This is meant as an example of the work that is expected. It is not a perfect example, so be sure that you are meeting all of the requirements set by the assignment/rubric.

Homework 2: Abstraction & Synthesis

ECE 2799

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1. Introduction

Our smart mirror is a smart home device that is meant to improve a customer's daily routine by offering quality of life and entertainment features. Users can get all of information they would normally get in the mornings all from one source. This could include the day's weather, their commute time, their calendar for the day, and much more. Each of these would be displayed on the mirror in front of them when they are brushing their teeth or applying makeup, allowing them to cut down on the time it takes to finish their routine.

A smart mirror has several design aspects that are essential to the product. These are the two way mirror material, a user interface, a display, and a System on Chip(SoC). These design options are required to construct a smart mirror and need to be analyzed to find the best option within each of these sections. The main requirements for each is keeping cost low while providing a benefit for the customer. If both these requirements are met, users would be more likely to feel that the smart mirror could be a useful addition to their daily routine. Other criteria are needed to evaluate these design options on an individual basis.

Beyond these elements that make up the core of a smart mirror, more components can be added that address customer desires. These improve the ability of the customer to use the smart mirror and receive information from it. One example of this is using sensor to allow the mirror to turn on and off when a user enters the room. Another component would be an on/off switch to allow the customer to turn off the mirror whenever they desired and increase their privacy. Many of the other additions would be done in software to add more features that a customer might want. Software additions would improve the entertainment and practical values of a smart mirror, two customer requirements we found in a survey of 26 potential users of a smart mirror.

The purpose of this report is to determine design components that are otherwise hard to conclude as well as to analyze the overall value of our smart mirror against other smart mirrors in the market. Generally, analysis needs to be done on the types of user interfaces that can be used, the type of display that can be used, the type of materials of two way mirrors available to us, and a way to make the mirror turn on and off automatically. Once the general design approach of these parts is chosen, analysis can be done on specific products for sale such as the System on Chip to control the smart mirror. The value of the overall product also needs to be compared to the value of other products on the market such as the QAIO smart mirror from Evervue to determine if our design offers some value against the competition.

According to the value analyses below, our final design approach has been narrowed down significantly. The user interface will be controlled using buttons and a voice control module. A phone app could also be created to help with initial setup if we have time. The display will be a normal monitor, not a touch screen. Otherwise, the cost will be too high. Mirror materials are still relatively split between glass and acrylic. For our prototype it may be better to use acrylic because of how much cheaper it is, even though glass would function significantly better. Lastly, the automatic on/off sensor will be created using a light sensor. The light sensor used does not need to be specific because it only needs to determine whether a light is on or off, not specific light levels in between. We also decided on a specific SoC, the Raspberry Pi 3B+, because it has all of the needed functionality and hardware connections. We also decided on a monitor, the Sceptre E225W, because of its cheaper cost while still providing the minimum specifications. Using these design components will allow us to put together a prototype of a smart mirror.

2. Design Options

Our general design approach involved going through customer requirements, keeping in mind that the general use setting of such a smart mirror was in a bathroom. The product was placed in the bathroom because there was less overlap with other smart home products like Google Home as they would be less likely to be placed in the bathroom. This meant that the overall product must have a focus on water-safety and privacy, two things that are much more important in a bathroom than other locations. The customer also had overarching requirements which we found using a survey to potential users of a smart mirror of which 26 responded.

Keeping in mind both customer wants and increased privacy needs in the bathroom, we began to brainstorm parts that needed to be ruled out immediately such as cameras. This rules out one of the only other approaches which is using a live image taken with a camera displayed as a mirror. We then looked at features that were required to make a functioning smart mirror keeping in mind cost, usability, and privacy when applicable. We conducted value analysis on these features: interaction methods with the mirror, information display, and two way mirror material to make sure that the product functioned at its most basic level. The customer also desired a way to turn the mirror on and off automatically so we conducted further analysis on sensors that would be able to do this.

First, we looked at how a customer would want to interact with a mirror. Options that could be used included touch screens, voice control, phone apps, remotes, wireless keyboards, and buttons. Each of these interface options provides vastly different ease of use and costs to the overall product.

Then, we looked at how the information could be displayed to the user. This could be done by using a touch screen monitor, or a normal monitor. All of these would provide a method of displaying information to the user. A touch screen would also be a method of interaction meaning multiple value analyses are conducted with it in mind.

Next, we looked at general materials for use as a two way mirror. We found that there are three general materials: film, acrylic, and glass. Each of these materials has many different options available so we analyzed some of the general options within each of these sections as well. All of these options provide a way to make a mirror but some function much better than the others.

Lastly, we looked at a way to make the mirror turn on and off automatically when it was desired. This could be completed using a light sensor, a motion sensor, timers, audio sensors, and cameras. Cameras were immediately ruled out and further analysis is done on the other components.

The design of the smart mirror also includes some parts that are less vital to the overall specifications of the project. These include an on/off switch that can be selected based on cost as any specific set of these will provide the basic functionality needed. There also needs to be some sort of frame to hold the mirror and its components in place. The simplicity of these parts means value analysis does not need to be done.

Overall, the design of a smart mirror is very specific. Many components need to be done in very specific ways. A System on Chip for example must be used, as a result, we decided to conduct a value analysis on actual SoCs on the market. We also conducted a value analysis on individual monitor options when we finished the general value analysis on displays. Both of these were done to get a better idea of how pieces of the product would fit together and how the smart mirror would need to be sized. Broader value analyses are shown directly below while more specific value analyses are done in Section 4.

User Interface Design Options

The user interface is one of the most important aspects to our product. There must be a method through which the user can interact with the mirror. There are many options that we can implement such as buttons, voice control, and motion control. We needed to find the best solution that satisfies both a user friendly control method and low cost.

We narrowed our user interaction options down to six different choices. We saw that other smart mirror competitors used remotes, wireless keyboards, and touchscreens. One company bundled a remote and a wireless keyboard into their product. It wasn't clear which one was supposed to be primarily used for interaction. We decided to compare them individually as if it was supposed to be the main form of control. We weren't sure if those were the best options so we compared them to our own ideas. We thought that voice control, buttons or a companion phone app would be simpler and cheaper. Voice control would be similar to Amazon Alexa or Google Home.

For both the remote and the wireless keyboard, we felt that using extremely hands-on devices in the bathroom wasn't ideal. They are also fairly expensive compared to a few of the other options. The remote can still be good for interactions with the mirror while the keyboard may be too clunky, especially without a mouse. A touchscreen is a good option because using it is very natural to anyone with a smartphone or tablet. Many of the interactions can be programmed such that users do not need to learn how things work. The biggest drawback of a touchscreen is the cost. Using a touchscreen panel will cost a lot more than any of the other options.

Voice control is a relatively new concept that's become much more commonly used in smart home products. It is also easy to use and learn like the touchscreen but does not cost nearly as much to implement. A button panel can also be simple to use however pressing buttons on a wall can make interactions clunky. Again, cost is one of the biggest benefits of using buttons. Using a phone app is complex in that it requires users to have a smartphone of some kind. It would have the same natural feeling that a touchscreen has, but it will also have slight complexity in that it needs to connect to the mirror. Having the phone app as a form of interaction means that a second form of interaction will be needed.

Our criteria can be split up into three categories. The first is cost, the second is initial setup and the last is general interaction. Under initial setup, there are three criteria that we will account for are setting up external accounts (ex. Spotify), picking the features and apps to use, and placement of apps and features on the display. These are all things that should only need to be done a few times before regular use. General interaction is split up into two criteria, using features and apps, and performing system tasks. Using features and apps include playing music, setting timers, or expanding widgets for more information. System tasks include scrolling through pages of widgets and other interactions that don't fall under use of features. Below is our value analysis in Table 1.

Table 1: Value Analysis of User Interface

	Criteria							
Component	**Cost**	**External Account Setup**	**Picking Features/Apps**	**Placement of Widgets**	**Using Features/Apps**	**System Tasks**		
Weight	8	1	1	2	8	7	**Raw Score**	**Weighted Score**
Remote	5	4	5	4	5	5	28	132
Wireless Keyboard	5	4	0	0	1	2	12	66
Touchscreen	0	7	10	10	8	7	42	150
Voice	8	0	3	4	8	5	28	174
Buttons	9	1	5	4	5	5	29	161
Phone App	9	9	8	7	3	3	39	148

Low cost is very important as it's one of the major product requirements. We weighted the cost highly at 8. We realize that initial setup does not happy very often and though the interactions might be a headache, they only need to be done a few times. Due to this, we weighted all the initial setup criteria low relative to general use. External account setup and picking features and apps were both weighted a 1. Placement of widgets was weighted a 2. General use will be most of what the user will do so we weighted it very heavily. We felt that if the mirror was not easy to use it would make it very pointless. We weighted the use of features an 8 and system task a 7.

Display Design Options

The display is an integral part of our smart mirror. We need to pick a monitor that fulfills our inexpensive material requirement. The monitor will be one of the most expensive components for the mirror so being able to find a monitor that meets the low cost requirement and is easy to work with will be difficult.

We've categorized our options into two major categories. There are touchscreen monitors and regular monitors. Within monitors, there are also LCD, LED, or OLED panels however that is a little too specific for our initial decision. We need to consider touchscreen panels because many customers wanted to use a touchscreen for their primary interaction with a smart mirror.

A touchscreen monitor is very beneficial in terms of usability. Customers are very used to touchscreen displays so using it would feel natural. However, a touchscreen limits our mirror size and the screen position greatly. This is caused by the mirror material limitation. In order to keep the touchscreen functionality, we need to use a film to create the mirror effect. This means that expanding the mirror to be larger than the monitor size could create a crease between the monitor and the other surface. This also makes it much more difficult to adjust the position of the mirror. Furthermore, a touchscreen will not work well in a steamy environment as touchscreens are known to behave poorly with wet fingers or wet screens. The cost must also be considered as touchscreen monitors cost much more compared to an equal specification monitor.

Regular monitors will make user interaction a little more challenging. It requires us to create a very fluid user interface through other means such as voice control or a button panel. The benefit of using a regular monitor is that the maximum mirror size is no longer limited and we can explore different mirror materials. Since there is no touchscreen functionality, we can use acrylic or glass mirrors placed in front of the display. This also gives us the ability to change the position of the mirror when designing the features. As long as we sufficiently waterproof our smart mirror, the display will have no problems with water and the cost of using a regular monitor are much lower compared to the touch screen.

We have six criteria for our monitor. Customer requirement and water interaction relate to user friendliness. Max mirror size, mirror material flexibility and screen position all relate to how versatile the display is in terms of how we can design the smart mirror. Cost is the last one which falls into our low cost product requirement. The value analysis for the monitors is in Table 2 below.

Table 2: Value Analysis of Display

	Criteria							
Component	**Cost**	**Customer Requirement**	**Water Interaction**	**Max Mirror Size**	**Mirror Material Flexibility**	**Screen Position**		
Weight	10	10	6	7	6	9	**Raw Score**	**Weighted Score**
Touchscreen Monitor	3	9	3	4	0	3	22	193
Regular Monitor	7	3	9	10	10	10	49	374

Cost and customer requirements are the most important criteria to us. Everything we do should be for the benefit of the customers' desire unless it can be proven otherwise. We also believe cost is very important because the customers want a reasonably priced product so we want to keep costs as low as possible. We weighted both of these criteria a 10 for those reasons. We also felt that screen position was important from a design flexibility standpoint. It gives us more wiggle room in terms of how the final product will look and it provides us with flexibility for follow up versions of the smart mirror. Screen position was weighted a 9. Maximum mirror size was also pretty important to us because we are aiming to create a bathroom mirror. Bathroom mirrors can be very large so the size limit would hurt us that respect and thus the size limit criteria was weighted a 7. Water interaction was weighted a 6 because we want to create the best experience for our customers. We felt that customers may not have considered the implications of using a touchscreen in a bathroom setting and thus did not realize that a touchscreen could actually hurt their user friendly experience. Mirror material flexibility was also weighted a 6 because we did not want to be limited to a fixed material. Mirrors can be created with a few materials which each have their advantages and drawbacks. For this reason, we wanted to have the ability to make a proper decision on which material would be the best for our smart mirror.

Two Way Mirror Material Design Options

The mirror itself is another critical part of the smart mirror. We will need to find an inexpensive material that will still give us a clear reflection and will allow the monitor to shine through brightly. We can't compromise the quality of the mirror too greatly otherwise our smart mirror isn't practical as a mirror which is its first and most basic function.

There are three main options that we can choose for mirror material. The first two are commonly used for regular mirrors, acrylic and glass. Two-way mirrors can also be made out of acrylic and glass. A film that is applied to a flat surface is the last material that can be used to create a mirrored effect. We will need to consider the size of our mirror when choosing a material. Each material also has a different thickness which we will have to consider. Acrylic and glass can be made to have different thicknesses however film will always be fairly thin in comparison.

Every material has its pros and cons. It is also very hard to judge each material because the quality and cost can vary greatly from manufacturer to manufacturer. Without being able to order samples and do a thorough in person comparison, we can only compare general qualities. We won't be addressing tinting since the materials can vary so much and the tinting can occur with every material. Mirror film on its own is cheaper compared to either acrylic or glass by a large margin. The film must be applied to a flat stiff material which means a second material needs to be sourced for the panel. This panel can be clear to decrease the cost compared to a mirrored panel. The film itself is simple to cut and work with however applying it without bubbles could be more challenging. Also in using the film, you must work with the back panel material. In most cases, film also does not have the same clarity as it's counterparts and can scratch easily.

Acrylic is medium price in comparison to film and glass. Acrylic can have the same clarity as glass but it is generally considered to be worse. The benefit of using an acrylic mirror is that it is a solid material and easy to work with. Acrylic can be purchased in varying thicknesses. Since acrylic is slightly flexible, the issue with varying thickness is that the thinner the material, the more likely it is to warp and produce a fun-house effect. When using acrylic, the thickness will have to be higher to prevent warping. An acrylic mirror can also be prone to scratching.

Glass is the last material that we can work with. It is the most expensive material but produces the reflections with the most clarity. Glass is very rigid so a thinner sheet can be used. However, since it is very rigid, it is also difficult to cut and built with. One factor that might not commonly be considered is weight. Glass is very heavy compared to both the film and acrylic. With all the other components of the smart mirror, weight should be considered as the entire thing needs to be mount on a wall.

For the value analysis, we are comparing five versions of our material. We are comparing the acrylic at 3mm and 6mm of thickness, the film with 3mm thick acrylic and 3mm thick glass as the back panel, and 3mm thick glass. They will be rated on price, clarity, weight, scratch resistance, ease of construction and warping. Everything will be rated on a scale from 0 to 10 with 10 being the best. The lower the price, the better the score. Better clarity is also rated higher whereas heavier materials are rated lower. A mirror that does not easily scratch receives a higher score and a mirror that is easy to built with receives a higher score. Mirrors for daily use shouldn't warp so the stiffer the material, the better. Table 3 below shows the value analysis with raw scores and the weighted scores.

Table 3: Value Analysis of Mirror Material

Component	**Price**	**Clarity**	**Weight**	**Scratch Resistance**	**Ease of Construction**	**Stiffness**		
Weight	10	8	3	6	4	5	**Raw Score**	**Weighted Score**
Acrylic (3mm)	7	7	4	4	8	5	28	219
Acrylic (6mm)	5	7	6	4	7	8	37	216
Film (Acrylic 3mm)	5	5	4	3	8	5	25	177
Film (Glass 3mm)	3	5	2	3	5	10	25	164
Glass (3mm)	4	9	2	8	5	10	34	236

The weights for each category were out of 10. Inexpensive materials is still one of our most important categories so it was weighted as a 10. Clarity is the next most important because our smart mirror still needs to be practical and be able to perform well as a regular mirror. We didn't end up considering weight of the material to be that important because different methods of wall mounting can circumvent how heavy the mirror is. Scratch resistance was averagely important because we can be extra careful when building the prototype. Ease of construction was also not heavily weighted because building with the material would only need to happen a few times with the prototype. Stiffness was weighed a little more because we knew it would affect the acrylic panels. Again, we want to avoid any fun-house effects because it ruins the point of a mirror. In the end, we saw that the glass (3mm) mirror is our best option even though it is the most expensive. The positive qualities of using a glass mirror still out weight the negative of the price.

Auto On/Off Sensor Design Options

Turning the display on and off automatically satisfies the product requirements of being user friendly and practical. We considered different options for achieving this. We looked at light sensors, motion sensors, timers, microphones, and a camera as possible options. All of these options were deemed feasible to implement however we wanted to choose the best option to satisfy our requirements.

A light sensor is used to detect the light level in a space. In this application, the light sensor will be able to evaluate whether or not the bathroom light is on. If it is, the display turns on, else it is off. Light sensors are advantageous because they are simple to implement, and convenient. The first thing anyone does when the go to the bathroom is flip on the light switch. This makes a light sensor an ideal choice. A disadvantage to the light sensor is depending on the sensitivity of the sensor, external light can unwantedly activate the display. Also, leaving the light on will cause the display to be on unnecessarily.

Motion sensors use infrared to detect an individual’s presence. This option would detect when someone enters the room and then turns on the display. When the individual exits the room, the display turns off. This option is advantageous because it relies on the presence of an individual. This ensures the display is only on when someone is in the room. A disadvantage to the motion sensor is the physical size to implement. It would require placement on the top of the mirror and integrating that into the frame could be challenging.

Timers were also considered. This option requires no sensory information. Instead, the display operates on a scheduled timer. This would likely be on during the day, and off during the evening. An advantage to timers is that they do not require any sensors to operate. However, a glaring disadvantage is the lack of user control over when the display is on. While being simple to implement, it sacrifices convenience.

A microphone or similar audio sensor would be used to detect sound. The way this would function is activate the display on the presence of sound. After a cooldown period of no sound the display would turn off. As with the motion sensor, the primary advantage is that the microphone relies on the user’s presence. A disadvantage is microphone sensitivity. If the user has many other smart home devices, using voice commands could inadvertently activate the mirror and vice versa.

We based our value analysis criteria on four metrics. These metrics were privacy, size, convenience, and affordability. Privacy indicates how revealing the option is. For example, if it's early in the morning, we don’t want the user waking everyone in the house up by activating the mirror. Size refers to the physical implementation of the component. Convenience is ranked on how intuitive this option is to use. Lastly, affordable accounts for how many resources are needed to implement this option. We ranked these metrics' importance as follows - convenience, size, privacy, affordability. The table below shows our complete value analysis for auto activation options.

Table 4. Value analysis for auto activation feature

	Criteria					
Component	**Privacy**	**Size**	**Convenience**	**Affordability**		
Weight	6	7	9	7	**Raw Score**	**Weighted Score**
Light Sensor	8	8	9	8	33	241
Motion Sensor	8	7	8	8	31	225
Timer	10	10	2	10	32	218
Microphone	3	6	6	4	19	142

Convenience was rated most important because it is a fundamental customer requirement. This ties back to the fundamental use of our product, it's supposed to 'just work' without difficulty. Next we rated affordability and size as tied. We need to prioritize affordability to compete with similar products in the market. However we needed to consider size because if the option is affordable but not able to be physically implemented, we'd need to consider other options. Lastly, we ranked privacy. This is because we covered privacy in more depth when evaluating our interaction and UI options.

3. Preferred Design Approach

Voice control and buttons were rated the highest from our user interaction value analysis. Touchscreen and a companion phone app were very close in 3rd and 4th. Voice control and buttons are our preferred design approach due to the balance between cost and user friendliness. We felt that a phone app could still be a good addition since it had high marks in the initial setup criteria. While touchscreen was still the best for usability, it costs too much for it to be feasible.

The regular monitor was a very clear winner after performing the value analysis. The benefit of a touchscreen monitor for a good user experience could not overcome the cost and other limitations it created. The regular monitor was much more well rounded and fit our purposes better.

Figuring out the best material to use for the mirror was a very difficult decision. In the end, the glass panel was the best after looking at our value analysis. In order to ensure the basic functionality of a mirror is intact, we need to use a glass pane. The low costs of the other materials were not enough to overcome the lack in quality that they provided.

We selected a light sensor as the preferred option for the auto on/off functionality. The light sensor and the motion sensor performed similarly in our value analysis. To choose over these two, we considered the realistic convenience of the feature if we implemented. A light sensor was chosen because we believe we can better implement this option. A motion sensor could have variable performance and result in lesser convenience for the user.

Low cost materials was very important to us. It is possible that cost was weighted too heavily in some of the comparisons. We are trying to keep to a strict budget and many decisions hang on whether or not the cost is worth the potential benefits. It is also possible that due to our price sensitivity, high cost components were rated lower in non-cost related categories then they might have been otherwise.

Another possible error is excluding or including certain criteria. From a customer or another engineers' perspective, we may have left out a criteria that we didn't consider. Additionally, our arbitrary value assignments could be skewed based on our viewpoint which could change the results of our value analysis.

4. Specific Component Value Analyses

We conducted value analyses within two design options on individual usable components to gather more information on how our prototype would need to be made. The first analysis we made was on specific system on chips available in the market. Making a smart mirror requires a SoC, therefore we felt it necessary to know which one we would be using going forward. There are many SoCs on the market which all have different manners of interaction available to them. We wanted to make sure that we had the ability to learn about how to use a specific SoC before we bought further components. We also conducted a value analysis on specific monitors available for use. This was to be able to start work on a prototype and make sure basic display functionality worked. Then we would be able to add additional features on top of it.

SoC Module Design Options

We needed to choose a system on chip (SoC) that had all the product requirements for this project. Specifically, these product requirements are video output, audio input/output, GPIO pins, USB ports, onboard memory, and wireless networking capability. The SoC satisfies our product requirements because it is the brain of the entire system. As we found, there are *many* options when choosing an SoC.

Options when choosing an SoC range from small boards costing $9 to fully functioning mini computers upwards of $300. Each one of them has their own advantages. Example advantages are, multiple ethernet ports, dual WiFi and Bluetooth, low power consumption, standard gpio libraries, 3D graphics acceleration, different OS choices, video outputs, an array of USB ports, and even quad core processors up to 2GHz. For our value analysis we considered these five different SoCs:

- Raspberry Pi 3B
- NanoPi Neo Plus2
- ODROID-XU4
- Parallella
- Raspberry Pi Zero W

Starting with the Raspberry Pi 3B, we found that this system is a great for general purpose computing and rapid prototyping. This SoC is particularly good for our purposes because it has all product specifications onboard, minus audio. Additionally, the Raspbian OS image is highly configurable for use with IoT projects. The price point is also very reasonable. The Raspberry Pi forums are also extremely active and there is significant documentation available. A disadvantage is it requires additional hardware for audio input and output. Another disadvantage is the DDR2 memory is slower compared to other options we considered.

The NanoPi Neo Plus 2 is a serious competitor to the Raspberry Pi. The board is designed to be used in IoT settings and has a minimal form factor and feature list. The features included on the NanoPi align with nearly all we want to do. The memory and CPU are faster than the Pi 3B. However, there are onboard features that are missing for our use, namely display and audio. However, there is an additional $4 module for the NanoPi that enables a VGA display. Additionally, there is an audio amplifier module available that enables audio out. Some disadvantages this SoC has is its operating system options. Support for these operating systems is not as extensive as Raspberry Pi OS.

The ODROID-XU4 was another interesting option. For only $59 this system is capable of serving as a standalone computer. The hardware on this board is more advanced than any option we considered. For example, this system can run the latest version of the Ubuntu desktop environment. However this board was not suited for our uses. There is no onboard networking or audio. Both of these require external hardware. Additionally, the GPIO pins have to be accessed using a 30 pin ribbon. Overall, this system is really neat however not practical for this project.

We also considered a board called Parallella. The concept behind this board is that it enables open sourced parallel computing. This makes this board ideal for small systems that require large amounts of processing power. This board has an incredible 18 cores - 2 ARM cores and a 16 core coprocessor. The smart mirror does not require large amounts of data processing. This renders the primary selling point of this SoC irrelevant. It only has one USB port and no GPIO pins making it impractical for our use.

Lastly, as a follow up to the Raspberry Pi 3B we also looked at the feasibility of the Raspberry Pi Zero W. This SoC is a scaled down version of the 3B and similar models. It has all of the required features for the smart mirror project minus audio. Similarly to the 3B, the support for this board beats the other non-Raspberry Pi options. The biggest drawback to using this board is the lack of USB ports and mini HDMI video output. USB ports can be worked around however, our monitor choice would require an additional adapter to go from HDMI to mini HDMI. Also, we would have to buy the additional hardware for implementing audio output.

Through this value analysis, we narrowed our choices down to the 3B, NanoPi, and the Pi Zero. Ultimately, the 3B came out on top due to its reliability and support resources. Depending on how according to plan our implementation goes, we could also implement on the NanoPi. This is a slightly cheaper option that would further minimize costs.

The tables below shows our value analysis for choosing an SoC. A 1-10 scale was used for assigning values. When assigning values, considerations were made if the feature was available we assigned based on its ease of use. If it was not available we assigned based on how easy it would be to set up. Other criteria such as hardware performance was considered when comparing for example, DDR2 memory to DDR3. Note that audio was not included in the value analysis as none of these options had suitable onboard audio.

Table 5. Raw data for value analysis

Component	**Price**	**GPIO Pins**	**OS Capabilities**	**Memory**	**Wireless Networking?**	**USB Ports**	**HDMI?**
Raspberry Pi 3B	$35	40	Raspbian, Snappy Ubuntu	1GB DDR2	Yes	4	Yes
NanoPi Neo Plus2	$32	44	FriendlyCore, DietPi	1GB DDR3	Yes	2	No
ODROID-XU4	$59	30	Ubuntu 16.04	2GB DDR3	No	2	Yes
Parallella	$99	48	Ubuntu 16.04	1GB DDR2	No	1	Yes
Raspberry Pi Zero W	$14	40	Raspbian	512MB	Yes	0	Yes

Table 6. Standardized values, weights, and scores

Component	**Price**	**GPIO Pins**	**OS Capabilities**	**Memory**	**Wireless Networking?**	**USB Ports**	**HDMI?**		
Weight	7	3	6	1	9	3	9	**Raw Score**	**Weighted Score**
Raspberry Pi 3B	8	5	10	6	8	9	8	54	308
NanoPi Neo Plus2	8	6	8	8	8	5	6	49	271
ODROID-XU4	6	4	5	9	5	5	8	42	225

Parallella	4	2	4	6	2	3	8	29	163
Raspberry Pi Zero W	10	5	8	3	7	0	6	39	253

The hierarchy of weighting was decided based on how important each feature was. Weight values were assigned an additional 1-10. For this value analysis, wireless networking and HDMI were the most important. Price and OS capabilities were also important considerations but not decisive. As long as we can keep the cost below $100 and run some sort of Linux we could develop this project to spec. More minor requirements were memory, USB ports, and GPIO pins. Memory requirements are minimal for the smart mirror. USB ports are also optional, it would be convenient as a backup in case some of our implementation does not work. Lastly, GPIO pins are minor as we do not need many, just three or four.

Specific Monitor Options

The monitor is a crucial component to our smart mirror. Without it, there would be no way to display any information to our customers. One of our product requirements is to have inexpensive materials. There are many types of monitors that we can consider which would fit our needs but we need to choose the cheapest one that will fit our needs.

There are many monitors on the market and they are all different in varying ways. The primary differences include cost, input ports, size, pixel density, brightness and peripherals. Monitors that also have a touchscreen are another type that we need to consider, especially since many customers prefered a touchscreen method of interaction with the mirror.

The most common input ports are HDMI, VGA, DVI, and DisplayPort. The screen size of a monitor is usually described by the diagonal length from corner to corner. It is common for monitors to range from 21.5 inches to 27 inches or larger. If the monitor has a 16:9 aspect ratio, we calculated that a monitor needs to be about 22 inches in size to have a 20 inch width. Often, the quality of a monitor is closely related to the resolution of the monitor. While the resolution of a monitor is important, pixel density which is the number of pixels in a given area actually provides a better measure of clarity.

Brightness is usually not considered when purchasing a monitor. However, we need to consider this because we need to ensure that what we want to display will shine through the two way mirror clearly. Monitor peripherals include speakers and other ports such as USB. We are not concerned with peripherals since we are likely to implement our own speaker or use ports on our SoC. Since monitors have all these varying features, the cost of monitors is also a very wide range. Since the range of costs is so large, picking the best monitor is very difficult.

HDMI is the best port for our monitor to have because most SoC chips support HDMI output out of the box. HDMI port position is also a factor to consider. HDMI ports that cause the cable to stick out of the back of the monitor will increase the thickness of our smart mirror.

HDMI ports that allow the cable to be flush with the monitor are optimal. The other cases would require us to purchase an additional adapter. Using a monitor that is larger than 22 inches could be a benefit if we want to make the mirror larger, but a larger monitor also increases the cost. A smaller monitor decreases the maximum size of our mirror but it also decreases the cost. We would prefer to have a larger monitor rather than a smaller one since we want to build at least a standard size mirror.

An increase in pixel density generally increases the cost of a monitor. For monitors that are 24 inches or smaller, most manufacturers use a resolution of 1080p. Some monitors at that size have a resolution of 1440p or even 2160p (commonly referred to as 4K UHD). The lower the pixel density, the less clear the monitor becomes. It is better for our smart mirror if the monitor has a higher brightness. We need to be able to display information clearly through the mirror material. It is also better to have less peripherals for the monitor that we choose. Peripherals are unnecessary for us and generally increase the cost of monitors. We will still consider monitors with peripherals since the cost does not always correlate to price. Touchscreen is very beneficial because the customer wants it but using it increases the cost greatly.

Since there are so many different options for monitors, we needed to narrow them down to a few musts have features before we could perform a value analysis on monitor choices. HDMI is a must for us because of how common the HDMI port is used. We are also looking at only 1080p monitors that are at least 21.5 inches. Monitors that were above 1080p were all too expensive to consider in our value analysis. We also won't be considering touchscreen to be a viable option because the minimum cost for any touchscreen monitor is too high. The variable options that influence our choice are price, brightness, screen size, HDMI port position and whether or not the monitor includes speakers.

For the value analysis, we assigned a value to each category. Under the price category, cheaper was better so the cheapest monitors received higher scores. We rated the monitor on cost from \$70 to \$119 on a scale of 0 to 10. In this case a cheaper monitor resulted in a higher score. Brightness was measured on a scale of 250cd/m^2 to 300cd/m^2 from 0 to 10 with higher brightness resulting in a higher score. For size, 22 inches in the optimal screen size. For each half inch away from 22", we dock a point from 10. We prefer a larger monitor over a smaller monitor. If the monitor is larger, we dock one less point and if it is smaller, we dock an extra point. For HDMI port position, it can be place so the cable stick out the back or to the side. Side is preferable and was rated a 10 while back was rated a 0. Built-in speakers are a plus if they are available. If the monitor had speakers, it was rated a 10 and 0 if it did not. Table 7 below includes the different monitors we are considering for the value analysis. Table 8 below is our value analysis.

Table 7. Raw Data for Value Analysis

Component	Price	Brightness	Size	HDMI Port Position	Built-in Speakers
Weight					
Sceptre E225W	$75	250cd/m2	22"	Side	Yes
HP Pavilion 22cwa	$95	250cd/m2	21.5"	Back	No
Sceptre E248W	$100	250cd/m2	24"	Side	Yes
Asus VP228H	$100	250cd/m2	21.5"	Back	Yes
Dell SE2417HG	$109	300cd/m2	23.6"	Side	No

Table 8. Standardized values, weights, and scores

Component	Price	Brightness	Size	HDMI Port Position	Built-in Speakers		
Weight	8	6	4	6	3	Raw Score	Weighted Score
Sceptre E225W	9	0	10	10	10	30	202
HP Pavilion 22cwa	5	0	8	0	0	13	72
Sceptre E248W	4	0	7	10	10	27	150
Asus VP228H	4	0	8	0	10	18	94
Dell SE2417HG	3	10	7	10	0	27	172

Each category was weighted on a scale of 0 to 10 with 10 being more important. Price is weighted as an 8 since it is important for us to keep to a budget of about $300. Since the monitor is one of the most expensive parts, we rated it as an 8. Brightness was another big consideration since the monitor needs to be able to shine through a mirror and be visible. We also realized that HDMI port position was going to be important because it could potentially increase the thickness of our mirror. We felt that these two things were both about equal but less important that price so we gave them a weight of 6. We then considered size and built-in speakers both to be relatively unimportant. In this case, a variation in size doesn't affect us too much and built-in speakers are a bonus that could be useful. We aren't sure if we would use the speakers so we felt it was a little less important than size. For these reason, they were weighted 4 for size and 3 for speakers. As seen by the table, the Sceptre E225W is the best monitor for us to use as the weighted score was 30 higher than the next highest.

Competitive Value Analysis

The smart mirror functions as a utility for convenience. This requires that the product has ease of use as the most essential criteria. We could further break down ease of use to mean a few different things. For example, we need to ensure that our applications will still be visible in a humid environment. If the mirror is foggy, it eliminates the convenience of a smart mirror. This concern was highlighted in the survey we conducted about smart mirror perceptions. Another component with regards to ease of use is interaction methods. Because the user will interact with the smart mirror in short intervals, interaction must be intuitive and convenient.

The smart mirror must also have a standard for quality. Although we are integrating electronics into a mirror, it still must function as a mirror. Some of the responses in our survey mentioned this requirement. Therefore, the original mirror function is the most important criteria of quality. If the smart mirror cannot function as a basic mirror, then there is no chance of the product being successful. An additional quality criteria is that the mirror must be able to function in a humid environment. Similarly to fogging the mirror for convenience, humidity can short the backend electronics and ruin the product. Survey respondents also indicated this is important to address in the design.

We also considered cost criteria for the smart mirror. The primary criteria for cost was that it should be affordable. To measure affordability, we researched the cost of a typical bathroom mirror as well as asked our survey respondents. Based on these results, we decided that keeping the total cost lower than $300 would be an optimal price point. Affordability was important to consider because a highly priced product would fail when simpler options are available at much cheaper prices.

Overall, these customer essential criteria were critical in designing our product. We weighted these customer criteria on a 1-10 scale. Higher numbers equals higher importance. The results are in the table below:

Table 9. Customer smart mirror criteria and weights

Requirement	Weight
Anti-fog	6
Convenient interaction	5
Mirror reflective quality	8
Humid environment tolerance	10
Affordable	7

The most important criteria is to function in a humid environment. This is because we need to ensure our product works in the environment we are marketing it for. Similarly, we ranked mirror reflective quality as second most important. We need to make sure the smart mirror can still function as a mirror. We ranked affordability after this. Similar smart mirrors sell for upwards of $1000. It will not be difficult to offer a less expensive product. However, to meet our customer expectations from our survey, we will have to cut that figure to less than a third. Next, anti-fog is an important but not decisive requirement. There are use cases for the smart mirror to not need anti-fog protection. While this is not ideal to leave this design criteria out, it is not top priority. We ranked convenient interaction below anti-fog. If necessary, we could design the smart mirror with no interaction and still have it function. However, to increase usability, interaction is considered for implementation.

While there is not a lot of competition in the smart mirror market, there are companies out there with products on the market. We looked at three smart mirror sellers and evaluated some of the features of their products. We did not find any details regarding humid environment tolerance and anti-fog. The three seller's smart mirrors we looked at were:

<u>Somelove Bathroom Mirror</u>

A simple and affordable smart mirror solution that integrates with Alexa. This is good competition because it uses voice control and sells for a low price compared to most options. However, there is no display and the only way to interact is via phone app and remote. This mirror is a good minimum benchmark for our project as it sells at $300. As far as satisfying customer criteria, this mirror does not have good interactivity per its Amazon reviews, and its ability to function as a normal mirror was not rated well. It did meet the affordability criteria and we assume it works fairly well in humid environments.

MOOWIM Smart Mirror

This mirror is more advanced than the previous option. They are competition because they have a lot of features packed into the backend. There is a fully functioning Android device behind the mirror. There is also a capacitive touch screen. However it does not appear like this mirror is advertised for the bathroom. This product also sells for $1600 making it much too expensive for the average homeowner. It meets the convenient interaction criteria with the touchscreen, and mirror quality based on reviews. We cannot be sure it meets the anti-fog or humidity tolerance because its purpose is not for the bathroom. Lastly, this mirror fails for being affordable.

Evervue QAIO

This last option we evaluated poses the most significant competition. It is a combination of the first two options. Evervue is the most significant competition our product would have because they market for bathrooms and have a full suite of features. Features include touch screen, and Alexa control. Also the mirror reflection quality is high and comes in a variety of options. The one weakness this product has is its cheapest model selling price of $999. If we can minimize the cost of our product we can compete with the Evervue mirror. This smart mirror meets all other customer criteria at a high standard.

We conducted a value analysis of our product versus these three options. Based on our product requirements, our smart mirror edges out over the Evervue mirror because of the affordability factor. If our mirror was priced the same, then our product would perform almost equally as the Evervue. The table below shows the complete value analysis results.

Table 10. Competition Value Analysis

	Criteria						
Product	**Anti-Fog**	**Convenient interaction**	**Mirror reflective quality**	**Humid environment tolerance**	**Affordable**		
Weight	6	5	8	10	7	**Raw Score**	**Weighted Score**
Somelove Bathroom Mirror	1	2	5	6	8	22	172
MOOWIM Smart Mirror	2	3	6	4	1	16	122
Evervue QAIO	4	8	8	8	3	31	229
Team #1 Smart Mirror	2	7	7	8	9	33	246

The biggest sensitivity in our value analysis is that Evervue sells a really excellent product. A possible error could be that we cannot execute a high quality smart mirror at the price we are anticipating. If we cannot, then we are reinventing what has already been done. Another sensitivity is our anti-fog solution has a risk of not succeeding. This would add error to our value analysis.

6. Conclusion

Our design choice provides several advantages and disadvantages against the competitors. The main advantage of our design is the cost of the product. We have tried to keep the cost under $300 and while some specific parts have not been chosen yet, it looks possible. This would be a major advantage over many of the competitors in the market if the sale price is that low. Another advantage of ours is the capability to add on software whenever a custom poses a suggestion or we think of another feature. Many competitors are using TVs in their smart mirrors which means software can not be added and the only thing that can be displayed are TV channels. To us, this can also be a disadvantage. We can not display TV channels and have not considered being able to do that. Another disadvantage of our design could be not putting in a touch screen. It would be the easiest way to interact with the mirror but we felt that the water and humidity in a bathroom would make it not work well enough.

We tried to include as many options for the smart mirror that the customer desired. We focussed our entire product on keeping the cost as low as possible while providing the essential components of a smart mirror. This would keep the cost within range of the average consumer and not a tech collector who would be able to buy a $1000+ smart mirror. We also included an automatic on/off option and on/off switch to allow for greater privacy. However, we did not provide a touch screen that the customer desired. We tried to overcome the value a touch screen would provide by offering both voice control and buttons. We felt they would function better in a bathroom environment and the cost of the mirror would be much lower. If time permits, we will also create a phone app to provide another manner of interaction. In terms of entertainment and practicality, the software would provide much of the ability to display information on the screen.

Our value analyses were conducted with the customer in mind and take into account research on different parts. Although more extensive value analysis could be done if more time was taken, for the purpose of a prototype, the results of our value analysis for each component are valid. With the ability to conduct further testing on individual components and more time to research more options, the value analyses could be improved and even more design options could be included in value analysis calculations. Value analysis in general is an imprecise science and any number of additions could be made to change an outcome at any time.

Our product would compete in the market as a cheaper version of a smart mirror. Mirrors with TVs in them are offered at similar price point to what we hope to offer our smart mirror at. However, they only offer the ability to watch TV through the mirror and don't offer any information features. The informational features would be our largest driver of consumers if the cost was low enough. Smart mirrors that offer these features cost significantly more in the current market. Providing more information to a user at a cheaper price than others would be our entry into the market.

The biggest design option that we need to focus more on is the two way mirror material. Both acrylic and glass are similarly scored in the value analysis done on them. However, we are worried that acrylic does not provide the minimum functionality of a working mirror. It may be too bendable and cause the reflected image to be curved. It will be hard to decide between acrylic and glass because although glass would remove this problem, it costs significantly more. Many of the other design options would be hard to reconsider unless we had the ability to conduct hands-on testing.