A11 - Ethical and Environmental Analysis

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1. Environmental Impact Analysis

**1.1 Manufacturing**

The complexity and size of the Smart Air Hockey Table necessitates that many materials are used to manufacture it and its components. A single Smart Air Hockey Table requires a master PCB and 128 sensor PCBs, which result in at least 5,092 cm2 of PCB being produced per table. Producing a PCB already requires a substantial amount of energy, hazardous materials, and copper [1][14]. Since there is no viable alternative process for producing PCBs, producing such a large cumulative area of PCBs is intrinsically harmful to the environment. Furthermore, the electrical components required to populate these boards and the connected peripherals have their environmental impact.

While the Smart Air Hockey Table only uses one microcontroller, an STM32U585VIT6, semiconductor manufacturing produces 31% of global greenhouse gas emissions and electronic chip usage is rising by 35% annually [2]. The microcontrollers required to manufacture Smart Air Hockey Tables are likely to have an insignificant impact on worsening this environmental issue. However, manufacturing Smart Air Hockey Tables would still directly contribute to the issue by further increasing demand and financially contributing to the semiconductor industry. In order to populate the 128 sensor PCBs required per table, 512 WS2812B LEDs, 512 DRV5033 hall effect sensors, and 256 CD74HC11 triple 3-input AND gates are needed. These components require some amount of energy and materials to produce. Each individual component may have a negligible environmental impact, but the cumulative environmental impact is non-negligible. This issue is worsened when considering the passives required to populate the PCBs as well. Furthermore, hall effect sensors typically use gallium arsenide, indium antimonide, or indium arsenide [3]. In addition to gallium and indium being critical rare metals, Gallium arsenide poses a significant health hazard while indium antimonide and indium arsenide pose a significant environmental hazard [4][5][6][7].

In addition to the components directly attached to the PCBs, the PCBs rely on connected peripherals as well. The Smart Air Hockey Table requires a PEC09 rotary encoder, two SSD1309 OLEDs, a power supply, a power relay, and a centrifugal blower. Fortunately, the rotary encoder and OLEDs do not significantly contribute to the environmental impact of the Smart Air Hockey Table. The PEC09 rotary encoder is a mechanical encoder, thus it does not need to use the same hazardous materials required by a hall effect sensor. The Office of Energy Efficiency and Renewable Energy tout OLEDs as being significantly better for the environment compared to alternatives [8]. Given the complexities of the power supply, power relay, and centrifugal blower used for the Smart Air Hockey Table, it is difficult to fully quantify their environmental impact beyond assuming a reasonable amount of waste is produced and energy is consumed for manufacturing.

Currently, the Smart Air Hockey Table primarily reduces its environmental impact during manufacturing through its mechanical design. The Smart Air Hockey Table’s mechanical design primarily consists of wood. Wood is a biodegradable and renewable resource and, thus, it is one of the most environmentally friendly materials to use. However, the wood should be sourced responsibility to ensure sustainability as manufacturing of the Smart Air Hockey Table scales.

The Smart Air Hockey Table could further reduce its environmental impact without requiring its design to be significantly altered by analyzing each of the components previously described and its manufacturer to choose the most environmentally friendly, commercial option. Analysis should focus on the power supply, power relay, centrifugal blower, and sensor PCB electrical components, especially the hall effect sensors. While more environmentally friendly alternatives may exist, it is important to note the monetary impact that may result from switching to an alternate component or manufacturer. After the environmental analysis of the components and their manufacturers, an economic analysis of the alternatives will be required to determine the economic feasibility of these options as well.

**1.2 Normal Operation**

After the initial environmental impact of manufacturing the Smart Air Hockey Table, the Smart Air Hockey Table will continue to impact the environment throughout its lifespan. Throughout the Smart Air Hockey Tables lifespan, most of the environmental impact will be caused by the power consumption required to run the Smart Air Hockey Table. While the average power consumption of the device is not currently known, it can be reasonably assumed that the power consumption will be significant given its functionality. The three subsystems that will likely contribute the most to the overall power consumption of the Smart Air Hockey Table are the centrifugal blower, the grid of WS2812B LEDs, and the grid of DRV5033 hall effect sensors. The centrifugal blower uses approximately 86.25 W [9]. WS2812B LEDs run at 5 V and a single LED can use up to 60 mA when at maximum brightness white. Therefore, the Smart Air Hockey Table’s grid of 512 WS2812B LEDs may use up to 153.6 W [10]. DRV5033 hall effect sensors run at 3.3 V and a single sensor can use up to 30 mA. Therefore, the Smart Air Hockey Table’s grid of 512 DRV5033 hall effect sensors may use up to 50.688 W. Thus, these three subsystems result in the Smart Air Hockey Table using up to 290.538 W. This estimate does not include all subsystems that make up the Smart Air Hockey Table, especially the intrinsic loss from the power supply. The environmental impact of power consumption depends on how the electricity is generated. In the United States of America, only 39.7% of electricity is generated by clean methods and only 21.5% of electricity is generated by renewables in 2022 [12]. Additionally, electricity generation accounts for 25% of the United States of America’s total greenhouse gas emissions in 2021 [13].



Figure 1: Sources of Electricity Generation for the U.S. Power Grid in 2022 [12].



Figure 2: Total U.S. Greenhouse Emissions by Economic Sector in 2021 [13].

Therefore, electricity consumption in the United States of America negatively impacts the environment by depleting non-renewable resources and contributing to global warming. While the Smart Air Hockey Table will not significantly worsen this issue, the Smart Air Hockey Table will somewhat worsen the issue by further increasing electricity demand on the U.S. power grid. Since the team is unable to meaningfully impact the rate at which the U.S. adopts a 100% fully renewable power grid, the Smart Air Hockey Table includes two features to help reduce its power consumption. As shown previously, the grid of 512 WS2812B LEDs contributes the most to the power consumption of the table as a whole. Therefore, the first power-saving feature allows the user to adjust the brightness of the LEDs. By allowing the user to lower the brightness of the LEDs to match the ambient light of the room, the overall power consumption of the table is reduced while maintaining the table’s functionality. Second, the Smart Air Hockey Table features a low-power mode which is automatically triggered after a predetermined period of inactivity is detected. The low-power mode turns off all peripherals besides the rotary encoder. Just turning off the centrifugal blower and the LEDs reduces the power consumption of the Smart Air Hockey Table by up to 239.85 W or 82.6% of the previous power consumption estimate. The Smart Air Hockey Table is still intended to be turned off when not in use, but the team recognizes that users may forget to turn off the table. Thus, the automatically triggered low-power mode will unintentionally reduce power consumption.

Besides the power consumption, the Smart Air Hockey Table will impact the environment if repairs are needed. While repairing the table will result in a smaller impact on the environment than manufacturing a completely new table, the impact of repairs on the environment should still be considered. Repairing the Smart Air Hockey Table will require replacing the faulty part, which results in the environmental impact caused by producing that part. Therefore, the environmental impact of repairs can be reduced by increasing modularity within the design to allow smaller portions of the table to be replaced by repairs. The Smart Air Hockey Table excels at this level of modularity. The master PCB and attached peripherals can be replaced without issue assuming an equivalent part is used. As discussed in section 1.1, most of the Smart Air Hockey Table’s environmental impact from manufacturing comes from producing the grid of sensor PCBs. However, these sensor PCBs are entirely independent besides the DuPont wires connecting them together. Therefore, individual sensor PCBs can be replaced as necessary for repairs rather than requiring that the entire grid be replaced. However, facilitating these repairs will be a logistical challenge. A repair service could be provided where consumers could pay for a representative from the company to perform the repair. An economic analysis would need to be performed to determine if the company could afford to provide this service. Furthermore, since the Smart Air Hockey Table is too large to be shipped for repairs, these representatives would need to come to the table. Therefore, the economic analysis would also need to consider where all this service could be provided. These issues could be avoided by making the master PCB, sensor PCB, and connected peripherals commercially available to consumers directly. However, this solution requires that the repairs could be performed by the average consumer with limited to no knowledge of electrical engineering. In addition, the repairs would also need to be safe enough to not risk harming the average consumer to avoid ethical concerns.

**1.3 End of Life**

While supporting repairability will extend the lifespan of the Smart Air Hockey Table, eventually the product will become unrepairable, or the consumer will decide to dispose of the product. Therefore, the environmental impact of the Smart Air Hockey Table at its end of life should also be considered. While the recyclability of PCB byproducts during the manufacturing process has seen significant improvements, the recyclability of PCBs themselves are still severely limited [14][15]. Given the limited feasibility of recycling PCBs and the fact that they are not biodegradable, the 5,092 cm2 of PCB per table pose a significant problem in how the Smart Air Hockey Table will negatively impact the environment by increasing demand on landfills. Similarly, most of the electrical components on the PCBs and connected peripherals are unable to be recycled. If repairability is promoted using one of the methods described in section 1.2 or a similar method, then the company could consider providing a service to take Smart Air Hockey Tables at their end of life to recycle them. The company would dismantle the Smart Air Hockey Table and use the components for repairing other Smart Air Hockey Tables. The feasibility of this solution would require an economic analysis to ensure that the company can reasonably afford to ship the tables, dismantle the tables, and test the recycled components. In addition, shipping the tables to a center for dismantling and shipping the recycled parts will have their own environmental impact. Thus, a further environmental analysis would be required to ensure that this process would reduce the Smart Air Hockey Table’s environmental impact rather than increasing it.

As alluded to in section 1.1, the Smart Air Hockey Table’s packaging being constructed with wood helps reduce its impact on the environment. While the rate of biodegradation in landfills is an area of active research and depends on the type of wood used, wood will decay in landfills [16]. This means that no additional processing is required, and the Smart Air Hockey Table’s frame will decay whether deconstructed with the previously described recycling method or if directly disposed of by the consumer. Additionally, while the decay of wood releases some greenhouse gases into the atmosphere, studies suggest that this is not a concern for the environment [16].

1. Ethical Challenges

**2.1 Mechanical Hazards**

 There are two mechanical hazards inherent to the Smart Air Hockey Table’s current design which could result in an ethical dilemma if not properly analyzed and addressed. First and foremost is the possibility for a mechanical failure with the Smart Air Hockey Table’s packaging. Given the high-speed and competitive nature of air hockey, consumers will reasonably expect that the Smart Air Hockey Table should be capable of handling forces from all sides of the table, including the playing surface. If the table were to suffer a mechanical failure during gameplay, then the consumer’s injury could range from a small bruise to a potentially life-threatening cut. Fortunately, these injuries can be avoided with a mechanical analysis of the maximum forces the Smart Air Hockey Table’s packaging can withstand from several key points. If the maximum force is below the expected use case of the Smart Air Hockey Table, then the Smart Air Hockey Table’s packaging can be redesigned to provide better support or stronger materials could be utilized. While user safety is paramount, the environmental impact of using different materials for the Smart Air Hockey Table’s packaging should be considered. In addition to performing a comprehensive mechanical analysis of the Smart Air Hockey Table’s packaging design, each manufactured table should undergo quality assurance to ensure that the packaging has been constructed properly. Quality assurance could be ensured by putting the packaging under different forces and checking if the packaging suffers a mechanical failure.

 Second, the centrifugal blower underneath the table contains blades which could cause harm if a user attempted to touch the blades while the blower is spinning. The centrifugal blower is a required component of the Smart Air Hockey Table; thus, it cannot be removed. Furthermore, the centrifugal blower’s location on the table cannot be changed without constituting a major redesign of the Smart Air Hockey Table. Therefore, user harm should be avoided by constructing a cage around the centrifugal blower, placing a warning label on or near the cage, and including a warning in the user manual. The cage around the centrifugal blower provides the primary deterrent by blocking access to children and unintentional access from other users. However, the cage must be constructed in such a way to ensure that airflow is not significantly affected while still ensuring a child’s small fingers would not be able to get inside. The warning label on or near the cage and the warning in the user manual act as an extra layer of protection by communicating the potential hazard to users.



Figure 3: Example Danger Label for the Centrifugal Blower [19].

**2.2 Electrical Hazard**

 The Smart Air Hockey Table’s centrifugal blower requires a high voltage and is powered by a wall outlet. Therefore, the Smart Air Hockey Table has the potential to deliver harmful and potentially fatal doses of electricity should the user be electrocuted by the table. While the Smart Air Hockey Table is not designed to electrocute the user in any way, the team has an ethical responsibility to ensure that a user could not be electrocuted due to a reasonable failure in any of the Smart Air Hockey Table’s subsystems. Electrical hazards can be prevented in two ways. First and foremost, all components that are part of the Smart Air Hockey Table’s power system, such as the power supply and power relay, should not be accessible by the user. Since the Smart Air Hockey Table’s frame is made of an insulating material, wood, then the power system’s location within the body of the table should be reasonably safe [17]. However, wood can be somewhat conductive when wet [17]. If this is deemed to be a significant risk to the user, then an additional layer of insulating material should surround the Smart Air Hockey Table’s power system. It is worth noting that this insulating material should be nonflammable to protect against a potential fire hazard as will be discussed in the following section.

**2.3 Fire Hazard**

 As alluded to, the Smart Air Hockey Table should take reasonable precautions to prevent the table from catching on fire to protect consumers and consumers’ assets. While the Smart Air Hockey Table’s packaging being constructed from wood offers protection from electrical hazards and improves the product’s environmental impact, wood is flammable. Wood begins being capable of igniting at 390 to 500 degrees Fahrenheit [18]. Research and testing will need to be performed on all components of the Smart Air Hockey Table to determine if they can reach a high enough temperature to ignite the wood or if they can ignite themselves under failure. Any components that suffer from either of these possibilities should be surrounded in nonflammable insulation to prevent fire from spreading to the table’s wood packaging. If the fire risk is too high, then a different material can be considered for the Smart Air Hockey Table’s packaging. Changing the material of the table’s packaging may have effects on the Smart Air Hockey Table’s environmental impact, the potential for mechanical failure, and the potential for an electrical hazard. Therefore, changing the material used for the table’s manufacturing should be used as a last result and carefully considered.

**2.4 Magnetic Hazard**

 Compared to the ethical concerns related to the hazards discussed in sections 2.1, 2.2, and 2.3, the Smart Air Hockey Table’s magnetic hazard may not seem substantial. However, the Smart Air Hockey Table’s puck contains a neodymium magnet that produces a strong magnetic field. The crushing force that can be generated by the magnet while in the puck should be analyzed to ensure that a user would not be seriously injured if an appendage, especially a finger, were caught between the magnet and a large, ferrous object. If the analysis determines that the crushing force is not significant, then a simple warning should be included within the user manual that recommends that the user should exercise caution while handling the puck near ferrous objects. However, if the analysis determines that the crushing force is significant, then the Smart Air Hockey Table would need to be redesigned to use a less powerful magnet. Since the strength of the magnet is significant to the Smart Air Hockey Table’s ability to detect the puck and thus operate, this change and alternative solutions should be carefully considered in such a case.

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