Introduction & Syllabus

ECE 476 Embedded Systems

Jake Glower - Lecture #1

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

ECE 476 Embedded Systems

- https://www.BisonAcademy.com/EC476/Index.htm

Target Audience:

- ECE majors at North Dakota State University
  - Elective for Electrical Engineers
  - Elective for Computer Engineers
  - Required for Software Engineers
- General Public
  - Python programming
  - Raspberry Pi Pico-W
  - GeeekPi Pico Breadboard Kit Plus

What we're going to cover

- Programming a microcontroller
  - Raspberry Pi Pico-W
- Use of a development board
  - GeeekPi Pico Development Board Plus
- Mid-Level programming
  - MicroPython

Background: IBM PC

The IBM PC came out in 1980

- DOS operating system
- Very good tool for ECE majors
  - Access to the hardware

Windows came out in 1993

- Easier to use than DOS
- Protects user from the hardware

Problem for ECE majors:

- We *want* access to the hardware

Background: Raspberry Pi

- Released February 2012

Full-blown IBM PC

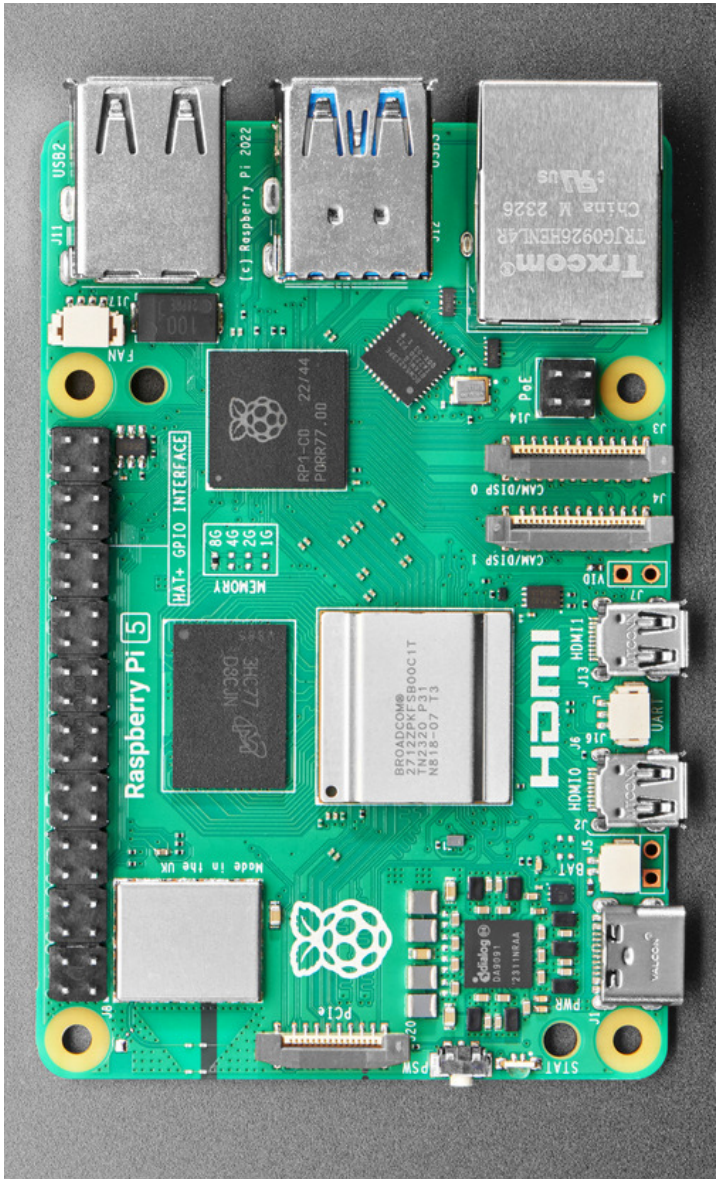
- ARM Cortex processor @ 2.4GHz
- 8GB RAM
- Windows-like operating system
- Access to the internet and Wi-Fi

Full access to the hardware

- 28 binary I/O pins
- Programmers can access directly

Current Version

- Raspberry Pi 5
- $80 from Adafruit



Background: Raspberry Pi Pico

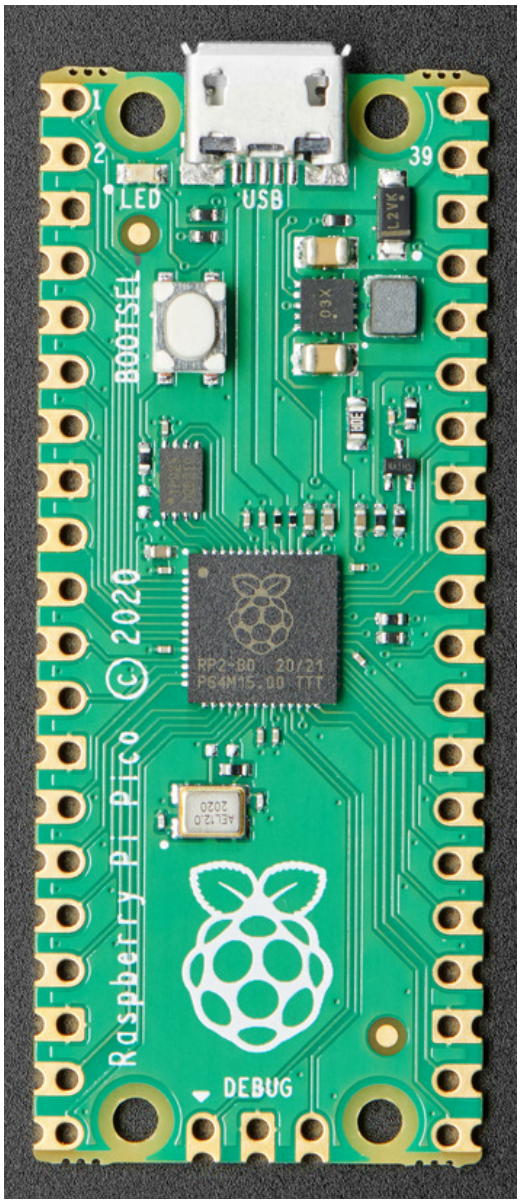
- Released January 2021

Microcontroller version of Raspberry Pi

- Dual ARM Cortex-M0+ @ 133MHz
- 2MB Flash
- 264kB on-chip SRAM in six independent banks
- 30 GPIO pins
  - 3.3V fixed
  - 12mA source/sink
- 4 x 12-bit, 500ksps A/D (3 external connections)
- 2 × UART, 2 × I2C, 2 × SPI, 16 × PWM channels
- 1 × Timer with 4 alarms, 1 × Real Time Counter
- 8 state machines total

Available from Amazon, Adafruit

- $4 from Adafruit
- $8 from Amazon



Background: Raspberry Pi Pico-W

- Released June 2022

Adds

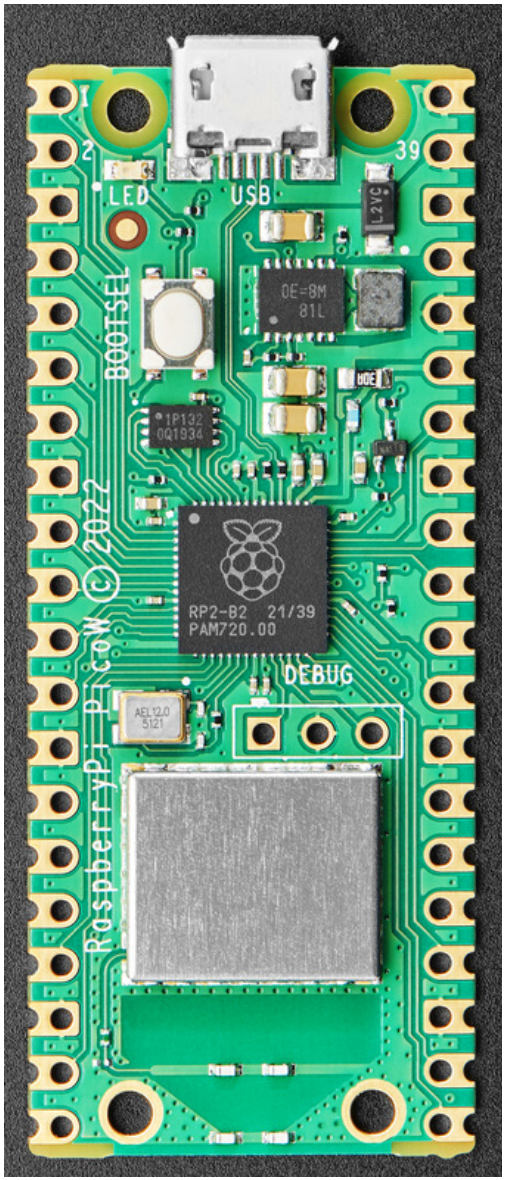
- Bluetooth
- Wi-Fi

Power:

- 3.3V or 5.0V
- Draws 20mA

Available:

- Amazon ($9 to $14 ea)
- Adafruit ($6 ea)



Development Boards:

The Pi-Pico doesn't *need* a development board

- It can operate free-standing
- Just give it power (3.3V or 5.0V) & ground

Development boards add convenience

- Many I/O functions are already there

ECE 476 is built around a development board

- GeeekPi Pico Breadboard Kit Plus Version
- $33 from Amazon
  - 2 x push buttons
  - 2 x LEDs
  - 1 x RGB LED
  - 1 x buzzer
  - 1 x XY joystick
  - 320 x 480 graphic touch screen
  - Connecters for all I/O pins
  - (Pico not included)

GeeekPi GPIO Expansion Module with 3.5inch Screen for Raspberry Pi Pico/Pico W

Visit the GeeekPi Store

3.8 ★★★★☆ 27 ratings | Search this page

$32.99

prime One-Day

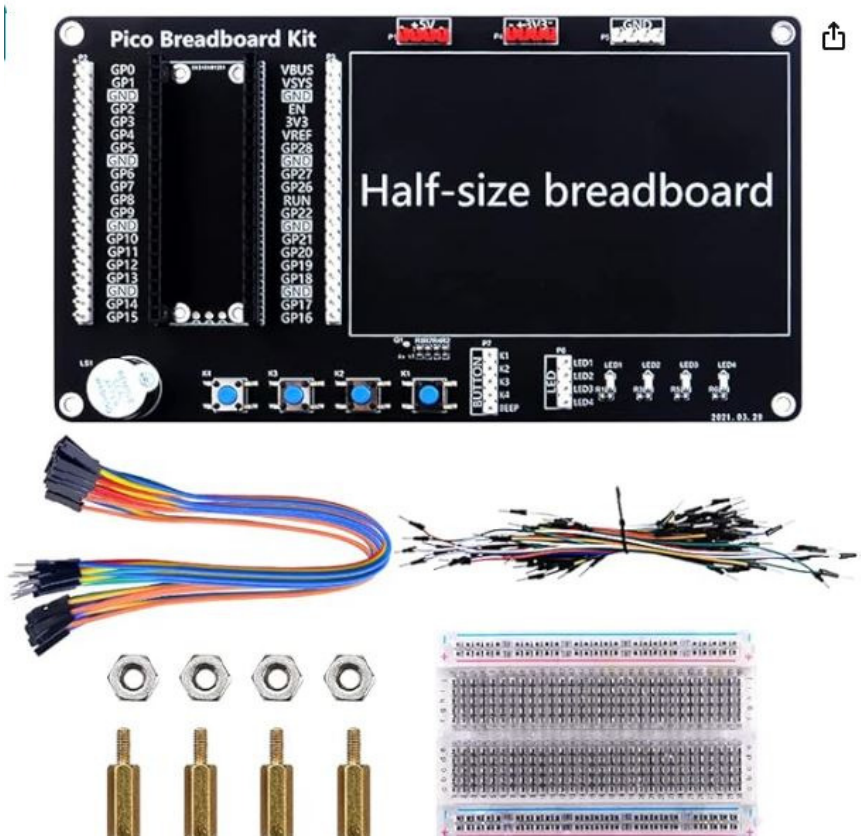
FREE Returns

Development Boards

- Other options

GeeekPi Basic Starter Kit for Raspberry Pico

- $17 from Amazon
  - 4 x push buttons
  - 4 x LEDs
  - Buzzer
  - Connectors for all I/O pins
  - Breadboard area
  - (pico not included)



GeeekPi Basic Starter Kit for Raspberry Pi Pico/Pico W, BreadBoard Kit with Half-Size Breadboard and Jumper Wire Pack for Raspberry Pi Pico/Pico W (Raspberry Pi Pico/Pico W Not Included)

Visit the GeeekPi Store

4.0 ★★★★☆ 148 ratings | Search this page

$16.99

prime Two-Day

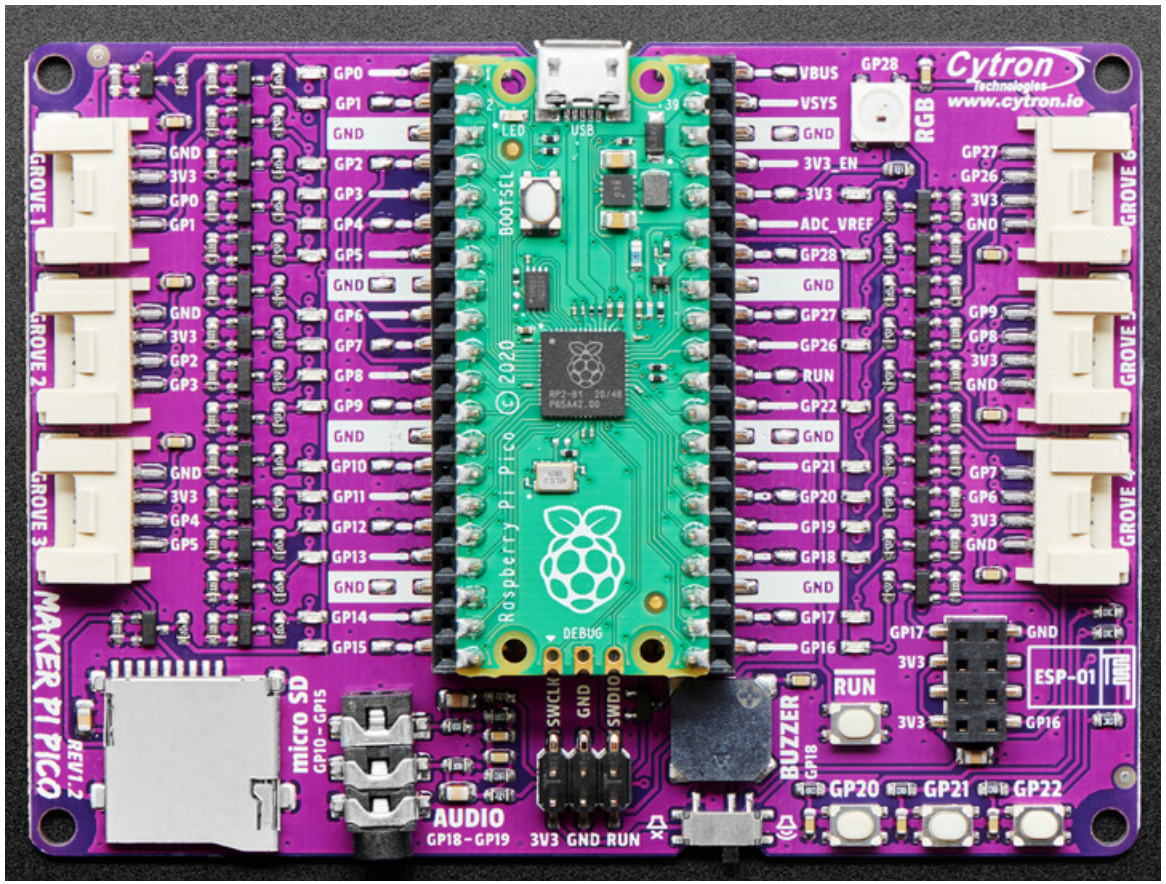
FREE Returns

Development Board

- Other Options

Maker Pi Pico Base

- $10 from Adafruit
  - 3 x push buttons
  - 27 x LEDs (all I/O)
  - Buzzer (speaker)
  - RGB LED
  - Connectors for all I/O pins
  - (pico not included)



Mid-Level Programming (Python)

- https://thonny.org (free!)

Hardware:

- Connections to sensors / actuators

Low-Level Programming

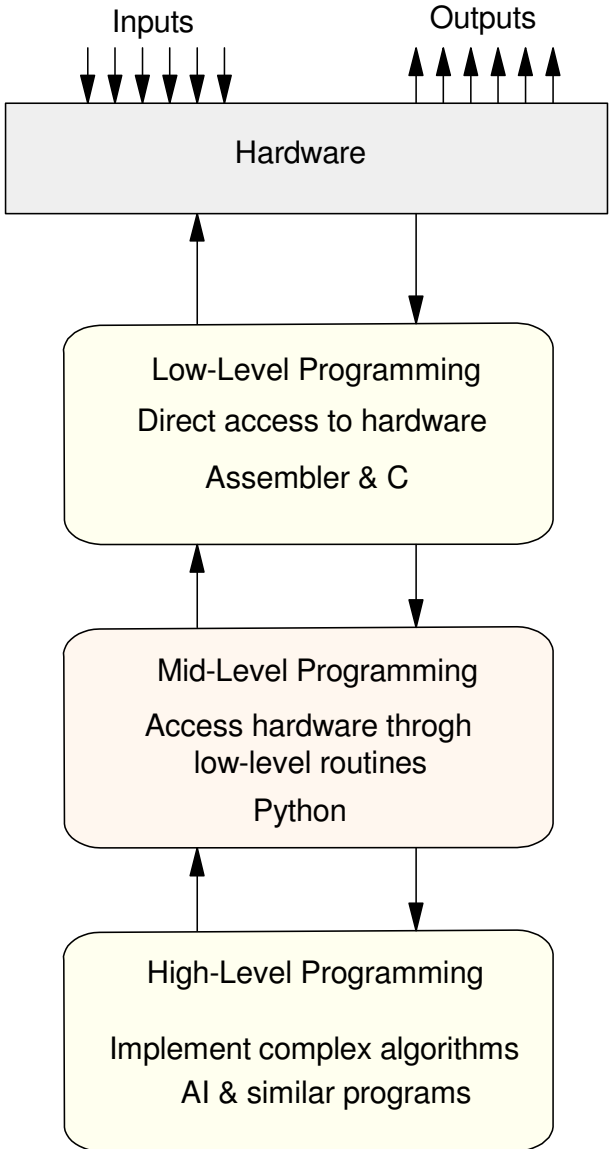
- ECE 376 Embedded Systems
- Read / Write to I/O pins directly
- Set up registers for I/O, interrupts, etc.
- Assembler & C

Mid-Level Programming

- ECE 476 Advanced Embedded Systems
- Access I/O through subroutines
- Python

High-Level Programming

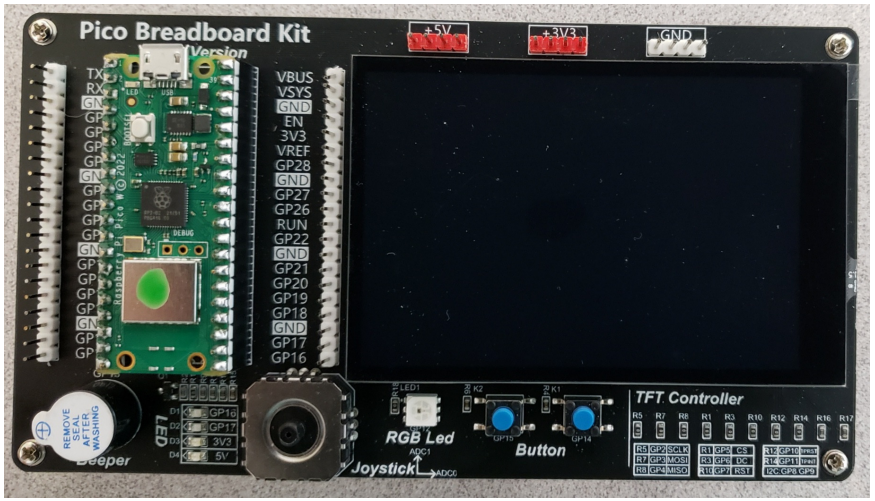
- CSCI courses on AI, etc



What Are Embedded Systems?

Electronics which includes a microcontroller

- Inputs: Sensors, what's happening?
- Outputs: Actuators: do something
- Microcontroller: Use software to control the outputs based upon the inputs



This is a fun course where you build, program, test, and demonstrate various devices

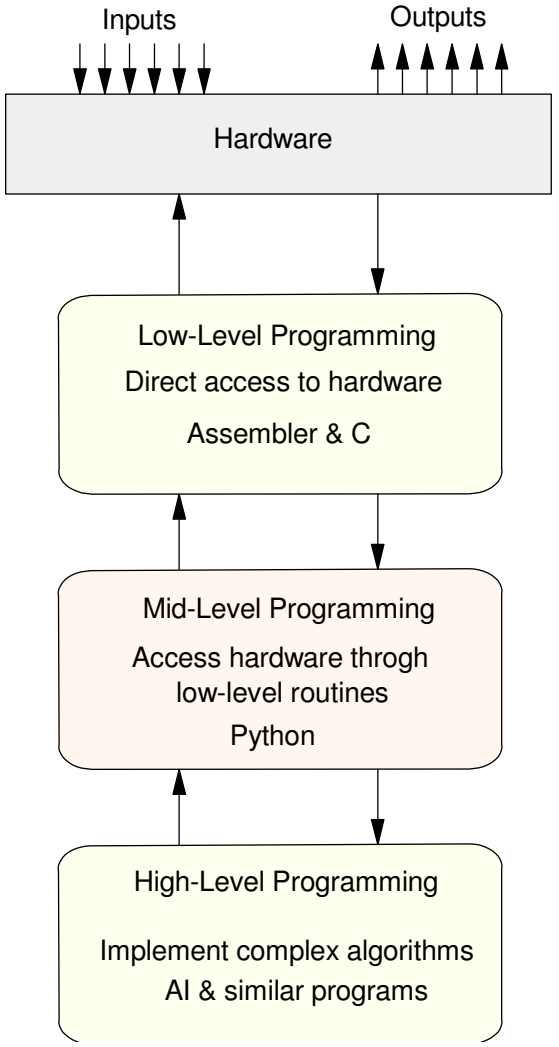
- Having a microcontroller allows you to much more than you could in other classes, much easier

Senior-Level Course

- Students don't know what they don't know
- 35 lectures = 35 things you can do with a microcontroller

What is Advanced Embedded Systems?

- Hardware (ECE 320 Electronics)
  - Circuits to buffer inputs and outputs
- Low-Level (ECE 376 Embedded Systems)
  - Focus on driver routines to access the hardware
  - Directly control registers, I/O pins
  - Assembler & C programming languages
  - example: how to generate a 100Hz, 30% duty cycle square wave
- Mid-Level (ECE 476 Advanced Embedded)
  - Focus on more complicated programs
  - Use driver routines to access the hardware
  - Python programming language
  - example: Control the speed of a motor using PWM
- High-Level (CSCI 4xx)
  - Focus on more complicated programs
  - Use lower-level routines to do task
  - AI languages
  - example: Get quad-copters to swarm



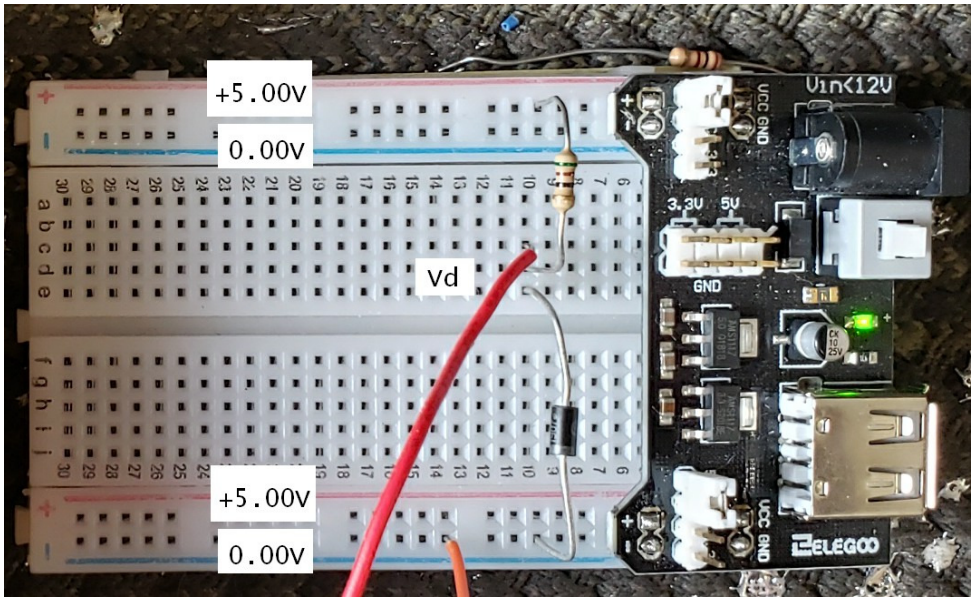
Prerequisite Knowledge

Prereq: ECE 376 Embedded Systems

- Not 100% needed

What you need to take this course

- Programming Experience
  - What is a program
  - Use of subroutines
  - Writing and debugging code
- Circuits Experience
  - Voltage, Current, Resistance
  - Voltage division
  - Basic op-amp circuits
- Breadboarding Experience
  - Building circuits on a breadboard



ECE 376 vs. ECE 476

ECE 376: Embedded Systems	ECE 476: Advanced Embedded
Low-Level Programming • Focus on driver routines • Access hardware • Setting control registers	Mid-Level Programming • Call driver routines • Focus on more complex tasks
Assembler & C • Fast • Access to hardware	Python • Slower • Easier to write and debug code
Microcontroller • PIC18F4620 @ 40MHz	Microcontroller • Raspberry Pi-Pico (RP2040 @ 133MHz)
I/O • Binary (LEDs) • LCD character display • Analog inputs	I/O • Serial port (SCI) • Graphics LCD display • Analog inputs (A/D) • Analog outputs (PWM)

Do I Need ECE 376 Embedded Systems?

Not really

- Different processor
- Different language
- Different objectives

If you need a refresher

- Bison Academy
  - https://www.BisonAcademy.com/Index
- ECE 320 Electronics
  - https://www.BisonAcademy.com/ECE320/Index
- ECE 376 Embedded Systems
  - https://www.BisonAcademy.com/ECE376/Index

BISON ACADEMY

ECE 111: Intro to ECE

ECE 206: Circuits I

ECE 311: Circuits II

ECE 320: Electronics I

ECE 331: Energy Conversion

ECE 341: Random Processes

ECE 343: Signals and Systems

Course Content

- Lectures 1-11
- Python Programming

How to read and write in Python

- Binary signals
- Analog signals
- Use of libraries

How to measure time

- and output frequencies

How to drive different motors

- motors with binary inputs
- motors with analog inputs

1	Introduction & Syllabus
2	Thonny & MicroPython
3	Loops & If-Statements
4	Subroutines
5	Binary Outputs
6	Binary Inputs
7	Serial I/O
8	Timing
9	Analog I/O
10	Motors with Binary Inputs
11	Motors with Analog Inputs
	Test #1

Course Content

- Lectures 12 - 24

Creating your own libraries

- LCD routines
- Matrix routines

Math & Random libraries

- What they include
- How to use their funcitons

Interrupts in Python

- Edge interrupts
- Timer interrupts

Controlling a DC motor

- Speed & angle control using interrupts

Reading Sensors

- Analog & Digital

12	LCD Graphic Display
13	Fun with LCD Graphics
14	Math and Random Library
15	Matrix Library
16	Edge Interrupts
17	Timer Interrupts
18	Speed Control of a DC Motor
19	Angle Control of a DC Motor
20	Analog Sensors
21	Digital Sensors
22	Data Collection & Text Files
23	Recursive Least Squares
24	Neopixels & Assembly
	Test #2

Course Content

- Lectures 25- 35

Using the Touch Screen

- Another way to get user input

Using State Machines

- Schedule when programs are run

I/O with Bluetooth

- send / receive data to your cell phone

I/O with WiFi

- send / receive data over the internet

25	Touch Screens
26	Touch Screens (cont'd)
27	State Machines
28	State Machines (cont'd)
29	Bluetooth I/O
30	Bluetooth I/O (cont'd)
31	Bluetooth I/O (cont'd)
32	WiFi
33	WiFi Weather Station
34	WiFi Relay
35	WiFi Data Logger

Bulletin Description:

- Specification, design, development, and rest of modern embedded systems using a high-level programming language. Prereq: ECE 376. F, S

Course Objectives:

By the end of the semester, students should:

- Be able to interface a microcontroller to binary inputs and outputs,
- Be able to interface a microcontroller to analog inputs and outputs,
- Be able to use a graphics display touch-screen for I/O,
- Be able to send/receive data to your cell phone using Bluetooth,
- Be able to access a WiFi network using a microcontroller, and
- Be able to do all of this using Python

Bison Academy

- www.BisonAcademy.com
- Where to access lecture notes, homework sets, etc. for ECE 476

BISON ACADEMY

ECE LABS

Advising Info
ECE Lab Supplies (new)
ECE 111: Intro to ECE
ECE 206: Circuits I
ECE 311: Circuits II
ECE 320: Digital Electronics
ECE 321: Analog Electronics
ECE 331: Energy Conversion
ECE 341: Random Processes
ECE 343: Signals and Systems
ECE 376: Embedded Systems
ECE 461: Controls Systems

Bison Academy: Syllabus

- Daily material (lecture topic in pdf format)
- Recorded lectures (YouTube)
- Sample Code (from lecture notes)
- Homework assignments

ECE 476: Advanced Embedded Systems

Syllabus: Fall 2024

Syllabus - HW & Solutions - Resources - Comments

	Date	Topic	Recorded Lecture *YouTube PlayList*	Code *Used in lecture*	Homework
M	Aug 26	Holiday			HW #1
W	Aug 28	1Introduction & Syllabus Slides #1	Video #1		
F	Aug 30	2 Thonny & MicroPython Slides #2	Video #2		
M	Sep 2	Holiday			HW #2
W	Sep 4	3 Loops & if-Statements Slides #3	Video #3	03 Timer2 Interrupts 03 For Loops 03 While Loops 03 d4 + d6	
F	Sep 6	4 Subroutines Slides #4	Video #4	04 Resistors 04 Convolution with Dice 04 Convolution with Polynomials	

Bison Academy: Homework and Solutions

Homework Assignments & Solutions from previous semesters

- Once the course runs for more than one semester

Tests and Solutions from Previous Semesters

- Good resource if you want sample problems to work on
- Code is usually removed (use sample code from the Syllabus as a starting point)

Fall 2021	Spring 2021	Fall 2020	Spring 2020	Fall 2019
1: PIC Background Solution #1 (pdf) Solution #1 (YouTube)	1: PIC Background Solution #1	1: PIC Background Solution #1 (pdf) Solution #1 (YouTube)	1: PIC Background Solution #1	1: PIC Background Solution #1
2: PIC Assembler Solution #2 (pdf) Solution #2 (YouTube)	2: PIC Assembler Solution #2	2: PIC Assembler Solution #2 (pdf) Solution #2 (YouTube)	2: Assembler Solution #2	2: Assembler Solution #2
3: Binary I/O Solution #3 (pdf)	3: Binary I/O Solution #3	3: Binary I/O Solution #3	3: Binary I/O Solution #3	3: Binary I/O Solution #3
Test #1 Test #1 Solution (pdf) Test #1 Solution (YouTube)	Test #1 Test #1 Solution	Test #1 Test #1 Solutions	Test #1 Test#1 Solution	Test #1 Test #1 Solution
4: C-Coding Solution #4 (pdf) Solution #4 (YouTube)	4: C Coding Solution #4	4: C Coding Solution #4	4: C Coding Solution #4	4: C Coding Solution #4

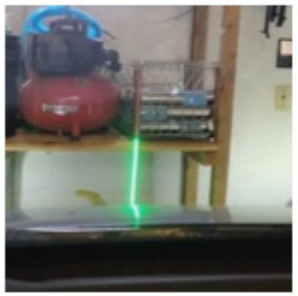
Bison Academy: Best of 476

Most homework sets have four parts

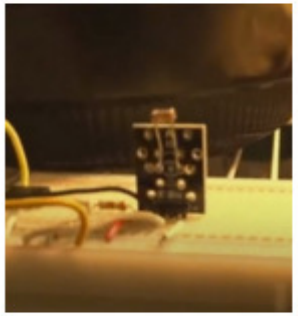
- Requirements
- Hardware & Software
- Testing
- Validation & Demonstration

YouTube videos work well for validating and demonstrating your code works.

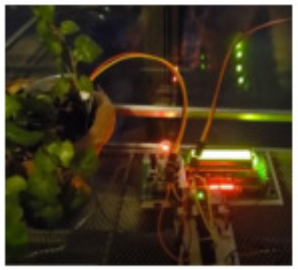
- The better videos are shared under "Best of 476" (with student permission)
- Good recruiting tool for ECE
- Good way to demonstrate your skills to future employers



Car Parking Sensor
Spring 2020
An ultrasonic range sensor dete
bar graph. When you're close e



Refrigerator Data Logger
Spring 2020
A PIC mircocontroller along wi
the time that the door remains



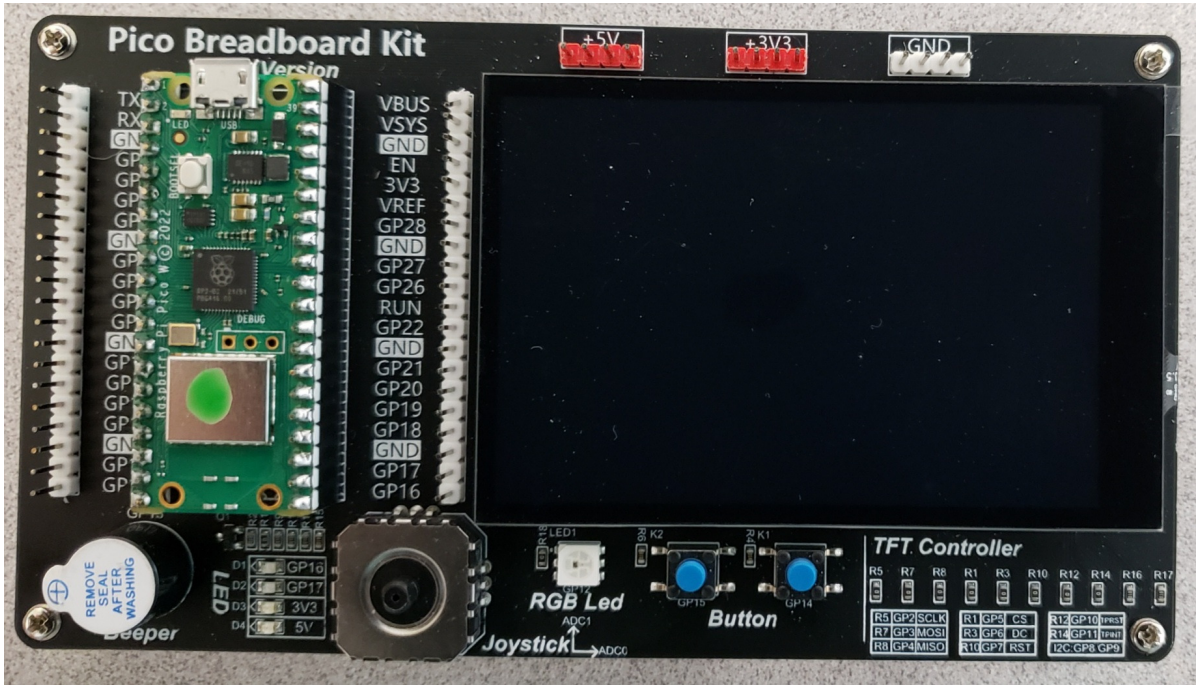
Automated Watering System
Spring 2020
A PIC mircontroller monitors t
on to water the plants.

Lab Kits

- GeeekPi Pico Breadboard Kit Plus Version
- $32 from Amazon
- (plus $9 for a Raspberry Pi Pico-W board)

Makes the class a lot more fun

- And understandable



Hy-Flex Model for ECE 476

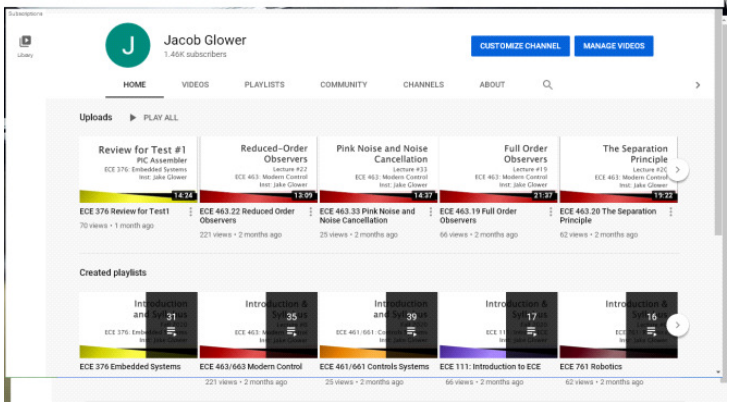
Students are welcome to take this course however they like:

- In-Person:
- Live-Stream: on Zoom
- On-Line: YouTube recordings of lectures

There is plenty of room, so you are welcome to attend each day however you like

- Whatever fits your schedule

Everyone is welcome to use the on-line resources on Bison Academy.



Evaluation Procedures and Grading Criteria

Grades will be the average of the following:

Midterms (x3)	Homework	Projects	Final Exam
50%	17%	17%	17%

Grades are rounded to the nearest 1%, with your final grade being

F	D	C	B	A
59% or less	60% - 69%	70% - 79%	80% - 89%	90% or more

How to Get an A or B:

Keep up and do the homework.

- This class involves programming and interfacing hardware to your computer board.
- The only way I know to understand this interaction is to do it yourself.
- Sort of like weight lifting: watching someone else lift weights isn't the same as doing it yourself

Grades in this class are often bimodal:

- People who did the homework themselves tend to get either an A or a B.
- People who did not do the homework or copied tend to struggle to get a D.

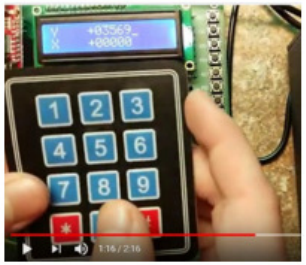
Homework & Lab Projects

Groups of 1 or 2 allowed

- Only one homework set per group

Exams serve as a check that you're doing the homework

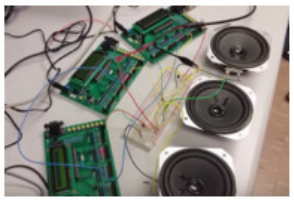
- If you do the homework, exams should be straight forward
- If you're giving moral support or copying code you found online, you'll probably struggle



Security Passcode Systems

Spring 2019

Using a numeric keypad, a passcoc buzzer sounds.



Mission Impossible Theme

Fall 2015

Using three PIC microcontrollers, th separate speakers.

ECE 376 Term Project: Padlock Solver

Padlock Solver

Spring 2014

This embedded system will determi motor turns the lock and goes throu tests the combination and a force s combination)

Open-Ended Assignments

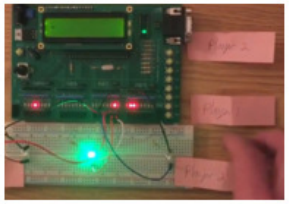
Most homework sets are open-ended:

- You are free to specify what it is you're going to build and program
- Subject to it including things that we're covering that week, such as stepper motors

Each write-up includes four sections:

- Requirements What your device does
- Hardware & Software: Schematics & Code
- Test & Validation: Data to verify your design works (voltages, frequencies...)
- Demonstration: In-person or YouTube

This allows you to tailor your homework to your own interests



Reaction Test Game

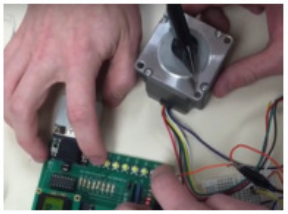
Spring 2016

A game is set up using a PIC proc
seconds later, a light turns on. Bc
- the fastest player wins. The time
LCD screen.

Scooby Doo Theme using Timer

Spring 2017

The theme from Scooby Doo is pl
each note and Timer2 sets the du



Stepper Motor Tennis Game

Spring 2016

A game is programmed where tw
the stepper motor reaches your si
miss, you suffer humiliation. Time

Legal Stuff:

Attendance: According to NDSU Policy 333 (www.ndsu.edu/fileadmin/policy/333.pdf), attendance in classes is expected. Students are responsible for the material covered in class and in assignments regardless of their attendance. Note that all lecture notes, homework sets, and solutions are available on-line at www.BisonAcademy.com

Students with Special Needs: Any students with disabilities or other special needs, who need special accommodations in this course, are invited to share these concerns or requests with the instructor and contact the Disability Services Office (www.ndsu.edu/disabilityservices) as soon as possible.

Academic Honesty: The academic community is operated on the basis of honesty, integrity, and fair play. NDSU Policy 335: Code of Academic Responsibility and Conduct applies to cases in which cheating, plagiarism, or other academic misconduct have occurred in an instructional context. Students found guilty of academic misconduct are subject to penalties, up to and possibly including suspension and/or expulsion. Student academic misconduct records are maintained by the Office of Registration and Records. Informational resources about academic honesty for students and instructional staff members can be found at www.ndsu.edu/academichonesty.

Academic Honesty Defined: All written and oral presentations must "respect the intellectual rights of others. Statements lifted verbatim from publications must be cited as quotations. Ideas, summaries or paraphrased material, and other information taken from the literature must be properly referenced" (Guidelines for the Presentation of Disquisitions, NDSU Graduate School).

ECE Honor Code: On my honor I will not give nor receive unauthorized assistance in completing assignments and work submitted for review or assessment. I have to complete all my work with complete integrity.

Veterans and Student Soldiers: Veterans and student soldiers with special circumstances or who are activated are encouraged to notify the instructor in advance.