Yixuan Li, Bernard Richawn, Adrian Santosh
ECE 445
Professor Arne Fliflet
2 Sep 2025

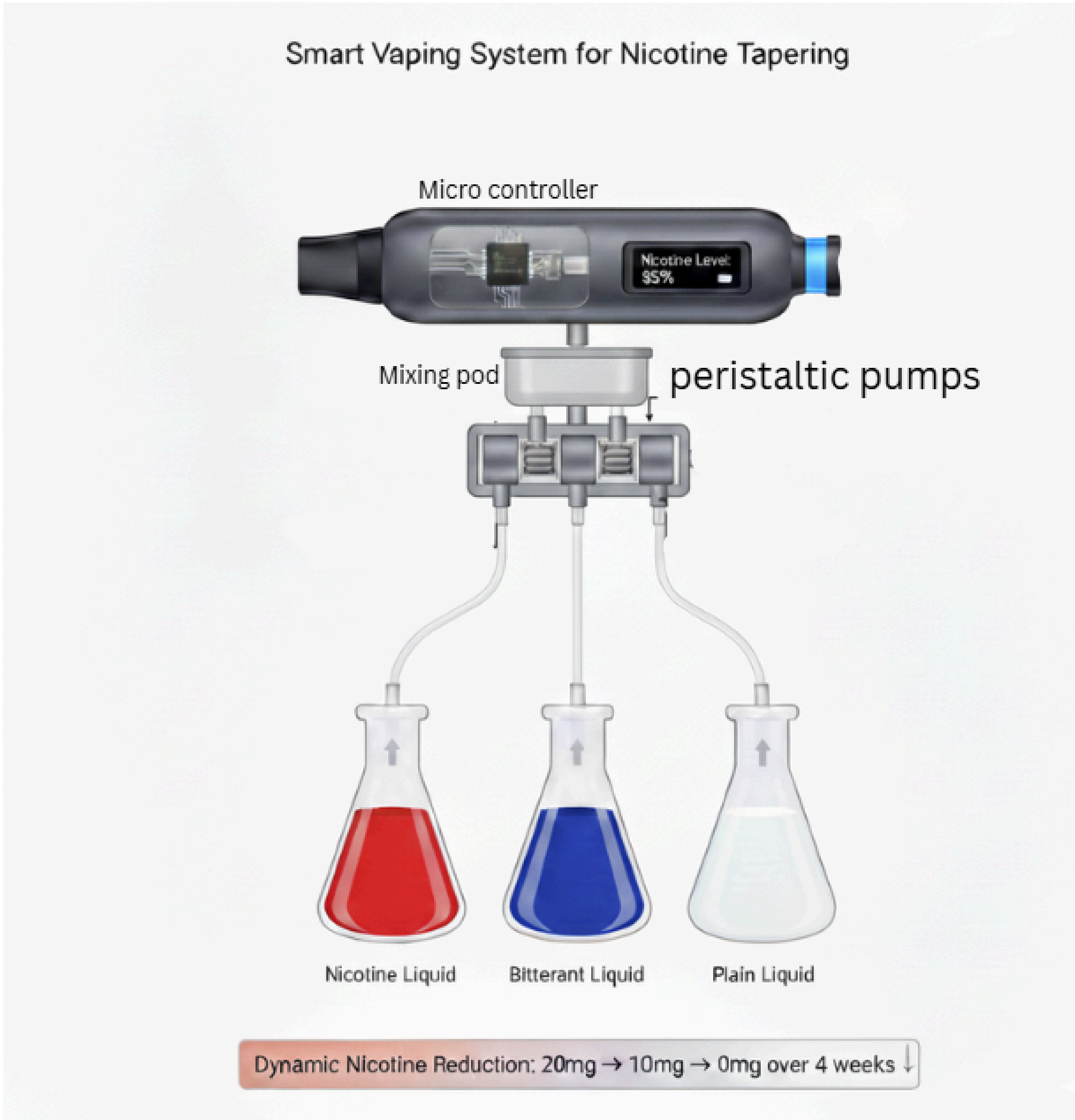
New Generation Addiction Control and Recovery Device System with Absolute Safety and Privacy - working with the FadeX Team

Introduction

1) Problem: Addiction, whether to substances like nicotine, alcohol, and fentanyl or behaviors reinforced by daily cues, often develops unconsciously and progresses unnoticed until it becomes deeply ingrained. Existing recovery methods are largely dependent on an individual's self-regulation and willpower. The current methods of treatments are often rigid, not tailored to daily fluctuations in cravings, and lack real-time responsiveness. This leads to frequent relapses : when attempts at reduction fail, the result of this can leave people in a worse spot from when they started, discouraging them from tapering off the substance , and even more resilient to it. For nicotine addiction, cravings can spike multiple times a day , but current tools do not adapt in real time to meet those fluctuations, leaving many smokers under- or over-dosing with ineffective or even harmful results.

2) Solution: The solution is a smart nicotine reduction device that monitors and adjusts the amount of nicotine a user inhales with each use. This system will incorporate a programmable control unit that gradually decreases nicotine concentration over time. By lowering the dosage in careful steps, the device reduces the dependency and the "bounce back" effect of sudden withdrawal. To further discourage continued use, the system can introduce safe, conditioning the brain to associate vaping with reduced satisfaction. This combination of gradual reduction and negative reinforcement helps to break both the physical cravings and the psychological appeal. The implementation centers on a PCB that controls the vape's motor and mixing components. Sensory measures how many inhalations, while the PCB adjusts according to composition of the vapor in real time by mixing nicotine with an bitter compound.the device will progressively lower its nicotine levels and increases the substitution, allowing the user's to adapt without severe withdrawal symptoms.

3) Visual Aid:



4) High level requirements

i) Sensing: The device reports a heart rate and oxygen level status within 60 seconds. Liquid load sensors and temperature sensors give the correct liquid weight and temperature up to 1g and 1 C accuracy.

ii) Analysis: The device calculates the required concentration of the dose with 1s.

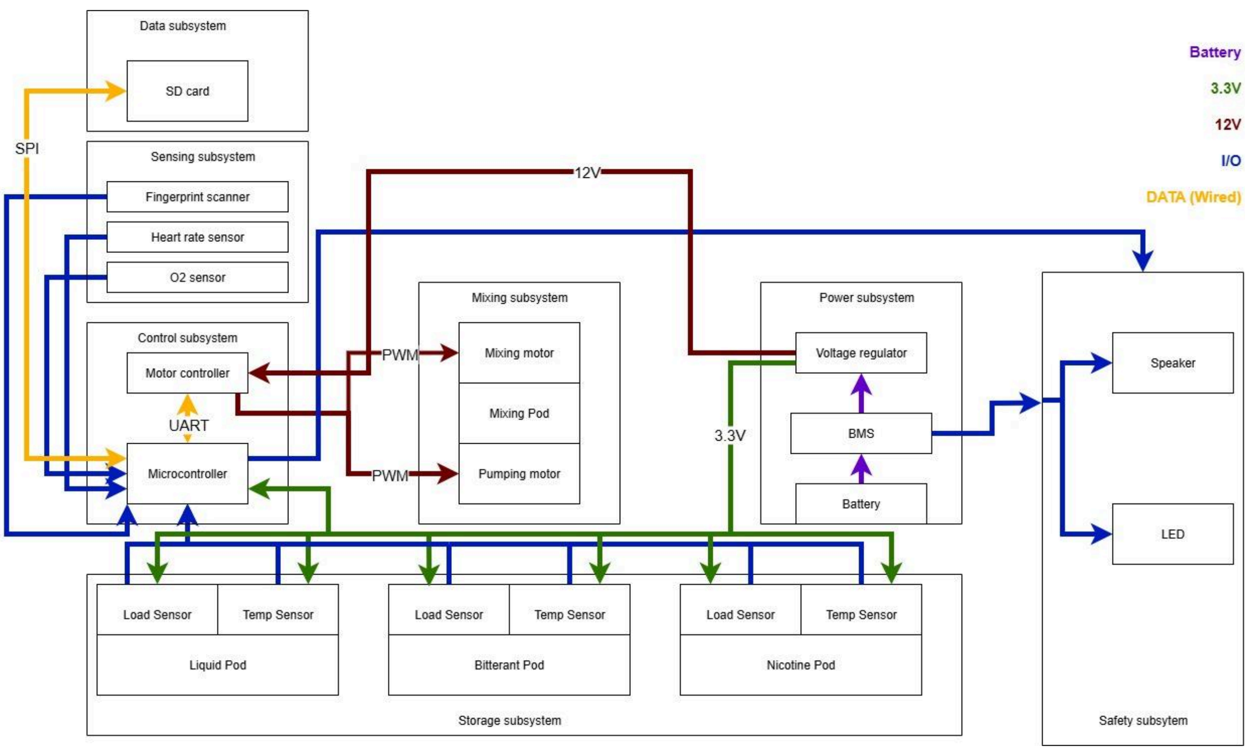
iii) Delivery: The system delivers the commanded dose concentration (using a safe test liquid) within 1% up and down of target as measured on a scale, and enforces a minimum lockout time between doses every time.

iv) Safety: If a red-flag condition appears (very high heart rate, high oxygen level, sensor fault, low battery, liquid leah, high liquid temp), a clear alert shows.

v) Privacy: The device works with no external network. All data is stored on a SD card and the user can erase all local data from the SD card.

Design

5) Block Diagram



6) Subsystem Overview:

a) Sensor Subsystem

The sensor subsystem gets real-time user data like heart rate and oxygen levels. It also has a fingerprint sensor to record and read fingerprint data for secure operation of the device and to prevent misuse. These signals feed into the microcontroller, which uses them to adapt the dosage and detect unsafe conditions.

b) Control subsystem
The ESP32 serves as the central processor that receives the data, controls safety logic, and controls the dosing concentration. It enforces system timing, gradual nicotine reduction, and abnormal command overrides. It communicates with the mixing and tank systems to ensure safety cutoffs. The motor controller controls the pump and mixer to enable the transport of fluid from the tanks to the mixing pod and ensure the liquid concentration in the mixing pod.

c) Mixing Subsystem
The mixing subsystem controls the fluid reservoirs in the storage subsystem. Each reservoir feeds fluid into the Mixing pod through a peristaltic pump. The mixing pod incorporates a stir mechanism driven by a DC motor, which mixes the fluid to create a mixed solution prior to being vaporized. This subsystem serves as a main point for the dose control and interacts directly with the control subsystem.

d) Power subsystem
The power system supplies regulated DC voltage (3.3V, and 12V) to sensors, motors and the ESP32 using regular 12V batteries.

e) Storage Subsystem
This consists of three tanks, one stores the nicotine containing fluid, another stores a liquid to dilute the nicotine fluid and the third contains a bad tasting fluid to decrease addiction. Each tank has a temperature and load sensor to monitor the state of the liquid and detect issues in temperature and leakage.

f) Data subsystem
This system is used to protect the users data and enforce data safety. Privacy is insured by the SD card, with no wireless network connections as all communications are through SPI.

g) Safety Subsystem
Safety components include alarms, flashing red LED , software shutdown logic, and fingerprint authentication for secure access. It connects logically both the microcontroller software and the physical safety hardware.

7) Subsystem Requirements:
   a) Sensor Subsystem
      i) Must be capable of measuring heart rate and SpO_2 levels within 60 seconds, with an accuracy of ±2%.

ii) Interfacing options must include an I^2C/Qwiic interface for the MAX30101 heart rate and SpO_2 sensor and analog inputs from the load and temperature sensors.
iii) If any of the requirements are eliminated the overall system cannot ensure proper dosing or safety.

b) Microcontroller Subsystem
   i) Must be capable of taking sensor telemetry data and calculating dose concentration within 1 second.
   ii) Must ensure lockout time between doses.
   iii) Interfacing options shall include GPIO for control of servos/pumps, I^2C for sensors, and SPI for data on SD card.
   iv) Failure to ensure lockout time or calculations for dosing and/or concentration could lead to unsafe delivery of nicotine.

c) Mixing Subsystem
   i) The mixing pod must mix dose accurately to a concentration of the target within ±1% of that concentration.
   ii) Pumps (12V peristaltic type) must deliver volume within ±5% repeatability.
   iii) Eliminating leak detection and safety checks makes the device unsafe.

d) Power Subsystem
   i) Must supply at least 5V @ 2A for pumps and 3.3V @ 500mA for sensors and microcontroller.
   ii) Must switch between active mode and "sleep"/power save mode.
   iii) Must include a circuit for undervoltage protection and overload (overcurrent) cutoff.
   iv) If a stable regulated supply is not provided, sensor and/or pump failure could lead to dosing errors.
   v)

e) Storage subsystem:
   i) Tanks for nicotine, neutral, and noxious liquid must all have leak detection capabilities and two layer containment.
   ii) We should also have a temperature detection to make sure that the liquid has the correct state and ensure a safe temperature.
   iii) Load sensors measure liquid level with an accuracy of ±1g and temperature sensors measure temperature with an accuracy of ±1°C.

iv) If the load sensors or temperature sensors fail, then the liquid would be unsafe for consumption by the user and may contaminate the surroundings due to undetected leakage.

f) Data subsystem
i) Must be able to interact with the microcontroller to read and write data using SPI interface for communication
ii) Must be able to store data for 1 year without corruption
iii) Must be able to store at least 1MB of data
iv) Data must not be accessible outside of the microcontroller and SD card
v) If the data subsystem fails, then the microcontroller would lose information of the previous dosing which is required to calculate the next dose concentration.

g) Safety Subsystem.
i) If any part of the system is damaged, safety measures should be enforced with a buzzer and a flashing red LED within 1s of failure detection.
ii) Buzzer noise must be clearly audible and flashing must be detectable
iii) If the safety subsystem fails, the user may be in danger due to overheating or leakage of liquid, overheating of battery or damage to motors leading to incorrect concentration of the dose.

8) Tolerance Analysis

The component most susceptible to risk in our system is the Adafruit 1150 peristaltic pump which is used to transport liquid from the liquid pods to the mixing pod for mixing according to the required concentration set by the microcontroller. The pump can get damaged or blocked while the tubing connected to the pump can leak affecting the flow rate of the liquid through the pump. A mathematical analysis of the Adafruit 1150 peristaltic pump can be modeled by breaking down its core components: the electric motor and the fluid dynamics of the peristaltic action. The overall performance depends on the relationship between the motor's power input (voltage and current), its rotational speed, and the resulting volumetric flow rate and pressure generated within the tubing.

1. Motor control and speed
The Adafruit 1150 is driven by a 12V DC motor. Its speed, and therefore the pump's output, can be controlled using pulse-width modulation (PWM).
Motor speed vs. PWM: The rotational speed of the DC motor, (ω), is approximately proportional to the PWM duty cycle, $(D).(\omega \propto D)$.The duty cycle (D) is a percentage

of the total period that the voltage is applied to the motor. A higher duty cycle results in a higher average voltage and therefore a faster motor speed.
Flow rate vs. motor speed: The volumetric flow rate, (Q), is directly proportional to the motor's rotational speed, (ω).$(Q \propto \omega)$Therefore, the flow rate can be controlled by adjusting the PWM duty cycle. However, this is a simplified model. Due to the pump's design, lower speeds can result in less precise and potentially pulsed flow.

2. Theoretical flow rate model
The ideal volumetric flow rate of a peristaltic pump, (Q_{ideal}), can be calculated based on its geometry and rotational speed. This assumes no backflow or slippage.
$(Q_{ideal} = V_{roller} \cdot N \cdot \omega)$ Where:(V_{roller}) is the volume of fluid displaced per roller per revolution.(N) is the number of rollers on the pump head.(ω) is the rotational speed of the pump head in revolutions per unit time. For the Adafruit 1150, which uses a "clover" pattern of rollers:$(V_{roller} = \pi \cdot (R^2 - r^2) \cdot L)$, where (R) is the outer radius of the compressed tube, (r) is the inner radius, and (L) is the length of the compressed segment. Since the tube is fully compressed, this isn't a simple calculation and depends on the specific geometry of the pump head and tubing. A more practical approach is to recognize the direct proportionality between rotational speed and flow rate, and use calibration to find the constant of proportionality.$(Q_{real} = k \cdot \omega)$ Where (k) is an experimentally determined constant for the pump, dependent on the tubing properties and fluid viscosity.

3. Fluid dynamics and non-ideal effects
In practice, the actual flow rate will be lower than the ideal due to pressure-related effects, especially at higher flow rates or against significant head pressure.
Head pressure: Pumping fluid against gravity or a pressurized system creates back pressure. This pressure can cause a small amount of fluid slippage or backflow past the rollers, especially at low speeds or with worn tubing, reducing the net flow rate.
Viscosity: The viscosity of the fluid affects the pump's performance. Pumping a more viscous fluid will require more torque from the motor to maintain the same rotational speed, increasing current draw. If the motor's torque is insufficient, the speed will drop, and so will the flow rate.
Tubing properties: The Adafruit 1150 uses 2mm inner diameter silicone tubing. The flexibility and internal friction of this tubing influence the pump's efficiency.Wear and tear: Over time, the tubing will wear and lose its elasticity, which can decrease the pumping pressure and result in a lower flow rate.
Material: The properties of the tubing determine how effectively the rollers create a seal and propel the fluid.

4. Electrical power analysis
The power consumption of the Adafruit 1150 is a function of its mechanical load. Input power: The electrical power consumed by the motor, (P_{in}) , is the product of the input voltage and current.$(P_{in} = V \cdot I)$, Where $(V = 12VDC)$ and (I) varies between 200–300mA depending on the load.Mechanical power: The power delivered to the fluid, (P_{out}), can be related to the flow rate and pressure.$(P_{out} = Q \cdot \Delta P)$, Where (Q) is the volumetric flow rate and (ΔP) is the pressure increase across the pump.Efficiency: The efficiency of the pump system, (η), is the ratio of mechanical power output to electrical power input. $(\eta = \frac{P_{out}}{P_{in}} = \frac{Q \cdot \Delta P}{V \cdot I})$ The efficiency of the Adafruit 1150 is likely low, especially at lower flow rates or with high friction loads, and includes losses from the motor, gearing, and peristaltic compression.

5. Practical considerations for mathematical modeling
A simplified mathematical model is sufficient for controlling the Adafruit 1150. This involves using an empirical relationship between PWM duty cycle and flow rate, which requires calibration.
Calibration: We connect the pump to a known fluid and use PWM to set different speeds. We measure the resulting flow rate over time for each speed.
Best-fit equation: We plot the data points and perform a regression analysis to find the function relating the PWM value to the flow rate. A linear relationship, $(Q = m \cdot D + b)$, is often a good first approximation, where (m) is the slope and (b) is the offset.

Ethics and Safety:

We care about ethics more than anything else, we will mainly be focusing on these three aspects of ethics: privacy, care, academic integrity, and humanity. All of them have a different focus on different groups of people.

a) Privacy:
Different people take different views on privacy, but we can estimate how people manage the privacy of themselves, especially for the parts that most people will agree on. Stoicism in Ancient Greece is one of the great examples. According to SEP, “The Stoics are determinists about causation, who regard the present as fully determined by past events, but who nonetheless want to preserve scope for moral responsibility by defending a version of compatibilism.” (Durand). Basically Stoics assume the world in a deterministic chain that contains so many minimal parts that can be determined for sure about what is going to happen in the future as long as we have sufficient information and correct models to make predictions.

Furthermore, “They say that every cause is a body which becomes the cause to a body of something incorporeal. For instance, the scalpel, a body, becomes the cause to the flesh, a body, of the incorporeal predicate “being cut”” (Durand). Again, Stoics assume the whole world as a system of interrelated parts that act on each other and also get opposite act force when one part acts on the other parts, and from their definition a human individual is just a bag of those smaller parts or particles that get limited to a shell named like “Rajesh”. So the only thing about what a human is is then just a wall to separate the “inner” particles and “external” particles.
Also, like many of the Greek ideology, “Stoic ethics is eudaimonist in structure, in the sense that it posits happiness (*eudaimonia*) – a well-lived, flourishing life – as the rational agent’s ultimate practical goal or end (*telos*).”(Durand) So, “Every human agent, it is assumed, wants nothing more than to live a flourishing, happy life and therefore arranges their own projects and efforts according to what they think will accomplish this goal.”(Durand) but the problem is “Unfortunately, however, most human beings are mistaken about what will in fact make them happy. Regardless of what they themselves might say about the value and success of their lives, most humans, according to the Stoics, hold false opinions about what their happiness consists in, i.e. false opinions about what is good.”(Durand). But then what is actually good? “Zeno represented the end as: ‘living in agreement’. This is living in accordance with one concordant reason, since those who live in conflict are unhappy... Cleanthes, [Zeno’s] first successor, added ‘with nature’, and represented it as follows: ‘the end is living in agreement with nature’. (Stobaeus, 63B)”(Durand). So living well is thus living in agreement with nature. “the corporeal mind is present everywhere within it, structuring and shaping the underlying matter according to an all-encompassing, perfectly rational plan. For a human being to live “in agreement” (homologoumenôs) with cosmic nature therefore requires attuning her own reason (logos) with that of the whole, by thinking the same thoughts about her situation and circumstances as does Zeus in governing the portion of the world she occupies (Cooper 2012). In this way, the flourishing agent lives in conformity “with the will of the administrator as the whole” (Diogenes Laertius, 63C).”(Durand). So as a conclusion, in the Stoicism view, living in accordance with nature is a good way of life, it is one of the most important things to live in agreement with nature and probably is the most important thing.
But then you may ask, why do we care? Well, in short, we care because trying to get information about other people’s privacy is not “in agreement with nature”. The original “in agreement with nature” idea suggests one should make the internal “small parts” to act similar and ultimately the same as the external “small parts”. And the fact that one trying to look into someone else' s edge is not “good”

in three ways. First, trying to take a look at how other people have the interaction internally is not part of nature and will mess up even more the internal process of someone. Second, it is by “nature” that someone is not happy to be investigated how one's own interaction for small parts work and that “one” will then practice feisty acts back to the source. Third, it is also by nature, bad to look into the details of how another person’s “internal parts” work together. That is immediately out of the natural order.

So with that being said, we will follow the thought to have the maximum respect toward privacy to make sure we are sufficiently respecting others, respecting other’s “agreement with nature”, and also respecting our own “agreement with nature”.

b) Care:

I also would like to put a strong emphasis on caring about each other, both in the meaning of caring about each other when working together as a team and caring about the product user that may use our design later.

“Drawing conceptually from a maternal perspective, Noddings understood caring relationships to be basic to human existence and consciousness. She identified two parties in a caring relationship—“one-caring” and the “cared-for”—and affirmed that both parties have some form of obligation to care reciprocally and meet the other morally, although not in the same manner.” (Sander-Staudt, “Nel Noddings”). As Noddings was talking about, caring relationships is as basic as mother loving children, meanwhile children loving back mother not for at least not just for the benefit. This should be an ethically true requirement and does not even be required to do so. It is a default method of every individual, not even like a moral law that needs to be developed later.

Furthermore, “She characterized caring as an act of “engrossment” whereby the one-caring receives the cared-for on their own terms, resisting projection of the self onto the cared-for, and displacing selfish motives in order to act on the behalf of the cared-for. Noddings located the origin of ethical action in two motives, the human affective response that is a natural caring sentiment, and the memory of being cared-for that gives rise to an ideal self.”(Sander-Staudt, “Nel Noddings”). In a more understandable sense, what she talked about here is the first type of motive, the natural caring, is from someone who feels “ought” to do something to care about others, like helping a drowning kid without even thinking about whether one should do it. The second type of motive, the ideal self, is a little more twisted but eventually comes with the same result. It means when one is indifferent about helping others on something or even just feeling opposed to helping someone on something, one still does a bit more thinking and then thinks that ideally, one should help. For example, if someone has diarrhea all over the place and fainted, someone walking by may just want to get away and ignore but feel still should morally take care of that individual and call 911.

With that being said, "Noddings rejected universal principles for prescribed action and judgment, arguing that care must always be contextually applied." (Sander-Staudt, "Nel Noddings"). Basically she means there is never something by itself is ethically correct to act on someone, we should always work with the mind about the ideal self and think about what the care receiver may need for feeling good.

Why do I mention all these? What I want to say is as human individuals, we are fundamentally social creatures, and we all should care about each other by nature. This matters a lot in group activities because as a group we need to have a group contract and rules to ensure we function well as a group together. In the case when nothing goes wrong all the rules should be followed. But for example what if someone has a headache? Maybe that person should still work. What if someone has a cold? Maybe that person should still try one's best to catch up. But what if someone got hit by a car? I would suggest the other two people should then try to help that person to get over it as much as possible. In some sense rules are rules but we should then just get applied to total utilitarianism and treat each other like machines. When accidents happen we need to take into account everyone's reasons and use the care principle to "care" about each other to avoid more damage. This is why French people say "liberty, equality, fraternity", because extreme freedom causes extreme exploitation, extreme equality causes extreme tyranny, the fraternity is there to prevent the extremeness of both sides, so it always stays on a balance and never loses it. And here, "care" is our fraternity to keep a balance between rules and tolerance. On the other side we should also care about what may be the problems with the user of the product. There are many engineeringly successful products that get designed every single year but still are infamous because of bad design toward "care". We should put ourselves in the "ideal self" to do careful thinking about what users may need to be cared about, thus we never make the functionalities that are harmful for others.

c) Integrity:

Why do we care about academic integrity? It sounds that we have an obvious answer there that it is wrong by rules but it is not the full image. Saying it is wrong to not follow academic integrity by rule is correct, but also not just correct by itself. For example it is by rule one not supposed to swim in the boneyard creek, and it is correct, but what if Loomis Lab get destroyed by an earthquake and someone get buried down there with the only escape spot being swimming inside boneyard creek, is that then still wrong to swim in there? I assume not.

I want to start by explaining how Socrates defines the word "Virtue". If we list some virtues: brave, helpful, optimistic, they seem like totally different identities that are just somehow "good". But if we think about it, why, for example, being brave is a virtue? Someone who gets scared by a cricket is definitely not brave. Someone who fights a wolf to save a baby is brave. But what about someone just deciding to fist fight a bear for no reason? It doesn't seem like the case to be brave here but rather just being stupid. It is the same case for helpful. If someone never helps others, that person is not helpful. If someone helps a granny get over a cross road, that person is indeed helpful. But what if someone says yes to anyone who needs any assistance(that may even be harmful)? That doesn't sound like being helpful. Same for optimistic. If someone is sad and has low expectations on everything that happens, that person for sure is not optimistic. If someone always holds a happy view even when the worst case happens, that person is optimistic. But what if someone never even thinks bad things could happen and just assumes the world always should be the best case to self? This again does not sound optimistic but rather stupidity and arrogant. So, what if virtue? Virtues themselves may have different meanings and seem to be totally different identities but all of them eventually point to the same result: The wisdom to balance in the correct range.

Academic Integrity is undoubtedly one of the most important if not the most important Virtue for an Engineer. It matters in both ways. First we have to be responsible about others morally. Second, this is the class U of I created for us to practice in a real design and if we lack this exercise then in the future when nobody is doing the exact same thing as we do the harm will be directly back to us. So we need to be wise on the balance of Integrity. We need to seek help and information wisely, mindfully, and carefully.

(Below are the set of integrity code we need to follow)

i) https://studentcode.illinois.edu/article1/part4
ii) https://www.ieee.org/about/corporate/governance/p7-8

d) Humanity:

"Humans can never be used as the way toward a goal. Humans can only be the goal." (Philip Hillmer, ECE316)

As Professor.Hillmer said, every human individual can never be used as the way toward a goal, and a human can only be the goal for a better wish, for example fixing someone's spinal cord should not come with the cost of cutting off someone else's spinal cord.

As ECE445 students we are not that destructive yet for humanity(I hope so). But accidents always can happen and since this is our first practice toward the real world, I think we should treat it as if it is a real impactful project that might bring the influence like an industrial revolution.

My intention here is to be mindful about every single decision we will make about the project, to worry about each human individual that might get influenced by this project. I don't remember the details but there were a lot of engineering disasters that got caught later, like someone decided to add lead into the gas to make it more flammable and eventually it cost all the air on the earth to contain a bunch of lead.

But first of all why should we care about humanity as a whole and in more detail why should we care about all the human individuals? In my opinion there are three main reasons:

First, Like I mentioned before in the Care part, as humanity we all naturally and ideally care about each other, no need for more information

Second, We care about the people related to us, and follow Darwin's theory that we as humans more or less are closely related, so we should be mindful about humanity and each human individual because undoubtedly we belong to the same family.

Third, this is what I call "common descendent theory": Premise 1: As humans we love our descendents by nature. Premise 2: Every single human individual has a possibility to have a descendent with another human individual. Premise 3: The descendants will be sad if one of the ancestors harm another ancestor, even just unconsciously. Conclusion: Based on Premise 2 it is just a matter of time for two human individuals to have a common descendent, and if one harm another person unconsciously, one's descendants will feel sad and one should them also feel sad and do the best to be mindful about what could happen and then try best avoid it.

So we should follow what professor Hillmer said, we should always try our best to think about humanity and each human individual. We shall never use any human individual as ways of reaching a goal. We should always aim for the well being of every single human with the best wishes.

Citations:

Durand, Marion, Simon Shogry, and Dirk Baltzly. "Stoicism." The Stanford Encyclopedia of Philosophy, edited by Edward N. Zalta and Uri Nodelman, Spring 2023 ed., Metaphysics Research Lab, Stanford University, 2023,
https://plato.stanford.edu/archives/spr2023/entries/stoicism/

Sander-Staudt, Maureen. "Care Ethics." Internet Encyclopedia of Philosophy,
https://iep.utm.edu/care-ethics/