Class Kit Vending Machine  
Conceptual Design

Nidhay Patel   
Department of Electrical and Computer Engineering  
*Tennessee Technological University*   
*Cookeville, United States of America*  
*npatel45@tntech.edu*

Austin Sigg  
Department of Electrical and Computer Engineering  
*Tennessee Technological University*   
*Cookeville, United States of America*  
*aesigg42@tntech.edu*Dillon Williams  
Department of Electrical and Computer Engineering  
*Tennessee Technological University*   
*Cookeville, United States of America*  
*dswilliams42@tntech.edu*

Ryan Reed  
Department of Electrical and Computer Engineering  
*Tennessee Technological University  
Cookeville, United States of America*  
*rcreed42@tntech.edu*Michel Turpeau  
Department of Electrical and Computer Engineering  
*Tennessee Technological University  
Cookeville, United States of America*  
*mmturpeau42@tntech.edu*

# Introduction

Around fifty devices a day are needed by students each year for their ECE (Electrical and Computer Engineering) courses. The main emphasis of this capstone project is the design and implementation of a vending machine that can loan out devices to students while keeping track of which students have taken the devices. A student can enter their information into the machine, and it will keep track of who has borrowed each device(s). Students will be able to view and choose which gadget to remove with the help of an LED (Light Emitting Diode) equipped drawer system. The purpose of this step in the design process is to complete the following: detail what subsystems must be in place in order for the vending machine to run, how these subsystems will interact with each other, and finally, what constraints each subsystem will have imposed on it and how each constraint can be tested. The following is a numbered list of specifications that are then discussed in the later paragraphs.

### 1. The machine shall be 2 to 4 feet in height.

*2. The machine shall use encrypted ethernet for data transfer*

*3. A Microcomputer/PC shall be used to manage the data and allow proper function*

*4. The devices shall be uniquely identifiable*

*5. The machine shall use a card reader to obtain identification*

*6. The machine shall have nonvolatile memory to store the programs and data*

*7. The machine shall have LED (light emitting diode) indicators*

*8. Locks shall be installed to prevent device theft*

*9. The machine shall allow auto-download of data given a USB drive*

The machine will be no taller than the average window height, which is around 2 to 3 feet, and no smaller than 2 feet in height. This allows for easy portability from the office to the student lounge at Brown Hall and vice versa. The machine will use ethernet to send data to our customers and be encrypted to avoid others from accessing the students’ information as well.

A Microcomputer (PC) will be used to manage the data acquisition system and allow the proper function of the machine. An SQL (structured query language) database will be programmed into the Microcomputer to hold the student ID (identification) number, name, email, course, and which board has been rented, as required by the customer. The boxes the devices are held inside must be uniquely identifiable according to the department, so each box must be scanned into the database before a device is taken. This is to prevent the theft of a device by any student and allows the customer to know which is taken. For the same reason, the machine shall have a card reader to ID every student. This way no student can fake the number, even if other information was incorrect.

For the entire machine to function after a reset and to remember information for the customer, the machine is required to have a form of nonvolatile memory such as MicroSD or an actual separate drive. The machine must have a series of LED indicators so the student knows which drawer and compartment to access when retrieving the board. Solenoid Locks shall be installed into the drawers and compartments so no single person can easily break through to the devices when the machine is unsupervised. The current plan is for a drawer and compartment to hold for several minutes to allow enough time for a worker to notice the attempt.

The following subsections provide detail on each of the previous requirements and how each shall be completed according to the customer.

# Background

A question that may arise from the conceptual design is: why use a PLC and a Microcomputer in the vending machine? One reason that a PLC is being considered is due to a PLC is cycle-based. When discussing execution schemes, there are two that can be used: event-driven execution and cycle-based execution. In an event-driven scheme, like a microcomputer, “a run-to-completion step is executed each time an event is raised,” while in a cycle-based scheme, like a PLC, “a run-to-completion step is executed periodically in regular time intervals,” [1]. The reason this needs to be addressed and specified is to show how a PLC can be useful in our design. Being event-driven, a microcomputer will wait to scan until input is sent to it. On the other hand, a PLC will constantly check all inputs and sensors on a certain time cycle. It’s important to have a cycle-based execution for the hardware components, such as locks and component sensors, because they are the main security measure against stealing the devices. There is a chance that if this scanning is done by the microcomputer, it could execute at the end of a long command, such as a “for” loop. If this is the case, the hardware scanning could happen minutes after the request was sent. Whereas if a PLC was used, the hardware could be monitored every scan cycle, for example, every 200ms. This makes PLCs more reliable in relation to securing the devices and monitoring hardware.

**\*\*\*\*\*\* Mick will discuss why we need to use Ethernet and how we will secure the data\*\*\*\*\*\***

# Ethical Considerations

During the process of designing this vending machine, every scenario that can occur must be taken into consideration. The vending machine will be plugged into the wall for its power supply. The supply voltage will be 120VAC before it’s sent through the AC/DC converter. It must be certain that the voltage is properly stepped down and converted to DC. The desired voltage is roughly 5V DC; given that “30 volts is generally considered to be a conservative threshold value for dangerous voltage,” a person could be severely injured in the event of incorrect conversion [4]. In order to counteract this, there will be a system in place to detect if there’s a spike in voltage or current in the AC/DC converter and trip the power supply. This system will most likely be a ground-fault circuit interrupter (GFCI). Having this within the power cord for the vending machine will comply with the National Electric Code (NEC) standard NEC 422.51, which requires vending machines that are powered by cord-and-plug to have a GFCI located near the wall plug [5].

In addition, security must be put in place to prevent student data from being compromised. One security measure is connecting the vending machine’s database to the ECE office’s computer by ethernet. This is because “An Ethernet connection is much more secure than a Wi-Fi connection. Data on an Ethernet network can only be accessed by physically attaching a device to the network, while data on a Wi-Fi network travel[s] through the air and can be more easily intercepted,” [6]. An Ethernet connection will make it more difficult to steal student information compared to a Wi-Fi connection since data can only be stolen by attaching a device to either the vending machine or the ECE office’s computers. In using Ethernet as a form of communication, the connection must follow the Institute of Electrical and Electronics Engineers (IEEE) standard IEEE 802.3-2018, which gives a selection of speeds at which an Ethernet connection must work [7].

To work with the Ethernet connection, a form of encryption will be used on the student information before it’s sent out. This will make the received information look jumbled, though it will be deciphered upon retrieval.

Finally, a scenario that must be considered is the stealing of a device from the vending machine. Given the chance that the faculty in the ECE office may step out of the office for a few minutes, there is a chance that someone could attempt to break into the vending machine to steal the devices within. To help prevent this, the vending machine will have locks on both the drawers and the lids of each device. There will also be a sensor system in place to detect if a box is in its compartment. While this will be mainly used for the SQL database, it can be given the purpose of detecting if a device is removed without approval.

# Block Diagram

## Constraints

The following is the list of constraints that will be imposed on our subsystems:

i) Microcomputer System

(1) The microcomputer must contain a database that is programmed with SQL and another language such as C++ or Java.

ii) PLC

(1) The PLC must interface with the locks and LEDs.

(2) The PLC must control the step voltage of the motors.

(3) The PLC must communicate with the microcomputer.

(4) The PLC must know the device occupancy of each drawer.

(5) The PLC must have a timer system.

iii) Communication

(1) The machine must have a USB port to auto-transfer information between itself and the drive.

(2) The machine must receive a CSV file from the faculty computer.

(3) The Ethernet connection used to send the CSV file must have a form of encryption to secure student information.

(4) The machine must have a barcode scanner to send the board number to the microcomputer.

(5) The machine must use a card reader to read information off of an Eagle Card and use it as a unique ID.

(6) The machine must have a user interface involving a touchscreen to enter certain student information (such as name and email).

iv) Power System

(1) The power system must have a ground fault current interrupter (GFCI) to protect against the current surge.

(2) The power system must have an AC/DC converter to send power to the voltage-sensitive components.

(3) The power system must have an emergency stop control.

## Microcomputer System

The microcomputer system should be able to meet the following criteria: It should have enough storage to hold device information, student information, and programming. It should also have connectivity ports such as a USB (Universal Serial Bus) and an Ethernet port.

The Microcomputer will not only be used for keeping up with the Database but also be responsible for communication with other subsystem modules. It should comprehend input signals from the Card Reader, User Interface (UI), and barcode scanner. Also, it should communicate with PLC for carrying out the operation of vending devices.

The Microcomputer will be mainly used for the following functions:

### 1) SQL Database

### a. Inventory

With the aid of a sensor in the PLC system, the database will be utilized to keep track of the inventory inside the machine and will be able to inform the client whether a device is loaded or unloaded. If the package is loaded, the system will verify that the barcode scanner has read it. The system will check to see if the box hasn't been scanned and if it is unloaded. The database's inventory area will then be used to store and record all of the data.

*b. Student Information*

The database will also be used to maintain a list of the students who have borrowed gadgets for classes, and it will be able to transmit the data to the customer over Ethernet and/or a USB drive. The identification will be entered into the database under the students’ section using the card reader that is attached to the computer. A user interface will be used to input the student's name and email. From a list of courses the database has, a course portion will then be selected. The barcode of the chosen board will be read by the scanner once it has been selected, and the consumer will then be able to use it.

To validate whether the information has been correctly processed and stored in the database, a mock trial will be done by using a teammate’s Eagle card and after that, the data will be downloaded to see whether the information stored in the database is accurate or not.

## PLC

In order to give the vending machine’s hardware reactive functionality, a PLC will be implemented along with its necessary sensors.

### Control System

#### User Interface (UI)

The PLC will control the hardware behind the UI used for students to check out their boards. The UI will allow students to enter their names and email. The UI will also interact with our microcomputer in order to send the student’s information to the database. The functionality will be tested by entering a generic name along with a team member’s email. Once this is done, the database will be checked for the entered information.

Input: Powered by the MCU, controlled by the PLC. The student’s name and email will be entered.

Output: Student information to the MCU to send to the database.

*b) Locks*

The locking system will be solenoid coils energized by the PLC. The PLC will run the student’s course number and board needed through comparison functions to find where it is equal to a board number that isn’t checked out. Once it finds equality, the corresponding locks will become un-energized so the student can grab the board. The functionality will be tested by running a test line in the PLC to see if a lock’s tag correctly updates.

Input: Powered by the vending machine, energized by the PLC.

Output: Locking and unlocking the drawers and compartments containing the devices.

*i) Drawer Locks*

The first line of defense for the stored objects is the locks for the drawers. Since these are easily accessible, they will require stronger locks than internal locks. They will have to resist forceful entry and external interference. These locks will return to standby (closed) after the item has been removed and the drawer is shut.

*ii) Compartment Locks*

These locks prevent the opening of the separate compartments inside the drawer. Since they are harder to access and in a more compact environment, the locks will not be as strong as the ones holding the drawers shut. These locks will return to standby (closed) after the item has been removed and the compartment is closed.

*c) Indicator*

The vending machine will have an indication system to guide the student to the correct drawer and compartment. When the PLC finds the correct board needed by the student, it will run the board’s tag through compare commands until it finds the corresponding indicator tags. Once the tags are found, they will be energized and un-energized on a timed system.

Input: Voltage from the machine, energized from PLC, set to flash at a certain interval with a timer system.

Output: Drawer and compartment indicators will flash to show where the device is located.

*i) LEDs*

To assist the user in identifying the location of their required device, there will be LED indicators on both the drawers and separate compartments. There is a total of 1 LED for each drawer, and 1 LED for each compartment inside of the drawer. When the user is given the location of their rented device, the LED will blink on the drawer that has been unlocked, as will the LED of the specified compartment. LEDs will return to standby after the item has been removed and the drawer has been shut.

*d) Timer System*

The PLC will run the timer system used in tandem with the lock and indication systems. This system will be used to hold the solenoid coils as unlocked for a reasonable duration in order for the student to grab their device (roughly 15-20 seconds). Once the time has elapsed, the coils will become energized and will lock once the drawer and compartment are closed. The timer system will also set the period of flashing for the indication system. Once the time for the coils has elapsed, the indicators will also stop flashing.

Input: Total duration from PLC, tag update from PLC.

Output: Solenoid coils will be unlocked for a given duration. During this duration, the indicators will flash to show where the device is located.

*e) Sensors*

To determine if the compartments of the vending machine need to be restocked, the PLC must know which compartments are empty or full. Sensors can be used to communicate the occupancy status of each compartment to the PLC. If there are no sensors, then the machine would not know which compartment is stocked with a device or not.

There are hundreds of sensor options to deliberate between; the sensor we choose must be able to fit in the designed compartment, not require to be recalibrated after implementation, and must be within the limit of our budget. Ideally, the sensor will send a one-bit binary signal back to the PLC for simplicity in communication and ladder logic code. In regard to this, photoelectric sensors are more advantageous than weight or distance sensors because they don’t send back a multi-bit signal.

The sensor we choose must be connected electrically to the control system to communicate feedback with the PLC. The sensor must also have power delivered to it; This can be delivered by the power supply.

The implemented sensors satisfy constraint ii (4) by communicating to the PLC which compartments have a device in them and which ones do not.

## Power Supply

For all of the mending machine’s main systems to execute their tasks, they must be powered electrically. We plan on using a wall outlet as our power source; we will connect a power cord with a ground-fault circuit interrupter, GFCI, to the power supply that is nested in our vending machine. This will supply power to the PLC, microcomputer, barcode scanner, card reader, solenoid locks, sensors, and LEDs. Most of these systems will all need varying direct current voltage levels which require an AC/DC converter.

*a) AC/DC Converter*

All of the systems that compose our vending machine require a lower DC voltage than the 120 V AC wall outlet supplies--the PLC will probably be the only system that is powered with 120 V AC. The AC/DC converter will step down the 120 V and convert the AC power to DC power. From there the voltage will be amplified by Op-Amp circuits each corresponding to the voltage level required by each system. This system satisfies constraint iv (2).

b) *Power Protection*

To physically guard our systems against current there will need to be several different circuit protection components to the point of redundancy. If the GFCI senses any leaks in the electric current it will immediately trip and shut off the power protecting the power supply of the vending machine—this satisfies constraint iv (1) There will also be a circuit breaker before the power supply and fuses after the power supply to protect each sub-system. With these multiple layers of protective measures, all of the systems will be safe from damage caused by possible over currents. To satisfy constraint iv (3) the power cord that connects the vending machine to the wall outlet will be accessible to unplug—acting as an emergency stop control.

## Communication

1. *USB (Universal Serial Bus) Port*

The vending machine will have a USB port as a form of communication between itself and the faculty computer. If there is something that must be

1. *Ethernet*

The ethernet cord shall be used to send and receive data to and from the customer. If the customer wants to see the database and who has taken items, they can request the file and it will be transmitted. The file will likely be a CSV from Excel that will feed from and to the database. The ethernet cable can be directly connected to the microcomputer and user PC using an ethernet connector which uses an RJ45 connector, and with the right steps of static IP configuration, one can start transferring data from the microcomputer.

Input: Encoded message to the database

Output: Message signal to the connected device

1. *Barcode Scanner*

To register the individual devices to the machine and properly keep track of the current owner of the device, a barcode scanner will be installed. When loading the devices, the user will first have to scan their barcode, registering them to the indicated compartment. This will tie the device’s ID to the compartment’s location. The next board cannot be loaded until the previous one has been registered and locked. This will allow the database to then tie the rented device to the student, allowing us to keep track of its possession.

Input: ID of the device.

Output: Registering the location of said device.

1. *Card Reader*

The card reader shall receive a signal from an ID card issued to the student by the college. When the signal is received, the device will send the data to the database through the microcomputer. The Reader will have an indicator light for a correctly scanned card to notify the student that he/she is good to proceed.

Input: Information from Eagle Card

Output: Create Data and send a signal to the microcomputer

1. *UI (User Interface)*

The user interface will be connected to the microcomputer and will allow the user to input their name, email, and which class(s) he or she needs a device for. The information is also relayed through the PLC system.

1. *LCD (Liquid Crystal Display)*

A User Interface (UI) is necessary for the student to select the necessary board since it can be used to collect information from the student, such as their name and email address, and when the information has been verified, the UI can be used to select the needed board from the given set of choices available. For the interface, it would most likely be a touch screen LCD if not a display for the user to input the information required. One of the constraints that we must follow is that it should be compatible with the microcomputer system we would end up using. For the system to work the following functions of the user interface should be read: a) should be able to recognize the depression of any key/screen and should be able to identify it and send it to the microcomputer. b) should be able to display coming off from different systems or subsystems or from the interface itself. Each time the operator accesses a menu function, the user interface module will send a notification to the main system i.e., Microcomputer. The relevant system will be informed by the microcomputer in response, and that system will then establish a direct connection with the user interface (UI). When the operator selects a menu function, the user interface module will communicate with the microcomputer, which will then alert the appropriate systems so that the function can be performed.

The system will be analytically validated by inputting student information and by selecting a board from the given set of choices and will be checked to see if the system was able to grab user information and send it to the database or not. The system would also be checked to see whether each message from the different pertaining systems is displayed properly or not. For example, if any information was not valid then the microcomputer should be able to communicate to the UI to display an error message and should ask the user to enter the information again.

Input: Message Signal to Microcomputer System

Output: Microcomputer signaling to PLC or UI itself.

# References

1. “Event-driven vs. cycle-based execution,” itemis. [Online] Available: https://www.itemis.com/en/yakindu/state-machine/documentation/user-guide/quick\_ref\_execution\_semantics#quick\_ref\_execution\_semantics. [Accessed: 25-Oct-2022].
2. S. G. Sakshi, “What is SQL & How Does It Work? A guide to structured query language,” *Springboard Blog*, 12-Oct-2022. [Online]. Available: https://www.springboard.com/blog/data-analytics/what-is-sql/. [Accessed: 14-Oct-2022].
3. “Microcomputer,” *Encyclopædia Britannica*. [Online]. Available: https://www.britannica.com/technology/microcomputer. [Accessed: 14-Oct-2022].
4. T. R. Kuphaldt and J. Haughery, “Electrical safety,” *Applied Industrial Electricity*, 01-Jun-2020. [Online]. Available: https://iastate.pressbooks.pub/electriccircuits/chapter/chapter-1/#:~:text=In%20industry%2C%2030%20volts%20is,resistance%20for%20protection%20against%20shock. [Accessed: 14-Oct-2022].
5. ElectricalLicenseRenewal.com, “422.51 vending machines.,” *ElectricalLicenseRenewal.com*. [Online]. Available: https://www.electricallicenserenewal.com/Electrical-Continuing-Education-Courses/NEC-Content.php?sectionID=134.0. [Accessed: 14-Oct-2022].
6. S. Enterprise, “What is the difference between a WIFI and ethernet connection?,” *Spectrum Enterprise*, 23-Mar-2019. [Online]. Available: https://enterprise.spectrum.com/support/faq/network/what-is-the-difference-between-wifi-and-ethernet-connection.html#:~:text=An%20Ethernet%20connection%20is%20much,can%20be%20more%20easily%20intercepted. [Accessed: 14-Oct-2022].
7. “IEEE SA - IEEE Standard for Management Information Base (MIB) definitions for ethernet,” *IEEE Standards Association*. [Online]. Available: https://standards.ieee.org/ieee/802.3.1/5263/. [Accessed: 14-Oct-2022].