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Unlock the Mystery: Puzzle Box

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***Abstract*—This project develops an interactive puzzle box with an electronic locking mechanism to engage young learners in logical problem-solving. The box features a series of switches and LEDs, and the user must find the correct combination of flipped switches to activate all the LEDs and unlock the box. A custom logic circuit, using AND and NOT gates, encourages iterative problem-solving. Concealed within the box, this innovative circuit adds an unexpected level of challenge that is more than one may initially expect. The box is designed to provide hands-on learning experience, employing a reward system designed to foster persistence and critical thinking. The project also explores the educational potential of the puzzle box as a tool for teaching foundational engineering logic to young children.**

***Keywords*—Puzzle, Electronics, Circuit, Logic**

I. Introduction

Educational puzzles are a creative way to make learning more engaging and interactive. Such puzzles encompass a wide variety of formats, including traditional brain teasers, interactive learning games, and technology-based applications, catering to different age groups and learning styles. Their ability to promote critical thinking, problem-solving skills, and teamwork makes them essential in modern educational practices [1,2].

Research shows that puzzles can improve cognitive skills like memory, attention, and creativity. When students tackle a challenging puzzle, they learn to observe patterns, think critically, and make connections—skills that are essential in both academics and everyday life. Furthermore, puzzles also encourage social interaction. When students work together to solve problems, they develop communication skills, learn to explain their reasoning, and build confidence in their own abilities [3].

Consequently, when tasked to consider our own electronics design project and build a prototype device, one that accomplishes a specific purpose as part of Northeastern University's Electronics course, we decided to design this puzzle box. Such a project not only demonstrated Northeastern's emphasis on experiential learning by having us invent, design, refine, and physically implement our ideas, but also allowed us to create a product that can benefit the next generation of students.

Our design extensively utilizes transistor-transistor logic (TTL) chips to perform logical operations. More specifically, 7408 and 7404 chips are used to implement AND gates and NOT gates, respectively. Two of the eight terminals of the chips are needed to power the chip, while the other legs are set to be an input or output of the relevant logical gate [4].

II. Design

This section details our key design choices, and the core components as listed in Table 1. Some concept art of the final product is shown on Fig. 1.

A. *Logic Circuit*

The logical circuit's design was optimized to exhibit largely unpredictable behavior and possess a unique solution. To ensure that the circuit only had one solution, the logic gates comprising the circuit were limited to AND gates and NOT gates. This had the added benefit of limiting the supplies needed to physically implement the design.

To ensure that the eight-switch circuit would exhibit largely unpredictable behavior, each light emitting diode (LED) was set to be controlled by three random switches. Once all four LEDs are activated, the solenoid lock is activated, unlocking the box. Our circuit design was simulated using Logisim Evolution, an open-source circuit design tool [5] as shown in Fig. 2.

Through the precise design of the logic circuit, the users are encouraged to apply a thorough problem-solving strategy. By ensuring that the circuit only has one solution, users are unlikely to be able to randomly guess the solution as there are 2^8 possible solutions. Moreover, by assigning three switches to each LED rather than two as shown in Fig. 3, it becomes difficult to systematically isolate the relevant switches. If, for example, there were only two switches per LED, then it would be simple to flip the switches one by one to identify which two

TABLE I. MATERIALS

Part	Quantity
1/4" wood for box	1.83 m^2
Jumper Cables	N/A
Wood Glue	N/A
Hinges (LifCratms: SUIMBH005)	2
5V Solenoid Lock (ASIN: B07TLVGH3Y)	1
MTS 102 3-position toggle switches	8
TTL Logic chips	4
Arduino (Uno R3)	1
Variable DC Power Supply (GW INSTEK GPS-3030DD DC Laboratory Power Supply)	1
RED LED (DigiKey 732-5016-ND)	4

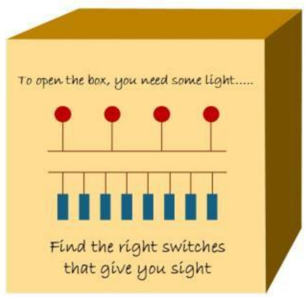

Figure 1: Concept art for final box design. The illustration highlights the eight toggle switches and their interaction with the four LEDs.

switches controlled each LED as there would be an immediate effect on each light. However, with the three-switch design as shown in Fig. 3, there are many configurations where flipping a certain switch will have no visible result. This necessitates a deeper level of problem solving.

B. Box Casing

During the design of the box's casing, strength and customization were major factors. By designing the walls to interleave with one another, the stability was greatly improved, as this design would limit the stress to our adhesive and would distribute force through the solid wall structure. Moreover, using wood of 1/4" thickness increased the external stiffness while not being so thick as to be incompatible with components such as the switches or LEDs. Lastly, by choosing wood over stronger materials like metal, the box would be more easily customizable. It would be much easier, for example, to drill holes, carve engravings, and fashion the appropriate shapes using a laser cutter. Figure 4 illustrates the CAD design employed for laser cutting the wooden casing.

The number of externally visible components was kept to a minimum. The hope therein was to promote the box's visual appeal as it would be more easily understood by children. From a head-on perspective, the only components visible to the user are the eight switches and the four corresponding lights. With a single source of input (switches) and separate source of feedback (LEDs), there are few ways for the user to incorrectly interact with the puzzle.

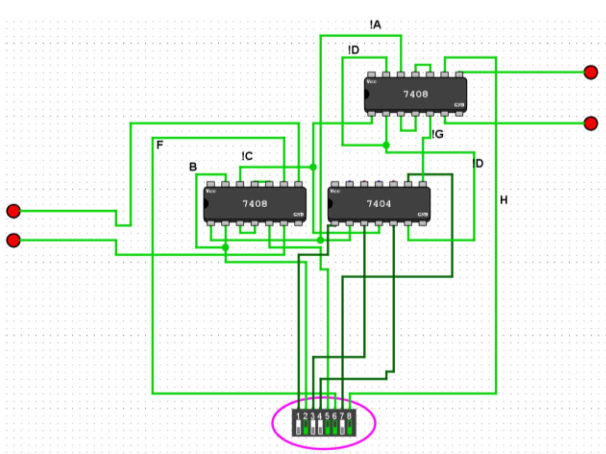

Figure 2: Logisim Evolution Simulation. This simulation illustrates the correct sequence of switches to activate all LEDs (shown as red dots), solving the puzzle.

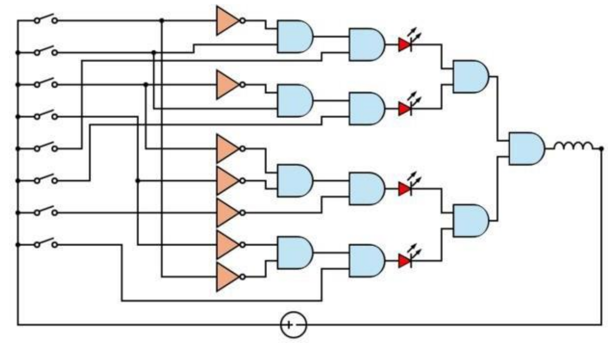

Figure 3: Simplified Circuit Diagram. Includes key components of the logical circuit and its interaction with the LEDs. Note: the solenoid symbol represents the solenoid lock.

The only other externally visible components are the hinges on the lid and the external power supply which are only visible from the back of the box. Until a battery can be installed in the box, the external power supply should only be operated by a responsible adult. External power is necessary for the demonstration of the initial design but in principle, there is no reason that it couldn't be replaced by a battery in the future, however, the solenoid requires high current.

C. Solenoid Lock

The internal components include a solenoid locking mechanism that remains extended until five volts of direct current are supplied, at which point the locking mechanism retracts, unlocking the box. The five-volt figure was a deliberate design choice as it is the voltage at which the other components function optimally. Furthermore, the lock includes a wedge design for the stopper as shown in Fig. 5. Thus, once the lid is opened, it can be closed again and will automatically lock without another power impulse. Such is the superiority of a retracting lock over an extending lock: not only can it re-lock automatically, but it also remains locked even if the box is disconnected from the external power supply. This limits the scope for cheating the game.

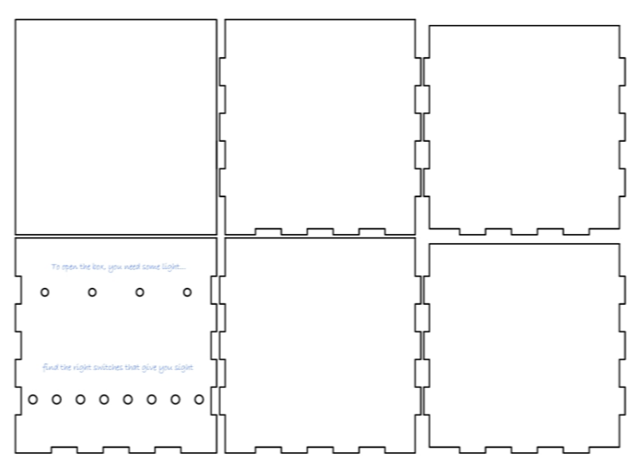

Figure 4: Box CAD Design. The design shows the dimensions of each side of the box as well as the interleaving of the edges.

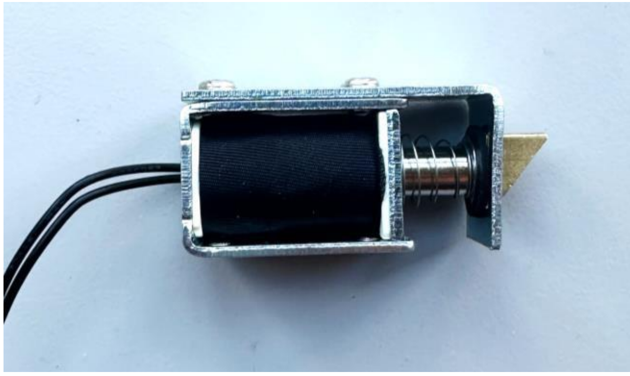

Figure 5: Image of Solenoid lock. Illustrates the presence of a wedge- shaped stopper.

D. *Arduino Microprocessor*

One unfortunate component limitation is that the lock can only be activated in a high-power state for a limited time (on the order of 5 seconds). Extending the activation time beyond this limit causes the lock's temperature to rise with negative consequences for its lifespan. Consequently, a microprocessor was required to enforce a time limit for the lock's activation. It is integrated into the circuit in series before the solenoid lock. It receives a high voltage from the logic circuit as an activation trigger and passes five volts to the solenoid for a two second time limit. After the time limit, the microprocessor will not activate the lock until the input from the logic circuit is turned off then on again. The chosen microprocessor was an Arduino Uno R3 due to its ease-of-use and availability [6].

III. Rules and Operation

To set the game up, begin by ensuring that the box is closed and that the switches are not set to the correct answer. We recommend either randomly flipping the switches or flipping them all in the same direction to initialize the puzzle, but any initial state should work. Next, connect the external power cables to a five volt direct current supply with the red wire on the positive terminal and the black on ground. Congratulations, those are all the steps required to enjoy the genius of our apparatus. Simply ensure that the children don't interfere with the power supply, and they should be free to apply themselves to the puzzle with all the associated merits.

Given the nature of children, it is prudent to address the possibility of cheating the game Neither we nor our testers have yet been able to find a way of cheating the game, short of using excessive force. However, we recommend that only one switch be flipped at a time to guarantee the stability of the internal digital logic.

IV. Conclusion

This project provided invaluable experience with the entire design, engineering, and manufacturing workflow. Not only did we learn how to invent and improve novel designs, but we also learned how to turn our abstract concepts into a physical reality. Moreover, after creating and refining our physical prototype, we gained a deeper understanding of the importance of communicating and presenting our design to a variety of audiences. Such is the power of experiential learning: not only did we hone a wide range of important skills, but we also developed a product with the potential to positively impact a generation's education.

V. Future Work

There are several practical and creative enhancements we would consider implementing if we were to continue this project. First, installing a battery pack within the box would make it significantly more portable and increase ease of use. The battery was so far omitted because of the possibility of overheating issues during troubleshooting but these should be avoidable in a final product. Second, the Arduino microprocessor could be replaced with a much simpler processor or even a custom 555 timing circuit. This would decrease the cost drastically as the Arduino currently costs more than the rest of the materials combined, and the box only requires a small fraction of its processing capabilities.

Apart from practical upgrades to the present puzzle, we would like to emphasize the customizability of our puzzle. Our modular designs allow for simple modifications such as changing the number of switches, the number of LEDs, or the puzzle's answer. What's more, we intentionally left space on the outer walls of the box where new puzzles could be added. Such puzzles could include custom combination locks, incomplete circuits which the user must complete, or similar challenges. Any new puzzle could be easily integrated into the internal circuit by putting it in series with our current circuit such that all the puzzles must be solved to unlock the box. Alternatively, if a developer wished for the box to open when any of the challenges are solved, rather than all of them, they could simply connect their circuit in parallel to ours, rather than in series.

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