small systems
- Good laboratory Environment, Health and Safety practice
- The application of basic physical principles to design functional systems with minimal losses and optimal pressure
- How to size, design and construct a simple rainwater harvesting system for residential use
- The use of hand tools and basic construction techniques
- Understanding the rules and regulations relevant to harvesting rainwater.
- The movement of water: pumping and power generation applications
- Basic understanding of water purification and treatment techniques to optimize: pH, chemical content, softening

Session 1: Introduction to fittings, physics, and power. In this workshop, students will construct a basic air pump using typical plumbing equipment and techniques. We will explore the potential for moving water to generate power while discussing some of the pros and cons of using hydro-systems as a “renewable” power source.

Session 2: Construct a rainwater catchment system. Students will receive a basic lesson on configuring a residential rain harvesting system for the arboretum greenhouse, while also learning about the individual components and where to acquire them. These components range anywhere from miscellaneous PVC pipe, adhesives, filtering devices, and common recycled materials that can be manipulated to serve as rainwater harvesting equipment. With the rain gutter outlet and rain barrel already in place, students will take what they have learned and apply it by assembling a complete system; with PVC fittings being interference fit, no lengthy adhesive wait times will be necessary.

Week 10: Project presentations—open house
Students will demonstrate S-lab tools in an open house, prepare and present materials and posters on their work and projects, and speak about them to the class and visitors.