

Cloudent

Exploring connected and quantified data relationships
between oral care providers and patients

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Abstract

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Strong communication between oral care providers and patients is necessary for patients to understand the health of their mouth. Cloudent is a system proposal that closes the gap between dental visits using connected devices at home and the dental office. Connected devices at the home quantify a patient's oral hygiene practices and will be used to create a tangible method of interaction for patients to understand procedures and issues explained at the dental office.

Cloudent

Exploring connected and quantified data relationships
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Thank you Kei for helping make this possible.

In memory of Joseph Ungari.

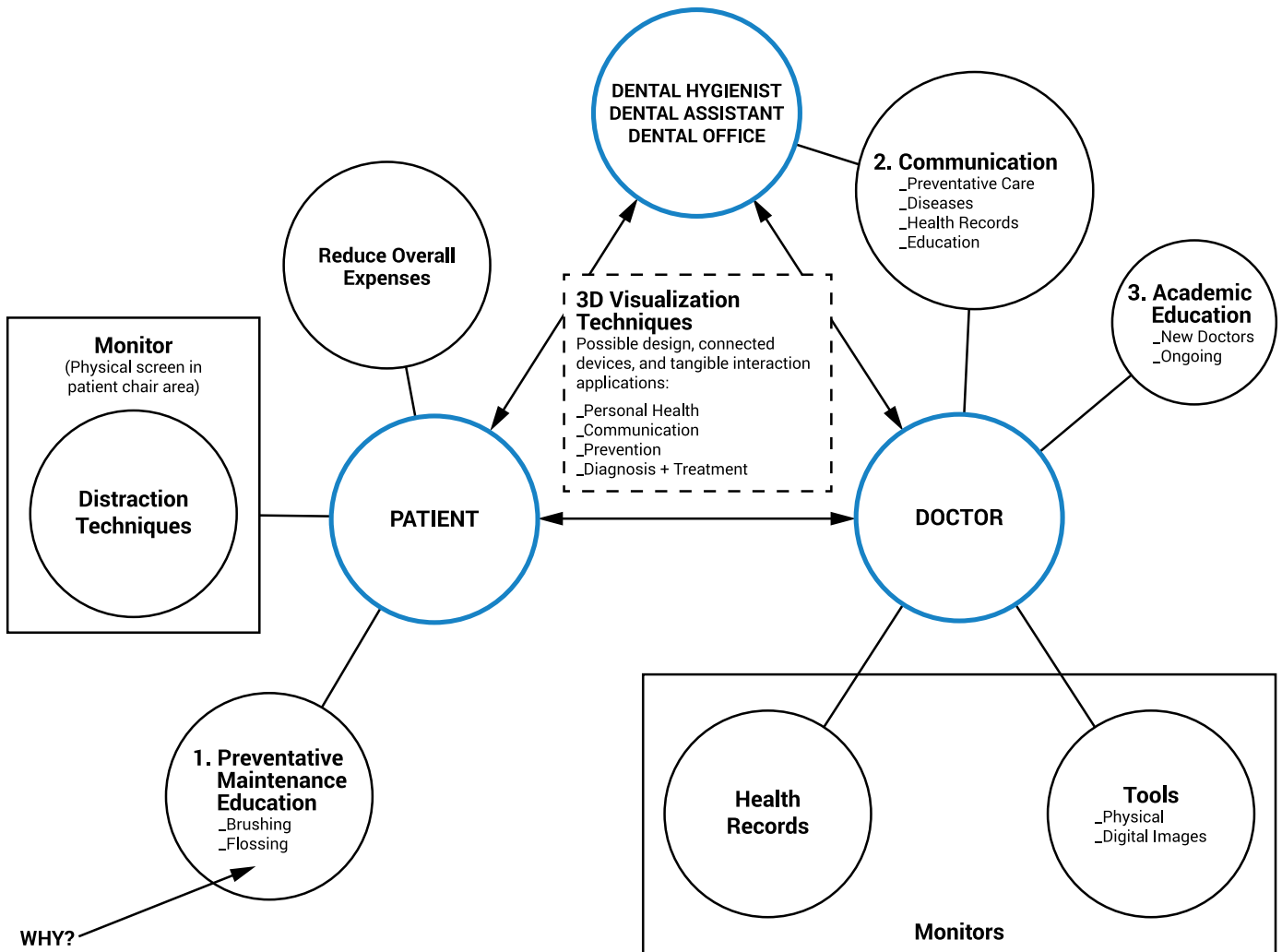
I. Introduction

This thesis proposes a meaningful application of connected devices, or Internet of Things (IoT), to address a specific problem in the dental field, broadening the common misconception that IoT is limited to objects connected to the internet. While in the past, digital and physical control systems were separated, connected devices and Tangible User Interfaces (TUI) have changed how users interact with and use objects. In this thesis, I examine one application of quantified data and motivation theory combined with the benefits of connected devices and TUI. The proposed solution, Cloudent, is a system connecting oral care providers to patients to improve patients' oral health.

The medical field has many control systems, both physical and digital, as well as many artifacts, applications, and stakeholders. These artifacts are tools such as handheld instruments, imaging machines, and monitoring devices. Applications include software such as internal and external patient information systems, specific product applications, and imaging programs. The doctor, doctor's assistant, patient, office, and insurance companies are stakeholders. The amount of information and interconnectivity between artifacts and stakeholders creates an ideal area to apply connected devices and Tangible User Interactions. I was interested in investigating all three of these areas for potential design solutions.

Problem Space and Preliminary Research

At the 2016 Immerse Summit, a virtual reality conference (11 October 2016), Dr. Joel H. Berg, Dean of Dentistry at the University of Washington and pediatric and caries specialist, presented a topic that he and other dental professionals have identified as a key problem in dental practice today: the lack of connectivity.



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Figure 1 – Problem space diagram

Using the knowledge I gained from his talk, I could then ask: how do you better connect the doctor, dental hygienist and other staff, patient, and tools; address multiple monitors for viewing health records and patient health; and better manage devices? To better visualize the problem space, identify the stakeholders, and identify their roles and responsibilities during a dental visit, I created a diagram that illustrates how each are connected (figure 1). My next step was to conduct preliminary research by surveying individuals in the dental industry. I received survey responses from 11 dentists, dental assistants, dental hygienist, and dental office employees. Four of these responses were incomplete but still provided useful information.

Survey respondents identified a problem area with current communication technology and methods. The dominant themes were time and communication between the patient and oral care provider. Respondents expressed doubts regarding whether or not patients fully understood health issues. The results from this initial survey both confirmed the issue of lack of connectivity identified

by Dr. Berg and provided me with a problem space for the future direction of my project. The problem space could be separated into three categories: preventative maintenance education, such as knowing how to take care of your teeth; communication between oral care providers and patients; and academic education, both continuing education and education for new doctors. I chose to focus on communication between oral care providers and preventative maintenance education because they focused on all three stakeholders: the patient, dentist, and dental hygienist. The question to drive my research was: how will connected, tangible interactions create easier and more fluid communication methods for oral care providers and patients?

II. Background – Approaches in Computing

The medical field has used connected devices to monitor real-time data (Yeole 2016). An example of this are devices such as the Pacemaker, a device that monitors a patient's heartbeat for irregular rhythms. The information is then transmitted to an external device for analysis. In this next section, I will explain Internet of Things (IoT) and Tangible User Interface (TUI) and their relevance to the medical field.

Internet of Things

Internet of Things (IoT) is a computing strategy that leverages networked and connected devices and can be in the form of physical and virtual objects (Porter 2014). The networked approach enables objects to collect and exchange data. This idea of connected devices was originally predicted as Ubiquitous Computing in 1991 by Mark Weiser, chief scientist at Xerox PARC, in his Popular Science article, "The Computer for the 21st Century" (Weiser 1991). He stated that contemporary computers were only physical objects that are unknowing of their environment, require skill to use them, and intrude on the physical space. Weiser predicted that in the future, computers would be able to adapt their behavior to surroundings, be indistinguishable, and be fit for specific tasks. One of the first examples of IoT was coincidentally created the same year Weiser published his article. Quentin Stafford-Fraser, then Research Assistant at the University of Cambridge Computer Lab, and his colleagues created a still-image feed of a coffee pot so they could monitor the status of available coffee (Stafford-Fraser 1995). This is significant because it was one of the first uses of what is now considered a webcam, but also because it brought real-time monitoring to consumer use through the internet. Real-time monitoring had



Google's Nest Thermostat

been used for scientific purposes, such as monitoring vitals of astronauts on the Gemini Program in the 1950s, but this was done through radio relays and not a network of computers (NASA 2016). Today, IoT has drastically changed how users interact with products. For example, traditional thermostats work by a user selecting a target temperature for the room, and in response the temperature sensor controls the heating, ventilation, and air conditioning (HVAC) to reach the desired temperature. Google's Nest, a smart thermostat for the home, shows how IoT has changed how temperature is controlled in the home. With Nest, the product learns and anticipates when a user is home and what temperature is desired based on the user's daily routine. While the user initially will need to interact with the product in order for the product to learn the user's behavior, Nest will learn to automatically adjust the temperature, and users seldom need to input data directly. In addition, because Nest is connected to the internet, users can view and manually control the temperature of their home through a smart phone. Nest also connects to other products, such as the smoke detectors and home monitoring systems. Nest is one example where the addition of IoT can improve a user's experience.

Tangible User Interface



Urp

Introduced by George Fitzmaurice, Hiroshi Ishii, and William Buxton in 1995, Graspable User Interfaces is the seamless combination of physical and virtual controls (Fitzmaurice 1995). Today, this interaction is called Tangible User Interface (TUI). Traditional input and output devices such as computers made clear distinctions between the physical and the virtual through use of a monitor, keyboard, and mouse. Input was done through physical devices while virtual objects and content were shown on the monitor. Even today with the use of touchscreens, input is still physical, through use of a finger or stylus to control virtual objects on a screen.

An early example of TUI is Urp, an urban planning project, created by John Underkoffler and Hiroshi Ishii from MIT Media Laboratory's Tangible Media Group in 1999 (Underkoffler 1999). In this project, users interacted with physical objects that represented buildings and wind direction on a projected surface. Underkoffler and Ishii created this product in order to address multiple problems urban planners face while designing for a city: shadow prediction, building proximity, building reflections, wind direction, and building visualization. The user would place the buildings in the area under the projection and use the "wind tool" to manipulate the direction of the wind. The projector then showed wind patterns created around the physical buildings along with shadows that would be cast by the sun. The user could then assign materials to the buildings that



Microsoft's Surface Dial being used on a Surface Studio

would also impact shadows cast and wind patterns. Urp is an example where real time interactions both helped professional urban planners in their design process for a space and allowed people who did not have a background in urban planning to understand the process.

A more recent example is Microsoft's original Surface, now PixelSense, which was first announced in 2007 (Derene 2007). The product was a table-sized display which users could interact with like a present-day tablet and on top of which users could place physical objects. If an object, such as a phone, was placed on the table, users could then share their content either on the table or swipe to share with other users' phones on the surface of the table. These swipe actions, called natural user interface (NUI), enabled users to use natural body movements to manipulate and interact with the display instead of relying on a physical input device. These NUI are now a common way for users to interact with objects, phones, televisions, tablets, and computers. In October 2016, Microsoft unveiled a new device, the Surface Dial, which combines NUI and TUI on their tablet device, Surface Studio (Microsoft Corporation 2016). The user places the Surface Dial onto the display and changes its behavior depending on the application that is currently running. This product provides users with a more granular physical interface for various tasks.

The Future and Application

Products like the Surface Dial are the start of a new method of interaction. What is most compelling is the question: what could happen if the Internet of Things and Tangible User Interface are combined? If Urp were connected to the network, users could pick any location in the world and simulate current environmental conditions. How could I apply IoT and TUI in the dental field to make changes the way Nest, Surface, and Urp did for their respective fields?

Current dental tools are not connected to the internet and are used independently. As seen in the dental field survey results, there are often communication problems between the oral care provider and the patient. Connected devices would address this problem by providing accurate data of the patient's health over time. This data could be transferred to physical objects in the dental office that oral care providers can use to communicate with the patient. These objects would be tangible but flexible to change as the data varied. Would the combination of connected devices and tangible objects create better methods of communication and visualization between the oral care provider and patient?

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III. Defining the Problem, Field Research, and Data Collected

Dentist and Dental Hygienist Interviews

In November of 2016, I interviewed a dentist, Jayna Sekijima, and a registered dental hygienist (RDH), Kim Chen, to learn about their daily workflow and to pinpoint problems. The information gained provided me an understanding of daily events, patient classification, the roles each stakeholder holds during a visit, and terminology used in the field. Using this roadmap, I was able to identify where problems they described happened during the day and compare this to other data collected.

There are three oral care professionals at the dental office who interact with the patient. Registered dental hygienists examine and care for the patient's teeth. These interactions include scaling and cleaning teeth, conducting x-rays, and scheduling appointments. Oftentimes, RDHs are assigned to a specific column, or chair. The dentist conducts final examinations of the patient's teeth and performs complicated dental procedures such as applying crowns. Dental assistants help the dentist during procedures such as fillings and will typically also prepare the patient and the tools used during procedures.

There are two types of patients: Prophylaxis and Periodontal (figure 2). Prophylaxis patients are generally healthy patients who come in for regular check-ups every six months. At these visits, patients will have annual x-rays, teeth cleanings, fluoride applications, and exams with the doctor. Periodontal patients have more frequent visits due to having symptoms such as bone loss or deep pocketing. These visits can be as often as every three months. The dental hygienist will look for further deepening of pockets and check the known

Registered Dental Hygienist (RDH) Workflow

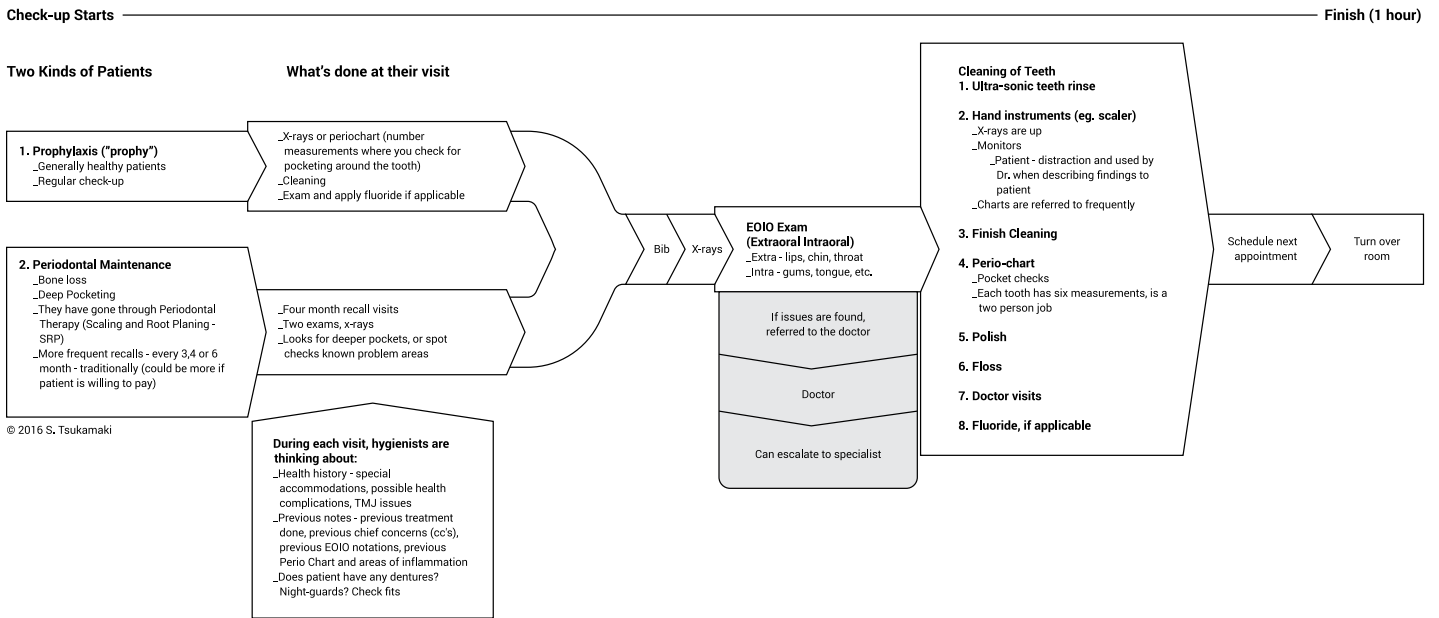


Figure 2 – Registered Dental Hygienist (RDH) workflow and classification of patients

Dentist Workflow

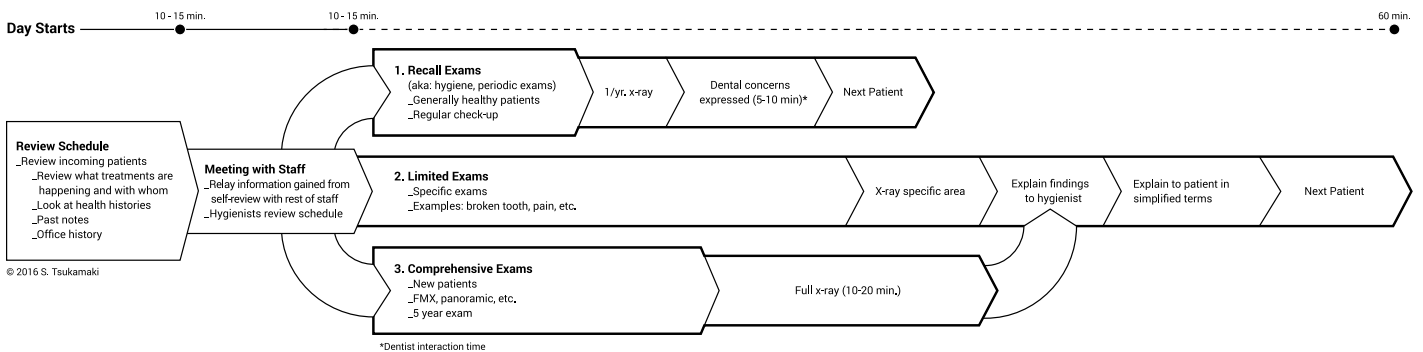


Figure 3 – Dentist workflow and classification of patient visits

problem areas in the mouth. Both types of patients receive Extraoral Intraoral (EOIO) Exams, where the hygienist observes and records any outstanding issues in the lips, gums, throat, and tongue. If a problem is found the dentist will be informed; if the problem is severe enough, the patient will be referred to a specialist.

Not only are patients classified into the two categories listed above, but visits are also classified into three groups: recall, limited, and comprehensive exams (figure 3). Recall, or hygiene and periodic exams, are regular, six-month check-ups. Limited exams are reason-specific visits such as chipping a tooth or other issues not found during a routine visit. Comprehensive exams are for new patients and are done every five years for regular patients. These exams include full mouth x-rays (FMX), panoramic x-rays, and a more detailed analysis of the

patient's oral health.

Pediatric Dental Practice



Pediatric dental operator

For a period of four hours, I conducted an observation at the University of Washington's Pediatric Practice in Seattle, WA. I observed Dr. Joel Berg, dental residencies, and dental students practice on patients. I also observed dental assistants, office workers, and parents of the patient. I observed oral care providers conducting recall exams, fillings, and sealants on patients ranging in age from approximately four to twelve. In addition, I observed how oral care providers interacted with and accommodated one patient on the Autism Spectrum. The oral care providers saw this patient in a separate room and tailored the type of procedures to their special needs. The purpose of this observation was to see how the different stakeholders interacted with each other and to better identify where the communication breakdown occurs.

A unique difference I observed that varied from the workflow of the dentist and RDH shown in Figure 2 and 3 was the presence of the parent as an additional stakeholder. Both the dentist and the RDH needed to communicate to both the patient and the parent about the child's oral health and history. In many cases, the oral care provider would talk to the parent first in order to build an understanding of the child's eating and oral care habits. In an already crowded environment of equipment, monitors, and furniture, the additional stakeholder further complicates the process.

Orthodontal Dental Practice



Orthodontist operator

For a period of three hours, I conducted an observation at Dr. Bobby Cohanim's orthodontal practice in Seattle, WA. I observed Dr. Cohanim, a clinical assistant, and a treatment coordinator interact with patients ranging in age from childhood to adults. I observed various practices, including braces adjustments, Invisalign and retainer fit checks, and an intraoral scan. The purpose of this observation was not only to see the interactions between the doctor, assistant, and patients, but to identify differences between this practice and the previous pediatric observation and workflow.

Two differences between the orthodontist and a general dental practice are the time spent with the patient and the procedures that are administered. While a recall exam at a general dental practice may last an hour for a regular cleaning, some patients visited the orthodontist for 15 minutes or less. Shorter visits consisted of checking progress or fit of orthodontic devices. Longer visits lasted closer to 20 to 30 minutes, due to adjustments of the orthodontic device

or the need for an oral scan or other imaging procedure.

Another difference is the need for patients to actively participate in maintaining the use of the prescribed orthodontic device. For example, patients will be given either a temporary or permanent retainer to wear after completing treatment such as braces. This ensures that the teeth do not revert back to their original position. It was observed that temporary devices were often not used as often as needed, particularly by adolescent patients. In addition, many adolescents were hesitant to inform the dentist about this. This is an example of communication breakdown between patient and oral care provider.

Patient Surveys

Using the workflow of the types of patients, appointments, and tasks completed during a dental visit, I created a survey for dental patients. I surveyed 48 dental patients and received 45 valid responses. The survey consisted of the below questions, which I formulated after interviewing oral care providers and conducting observations in dental clinics. Two responses were invalidated because the respondent worked in the dental field, and one participant submitted an entirely blank responses.

1. Do you work in the dental field, such as a dentist, dental hygienists or assistant?
2. How long has it been since your last dentist appointment?
3. What best describes the type of appointment you had last?
4. How long have you been seeing your dentist?
5. How comfortable do you feel asking your dentist about dental issues?
6. Please rank what you feel is the most important to least important about a dental visit. One is the most important, six is the least important
 - a. Preventative maintenance education (examples: brushing teeth, flossing, braces cleaning, etc.)
 - b. Viewing x-rays and images of your teeth as it pertains to your health
 - c. Understanding what the doctor, hygienist, or assistant is trying to convey
 - d. Pain management during visit
 - e. Being physically comfortable in chair
 - f. Understanding your mouth health
7. From the previous question, please explain your number one choice (why is this most important to you?)

I focused on responses to Question 6, what patients identified as being

Results based on average ranking score

1	Understanding what the doctor, hygienist, or assistant is trying to convey	4.21
2	Understanding your mouth health	3.91
3	Pain management during visit	3.84
4	Preventative maintenance education (examples: brushing teeth, flossing, braces cleaning, etc.)	3.51
5	Viewing x-rays and images of your teeth	3.00
6	Being physically comfortable in the chair	2.65

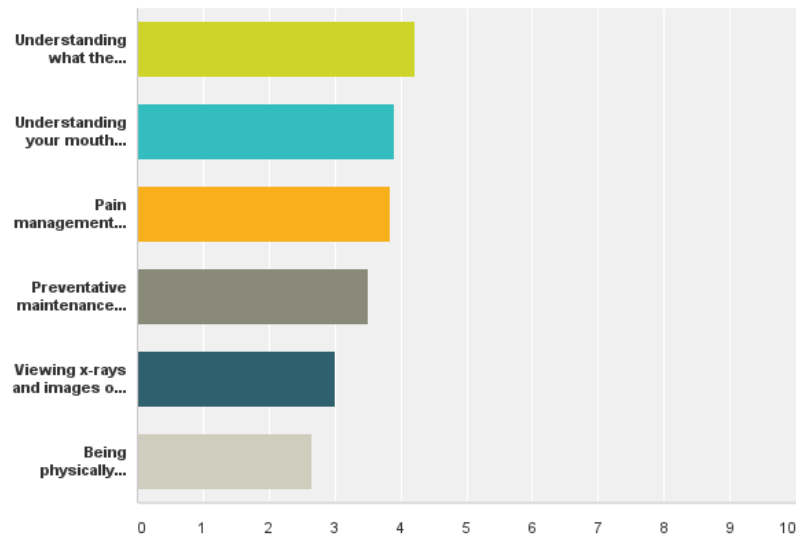


Figure 4

most important during their dental visits. The two most important options were “understanding what the oral care provider was trying to convey” and “understanding mouth health” (figure 4). One individual stated, “If it is important to my health it’s very important that I understand what they are telling me, in terms I can understand, so I can make appropriate decisions or changes as needed.”

These findings, combined with my clinic observations and previous survey results, provided me with more specific opportunities for an applied design.

Areas for Opportunities Identified

Stakeholder Interaction Time

During interviews, both the dentist and hygienist mentioned limitations on how much time was allotted to explain oral care to a patient. The Registered Dental

Hygienist (RDH) workflow, Figure 2, shows how full an hour appointment is. One hygienist mentioned that they only have a few minutes to explain issues to patients. While they can talk to the patient during procedures such as a mouth cleaning, patients aren't typically as engaged as in a face-to-face conversation and have no opportunity to respond or ask questions. Similarly, dentists typically have five to ten minutes with each prophylaxis, or healthy, patient, as they tend to spend longer time with periodontal patients with specific issues.

Patient's Lifetime

In a patient's lifetime, time also plays a major factor in the development of dental issues such as tooth decay. Tooth decay may develop from improper brushing and flossing. This can lead to tartar build-up and plaque, and if not taken care of, tooth decay. Currently, dental offices have images and models of tooth decay, which only represent the end result of tartar build-up and plaque. These models are static and cannot show changes over time, which makes it difficult for the patient to envision how their current state could develop into a more serious issue.

In-Office Dialogue

In my initial interview with dentists and the hygienist, I identified the lack of adequate communication techniques for conversations between oral care providers and patients as a potential design opportunity. Currently, communication between the provider and patient is done through drawings and illustrations, 3D models of teeth, verbal descriptions, brochures, and x-rays. Drawings and illustrations are time-consuming and may be difficult for the patient to understand. Similarly, verbal descriptions are difficult for the patient to visualize. Brochures can be useful for providing patients with general information about health and preventative care, but they are not tailored to the patient's experience or circumstances and therefore have limited applications. These brochures may also show extreme cases of health issues; as a result, many patients, especially those without severe cases, may not be able to relate to the information. The same can also be true about physical 3D models. Models are typically generic and it may be difficult for patients to apply a described dental concept to their own teeth. In addition, models are expensive, which deters dentists from buying the variety of models necessary to cover the wide spectrum of dental issues. Lastly, x-rays are difficult to understand. Patients do not have the technical expertise or knowledge to understand the orientation of the x-ray, location, or meaning of the images. While these images are meaningful to the oral care provider, they have limited usefulness in communicating with the patient.

Displays and Recording Information

There are currently at least two displays for oral care providers to use at each chair, one showing the patient's medical history and information, the other showing x-rays and other images. In many offices, it is now common to see a third display for the patient. This is used as a distraction technique for the patient during a procedure or cleaning. It can also be used to show the patient images while talking to the RDH or dentist. Although the first two displays are used frequently by the dentist and RDH while working on a patient, they are located behind the oral care provider. This forces the oral care provider to turn away from the task they're conducting on the patient. Furthermore, the inefficiency of this setup is evident when the dentist or RDH is recording information. Oftentimes a second individual is asked to record data during a procedure such as a pocket measurement, a numeral measurement of the space between a tooth and gum. During this procedure, one oral care provider calls out a series of numbers to the assisting individual, who then inputs them into the computer. This scenario was identified by an RDH as a constant problem. Not only is the process itself time consuming, it requires one RDH to leave their assigned chair to assist another. As shown in Figure 2, RDHs have a short amount of time between and with each patient, and requiring two oral care providers for this one task adds further demands on their already busy schedules.

Engagement

Another focus area is engagement of the patient. This includes a patient's engagement in their oral care both during and outside the dental visit. Engagement includes: understanding a procedure and why it's being conducted, preventative oral care such as flossing and brushing, and making healthy choices for food and drink. It was noted that many patients lose interest in their oral health if the perception was that their teeth were healthy. This could cause patients to become complacent about ensuring that their home care was as thorough as necessary to sustain a healthy mouth. This was particularly seen in the pediatric and orthodontal clinic. At the pediatric clinic, it was observed that while a parent was engaged in their child's oral care habits, oftentimes the child could not comprehend long-term effects of not completing tasks such as brushing and flossing.

In reviewing the five areas of opportunity above, I believe the patient's lifetime, in-office dialogue, and engagement offer the most potential for a design application. All three of these areas could benefit from connected devices at home and in the dental office that could create tangible methods of communication during an office visit.

IV. Project Scope

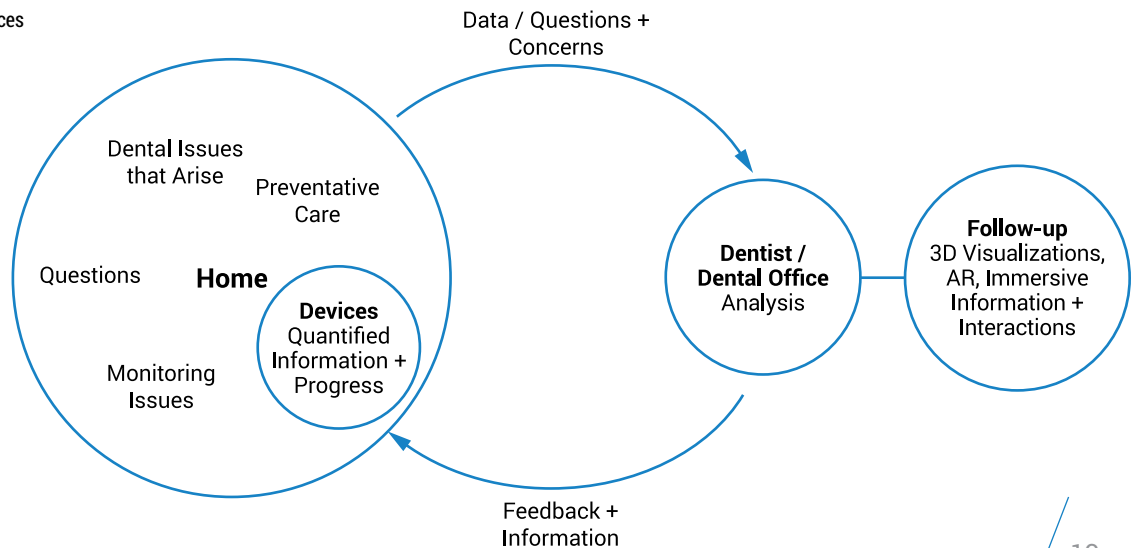
Design Opportunities

As a result of interviews, surveys, and observations, I was able to identify three potential project areas: home monitoring, office visualizations, and multiple monitors and information management.

1. Home Monitoring

Home monitoring would address reminders, education, communication, and quantified dental hygiene practices (figure 5). Currently, products such as the Sonicare DiamondClean inform users how long to brush each quadrant of their mouth. While brushing for the proper length of time is important, there are no current methods to easily record data or issues that arise while at home. Having connected devices at home could allow home care to link with a patient's dentist, allowing for quicker diagnosis and potentially preventing further damage to the mouth and teeth.

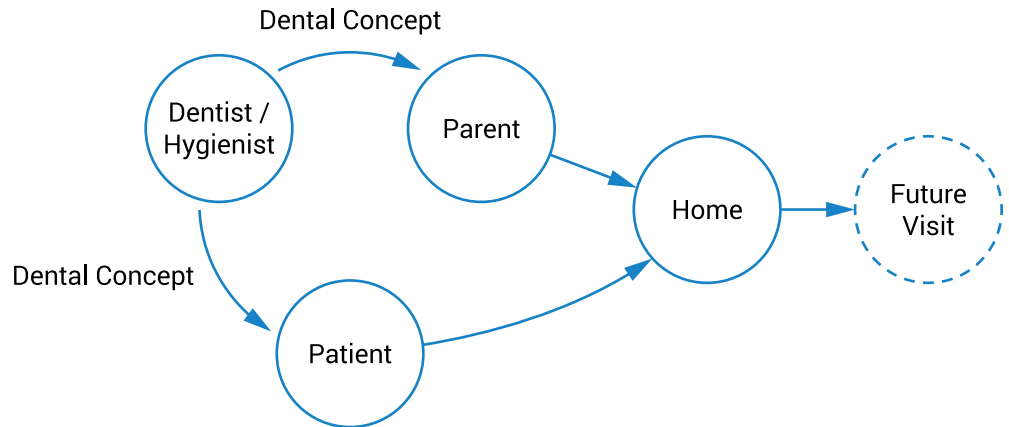
Figure 5 – Home monitoring uses devices to communicate to the dental office regarding oral care issues.



2. Office Visualizations

Office visit visualizations would enhance current practices for explaining dental procedures and preventative care methods (figure 6). Current methods include sketches, verbal descriptions, and models, which are sometimes inadequate in communicating health issues to patients. My proposed design would provide hygienists and dentists new tangible methods for describing oral health to patients. Providing more tangible experiences for both the dentist and patient could facilitate more meaningful conversations and a better understanding of oral health.

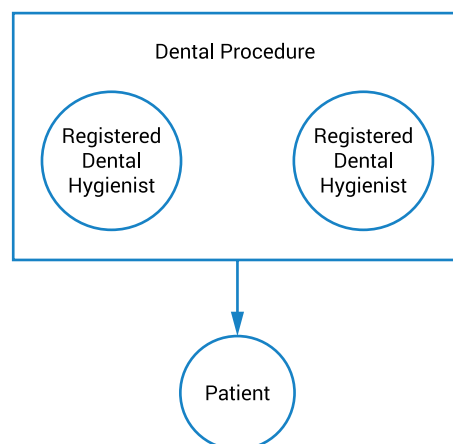
Figure 6 – Better visualizations for explaining dental concepts to patients to create better understanding of preventative care for future visits



3. Procedure Management

Oral care providers must frequently reference a wide array of information in various charts, images, and notes for each patient (figure 7). Creating a solution for addressing multiple monitors and managing information could drastically improve the experience for the oral care provider and patient. Currently, procedures such as a pocket check need multiple hygienists to measure and record information. I propose a design that addresses this issue by providing oral care providers with an up-front visual management system that creates a more efficient workflow.

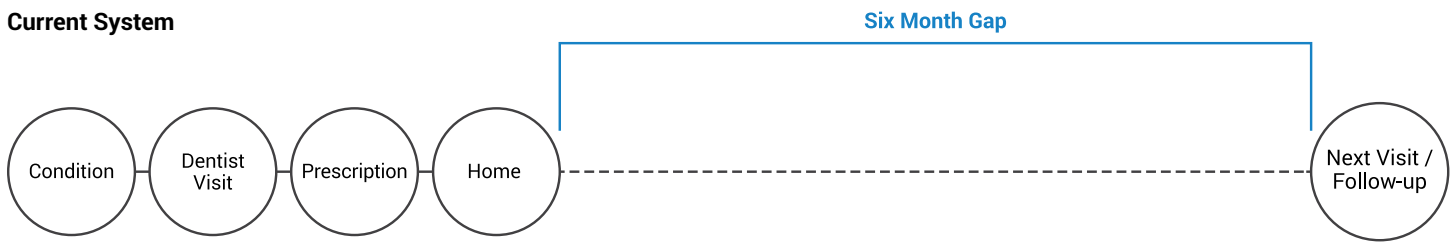
Figure 7 – Providing an up-front visual system will create more efficient procedures for the oral care provider and be more comfortable for the patient



System Proposal

I initially thought to choose one of the three opportunities listed above. While reviewing potential designs for each direction, however, I realized that the problem I was trying to solve was systemic and not limited to a single design. This led me to combine the three identified areas into one. My design addresses all three problem areas simultaneously by filling the gaps between dental visits. Currently, a generally healthy patient visits their dental office every six months in the United States (figure 8), and at the conclusion of the visit the oral care provider gives the patient suggested areas for improvement or monitoring to maintain healthy teeth. The patient then returns home with little to no interaction with the dental office until their next visit. My proposed system, Cloudent, would fill the gap between visits by quantifying oral hygiene and communication between the patient and dental office via connected devices and data collection. The data from the patient may be used as a reference point when talking about their health when they return for a check-up.

Current System



Proposed Cloudent System

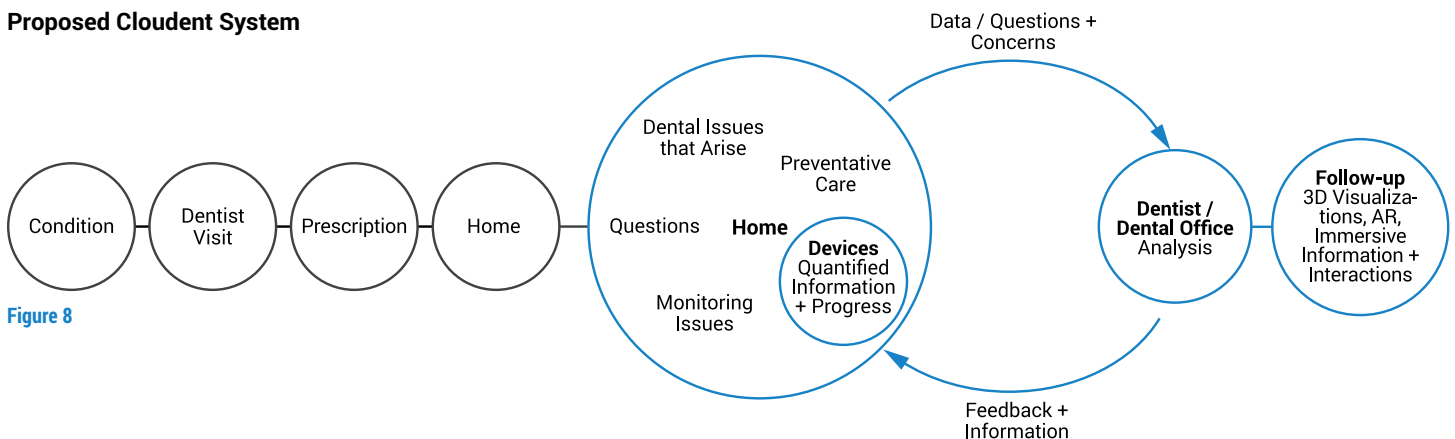


Figure 8

In order to implement the proposed system, I need to understand quantified information and patient motivation. What factors are required for patients to be engaged in collecting data to share with their oral care provider?

V. Theory of Self-Experimentation and Motivation

Theory of applying self-experimentation to dentistry

Many patients disengage from high quality oral hygiene practices as more time elapses since their last dental visit. The six-month gap between visits for prophylaxis, or healthy, patients results in communication issues and decreased engagement in preventative maintenance. I believe using connected devices and quantifying oral care practices at home will improve the patient's health. How will connected, quantified, and tangible interactions create easier and more fluid communication methods for oral care providers and patients in order to increase patient engagement in their healthcare?

In 1953, behavior psychologist B.F. Skinner advanced the concept of using science as an objective observer to understand human behavior (Skinner 1953). In 1981, another psychologist, Allen Neuringer, urged the use of self-experimentation, or scientific research conducted on oneself, and saw this behavior as "becoming as common and accepted as attending church, going to a ball-game, or seeing a therapist" (Neuringer 1981). Neuringer's six attributes of self-experimentation are: *increasing input and direction variability, acquiring data, discoveries, providing proof of change happening, creating daily habits, and the result(s) being believable by the individual.*

Today, Neuringer's vision of self-experimentation is manifested in the form of the quantified self. As of 2013, 60% of adults in the United States are tracking an aspect of their health such as weight, diet, or exercise (Swan 2013). This phenomenon is due in part to increasingly accessible technology that can track, collect, and display data chosen by the individual. This technology is the objective observer that Skinner proposed above.

Currently, patients and oral care providers often face communication and engagement issues regarding the health of the patient's mouth. This is impacted both by communication breakdowns in the office, due to generic models or lack of visualization aids, and the lack of interaction between the oral care provider and patient once the patient has left the office. How can applying Neuringer's attributes of self-experimentation increase patient engagement in oral healthcare? Figure 9 illustrates where I see potential to apply Neuringer's attributes of self-experimentation to the proposed system.

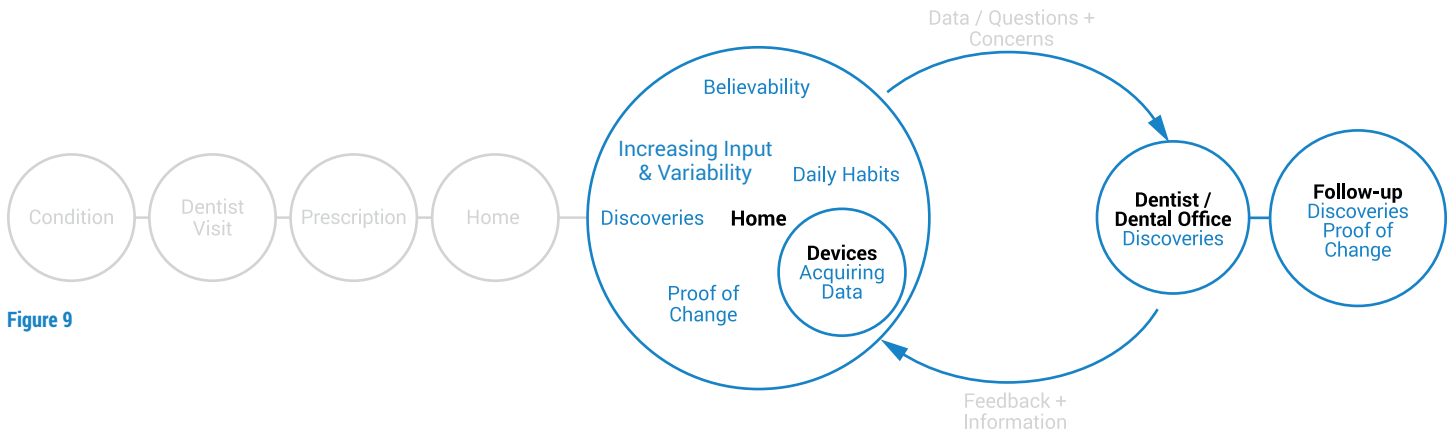


Figure 9

Increasing Input and Direction Variability

There are many variables a patient can control in their self-care regimen that affect their oral hygiene, such as brushing and flossing time and location; wearing orthodontic devices for variable lengths of time; angle of the toothbrush to the teeth and gum line; the number of times teeth are brushed per day; sugar intake; and using mouthwash.

Acquiring Data

Data could be collected through the electric toothbrush with an interchangeable head that could attach to other instruments, such as an intra-oral camera. Other types of data can be patient behavior, environmental factors, and observations made by the patient.

Discoveries

Discoveries could take place at the patient's home and at the dental office. Home discoveries could include whiter teeth and improving efficiency of brushing and flossing. Office discoveries could include shallower pockets and decreased amount of plaque on teeth.

Proof of Change

As the patient tracks their oral hygiene over time, they will collect evidence that their habits are improving or declining.

Daily Habits

Many of the oral care providers I interviewed noted that proper daily oral hygiene habits are critical for maintaining a healthy mouth. Practicing self-experimentation by quantifying oral care can lead to healthier habits for the patient.

Believability

Through observation, I noted that many patients were not engaged in their oral care, especially if they perceived their teeth to be healthy. Through a quantified oral care system, patients can receive feedback on whether their teeth maintained their health or if there is a decline over time in their oral health.

Theory of Motivation and Engagement

Motivation is categorized into two types. First, intrinsic motivation is the act of doing an activity because it brings pleasure and satisfaction from engaging in the activity (Ryan 2000). Second, extrinsic motivation is where a person does an activity not for the pleasure but for the desired outcomes. Psychologists Edward Deci and Richard M. Ryan have studied these types of motivation and how they apply to athletes (Mageau 2003). Intrinsic motivation is seen in athletes who enjoy exercising, training, and playing a sport for their own value. Oftentimes in extrinsic motivation, there is a coach providing motivation and support for the athlete. In the dental field, this coach-to-athlete relationship is analogous to the relationship between the oral care provider and the patient. In both scenarios there is one stakeholder who is trying to motivate another to change or maintain habits to improve.

In 2003, psychologists Genevieve A. Mageau and Robert J. Vallerand assembled common traits on how coaches support their athlete (Mageau 2003). These traits are: *provide choice within specific rules and limits, provide a rationale for tasks and limits, acknowledge the other person's feelings and perspectives, provide athletes with opportunities for initiative taking and independent work, provide non-controlling competence feedback, avoid controlling behaviors, and prevent ego-involvement in athletes*. I applied five of these seven traits to the relationship between an oral care provider and the patient and have changed the wording to more accurately describe this relationship.

Provide choice within specific rules and limits

The American Dental Association recommends that patients brush their teeth twice a day for two minutes and floss at least once per day. While it is recommended to floss before brushing, the time of day is not prescribed, and

the American Dental Association simply states that completion of these tasks is most important Association 2017). Allowing patients to choose when they brush and floss could allow patients to be more inclined to complete these tasks as fits their schedule.

Provide a rationale for tasks and limits

Oral care providers could not only provide patients with certain tasks to complete, but could also explain why and how to complete them. The need for clear rationale is supported by this response from my patient survey: “if I don't understand my own oral health or the reasons for the recommendations given, I'm not motivated to maintain good oral hygiene after my visit”.

Acknowledge the patient's feelings and perspectives

The tools and feedback used for connected devices between the patient and the oral care provider could be adaptable to the patient and their needs. For example, interfaces and feedback should be different for young children, adolescents, and adults. By tailoring the feedback to each patient, the patient will have a more personal experience with the product and be more engaged in their oral care.

Provide patients with opportunities for initiative taking and independent work

The product would provide feedback to the patient, allowing the patient to monitor positive or negative changes in their oral health. Without prescribing a set course of action, the product would allow patients to take control and initiate a change in their behavior to affect the outcome.

Provide non-controlling competence feedback

One of the key components of the system is the ability for oral care providers to provide feedback to the patients regarding questions or issues observed from the patient's self-exploration and quantified data. In order for the patient to maintain motivation to continue using the system, oral care providers must provide the feedback in a knowledgeable but non-controlling way.

I focused on three of Neuringer's attributes of self-experimentation: increasing input and direction variability, acquiring data, and daily habits. I applied these three attributes to a design for a home oral care kit and an in-office tool. These designs would allow patients to quantify data and facilitate communication between the oral care provider and patient.

VI. Design Exploration

The following are descriptions and illustrations of the devices that are used in my proposed system, Cloudent. The two main components are the Home Oral Care Kit and dental office Mouth Model.

Home Oral Care Kit

The home oral care kit consists of a stand that represents the patient's mouth, an electric toothbrush, a flossing device, a charging plate, and an intra-oral camera (figure 10). This product is provided by the dentist as part of a prescription tailored to improve specific areas of a patient's oral health. In addition to the above pieces, other products such as a dentist mirror, sonic water jet, and teeth scaler may be added to the kit to fit the needs of individual patients.



Figure 10 – Home Oral Care Kit

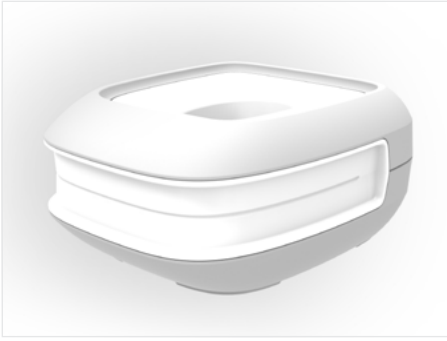


Figure 11

Mouth Representation Stand

This stand holds the toothbrush upright on the charging plate and creates a tangible object for the patient to interact with (figure 11). The design of the stand has a U-shaped cutout in the middle, which represents the patient's mouth. This model of the patient's mouth will display a series of colors showing where the patient has brushed and flossed. Colors will be used to represent the patient's oral care habits compared to their dentist's prescribed actions or recommendations regarding factors such as length of brushing or areas of concern. Green indicates the patient is meeting expectations while red indicates a need for improvement (figure 12). Current technology could be used for this display. This interaction may be screen based, using a flexible e-ink display, or be augmented and shown through the patient's phone or bathroom mirror. This augmented technology is currently being used by Lego(Spreer 2014) at their stores as a unique way for customers to view the model inside a chosen box (figure 13). As technology progresses, I envision a seamless integration between the information presented and the physical product.



Figure 13 – Lego AR screen in retail store

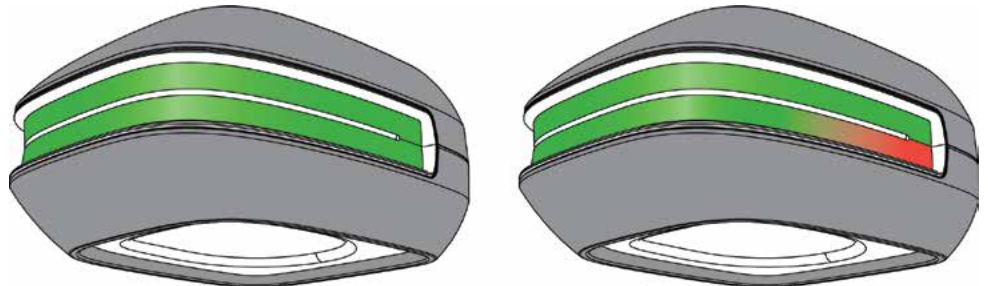


Figure 12 – Left: green indicates the patient has met standards. Right: red indicates the patient has missed the standard

Figure 14



Toothbrush

The toothbrush consists of a handle and replaceable brush heads (figure 14). Patients not only clean their teeth but track the duration of use and location of brushing. Using haptic feedback such as vibration length and intensity, the toothbrush informs the patient when to change location and proper brush angle. If the patient is holding the brush at an incorrect angle, the vibration strength and pattern increases, and as the user moves the brush into the correct position, the vibration lessens and becomes more smooth.



Figure 15

Flossing Device

Like the toothbrush, the flossing device will track location of use and proper use (figure 15).

Charging Plate

This plate charges all the patient's tools in the kit (figure 16). Additionally, the plate acts as an interface that tracks when the products have been used and provides an overall summary of the patient's progress and oral care habits. Green and red dots light up on the rim of the plate displaying the last 30 days of use (figure 16). In addition to charging devices and providing a summary of events, this piece of the kit connects the prescribed tools to the oral care provider via the network. Before a dental visit, an oral care provider reviews the data collected from the devices.

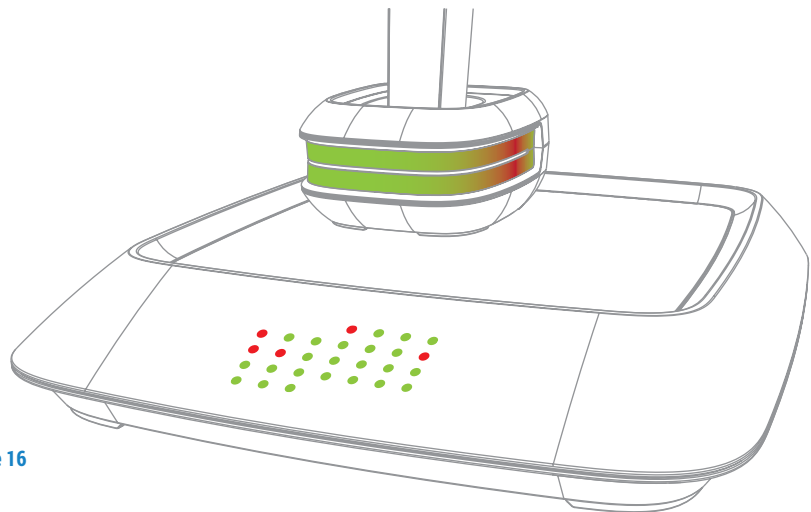


Figure 16



Figure 17

Intraoral Camera

An intraoral camera is a device used to capture detailed images of teeth. By providing a camera for home use, dentists can ask the patient to provide periodic updates on their teeth, particularly when there is an identified issue (figure 17). Additionally, adding light refraction (Lussi 2001) to the camera can help patients prone to caries detect them early and schedule an appointment to receive treatment before tooth decay begins.

Dental Office Tools

To facilitate more engaging conversations, streamline workflow, and reduce monitors in the dental operator, I designed a model of the mouth for oral care providers to use with patients to describe current and past conditions of their oral health and describe procedures. This device would be would work when paired with augmented reality glasses.

Mouth Model



Figure 18

One of the issues identified by a dentist is that models of teeth are not representative of a patient's current condition. Figure 18 shows a model of an extreme case of gingivitis, which may not reflect the current state of the patient's condition. Thus the oral care provider may face difficulty explaining the impact of the issue to the patient, who cannot correlate the model with their own mouth health. The mouth model paired with augmented reality can show the patient's actual teeth (figure 19). This model provides a tangible object for the oral care provider and patient to hold and observe, facilitating easier visualization of issues as the oral care provider describes them to the patient. Both the oral care provider and the patient can control the viewing angle of the teeth by physically rotating the model. The model can be opened and split apart to show a visualization of the backside of the teeth.



Figure 19

Augmented Reality Glasses

To ensure proper sanitation, patients and oral care providers currently wear protective eyewear. This protective eyewear provides an opportunity to integrate augmented reality technology without necessitating change in the current environment. Oral care providers and patients alike would wear the glasses during a procedure and use them to view information displayed on the mouth model (figure 20).

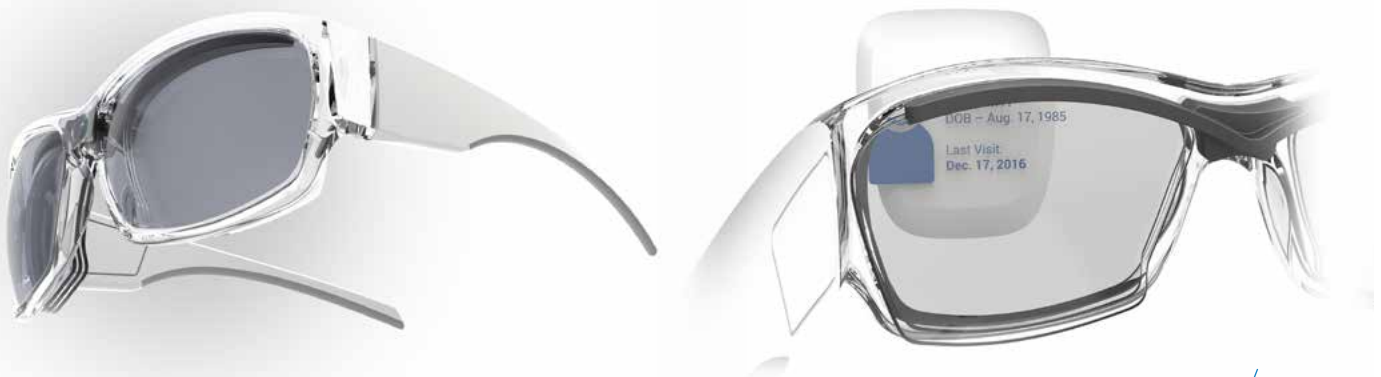
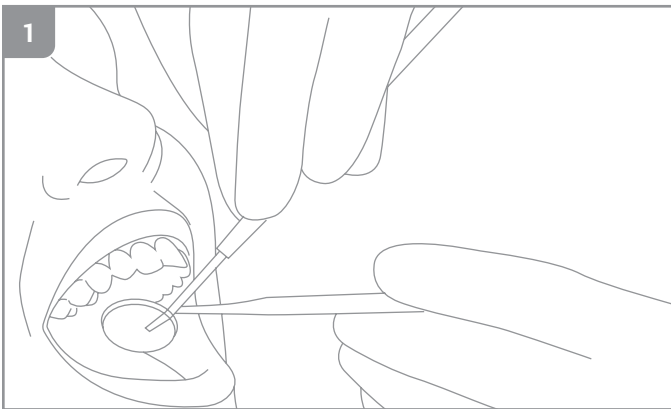


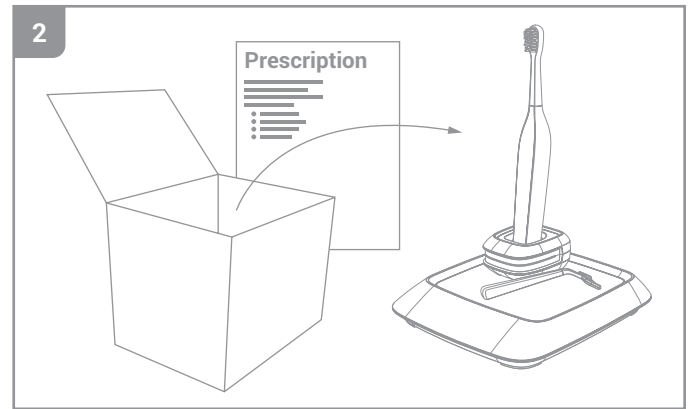
Figure 20

Providing oral care providers with augmented reality glasses not only allows them to see the patient's data but also brings the information up-front and into their line of sight, replacing the current system where monitors are inconveniently located behind the oral care provider. Having the information in the line of sight would allow oral care providers to easily correlate the data to the physical phenomenon or attribute. Augmented reality glasses would also improve ergonomics by removing the need for oral care providers to turn around to view patient information. Augmented reality glasses can also incorporate other features such as a built-in microphone and audio player, which would be useful for when the hygienist conducts procedures such as pocket checks on a patient. This would eliminate the need to bring another hygienist into the room to record data, increase efficiency, and reduce current time constraint burdens.

The following storyboard depicts how the patient and oral care provider uses the product and how the devices interact with each other in my proposed Cloudent system.



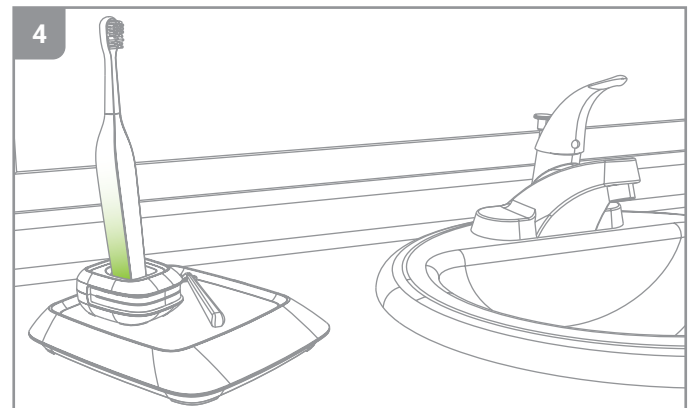
1 Patient receives diagnosis during a dental check-up, such as deep pocketing that could lead to gingivitis.



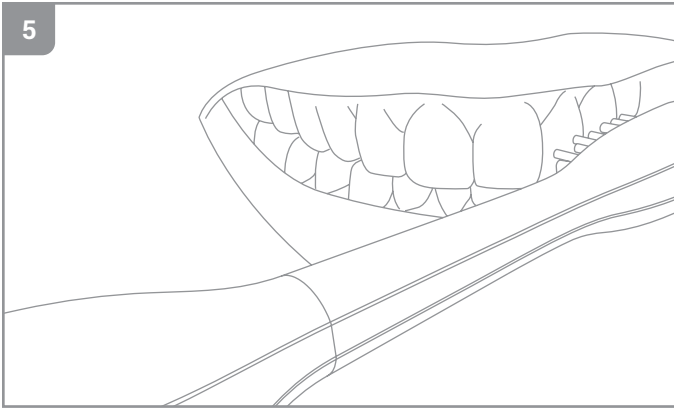
2 The oral care provider provides the patient with a prescription. The prescription is the home oral care kit.



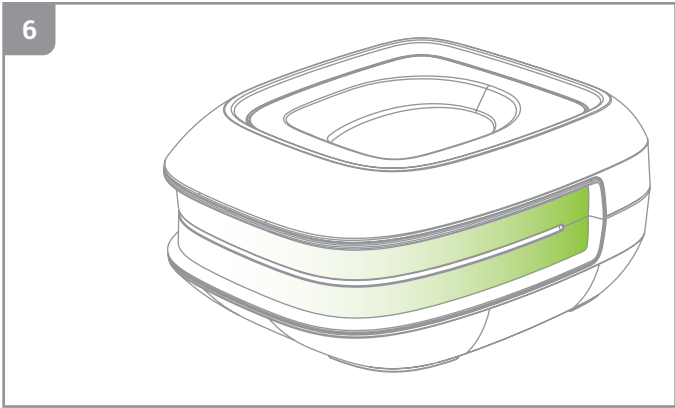
3 Patient takes the oral care kit home.



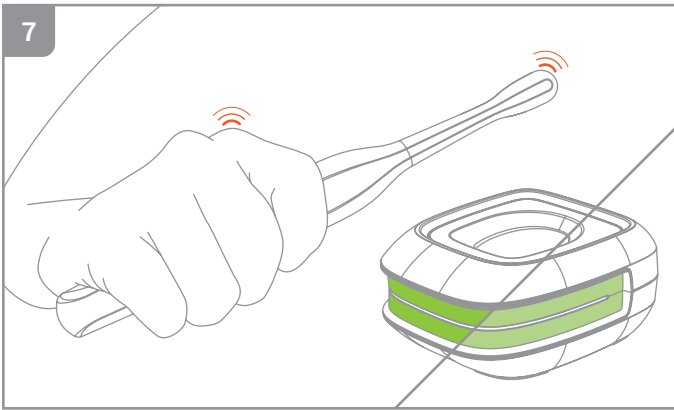
4 When charged the toothbrush's sides glow green.



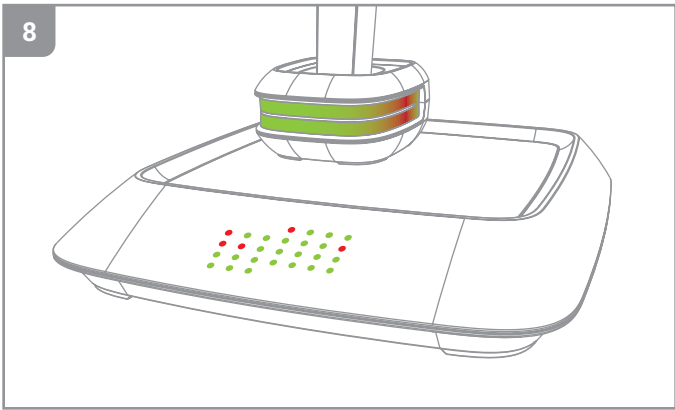
5
Patient brushes their teeth.



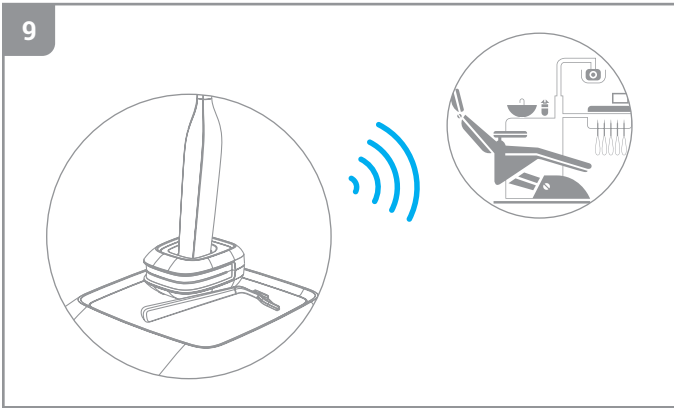
6
The toothbrush stand, which represents the patient's mouth, shows progress of teeth cleaning.



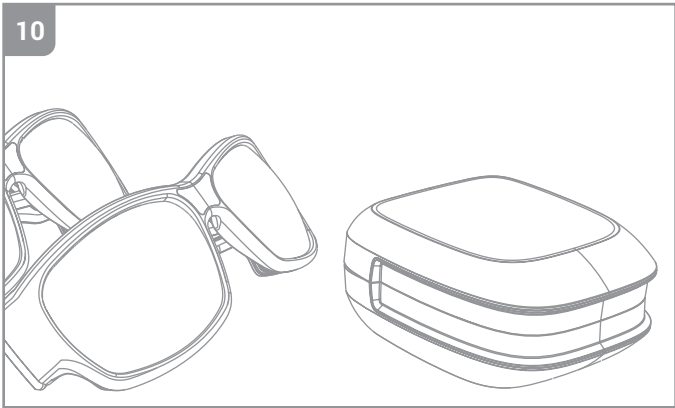
7
The toothbrush provides haptic feedback regarding time, quadrant, and angle. The toothbrush stand indicates pressure through the intensity of green and red.



8
When finished, the mouth stand provides a summary of how well the patient brushed their teeth. On the bezel of the charging tray, a monthly summary is shown.



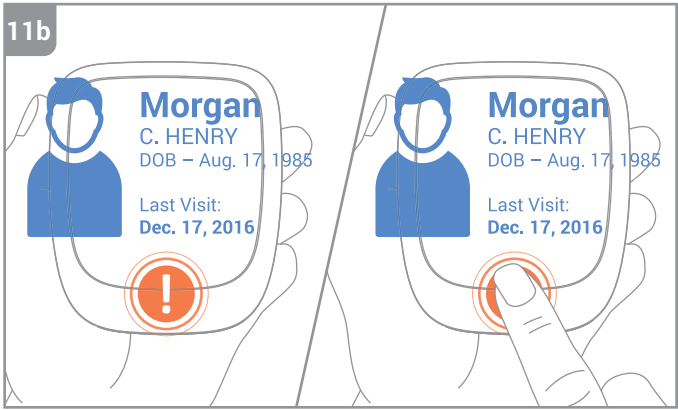
9
Data is sent to the patient's dental office via the cloud.



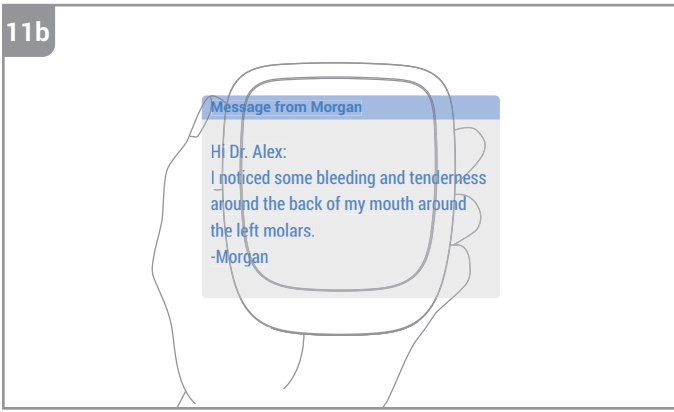
10
Through augmented reality glasses, the oral care provider can view the patient's oral hygiene and health on the mouth model.



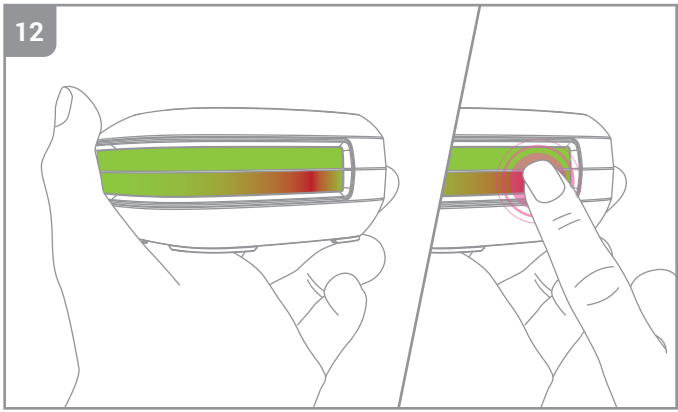
Patient information appears on top of the mouth model.



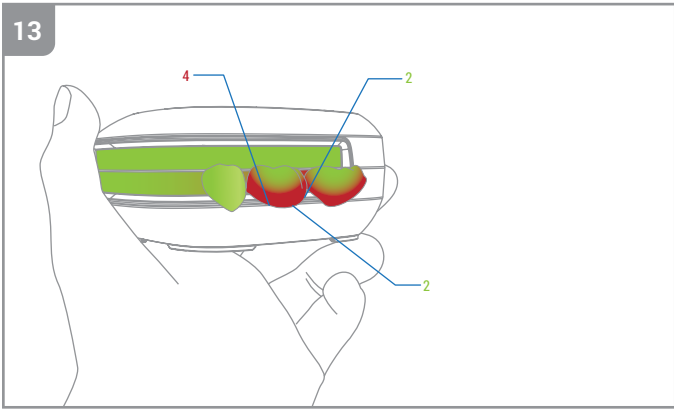
If the patient has sent the dentist a message or has a concern, an icon appears. The oral care provider can then select the icon to see the message and information.



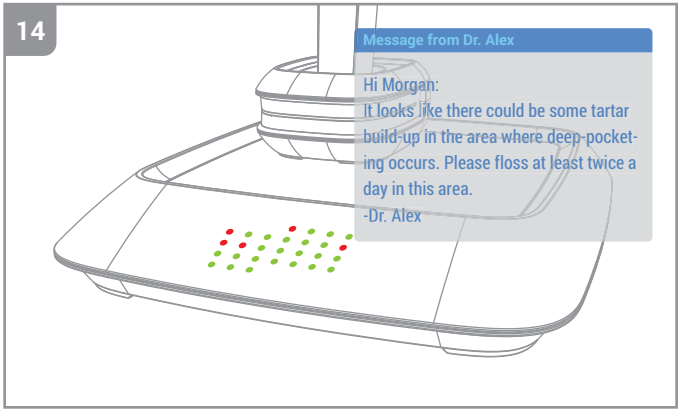
Messages from the patient appear on the top of the mouth model.



Left: the summary of overall oral care. Right: the oral care provider can select an area for more detail.



Detailed information about the area selected is shown.



The oral care provider can respond to the patient's question and provide guidance.

VI. Conclusion

In the past, digital and physical control systems were separated. Today, connected devices and Tangible User Interface (TUI) have changed how users interact with and use objects. Connected devices, also known as Internet of Things (IoT), is a network of objects and software that collects and exchanges data. TUI is the combination of physical and virtual objects and environments. The medical field has many of these physical and digital control systems along with artifacts, applications, and stakeholders. Due to the large amount of information and interaction between artifacts and stakeholders, the medical field creates an ideal area in which to apply connected devices and Tangible User Interface technologies. I applied these two technologies to the dental field after dental professionals identified the lack of connectivity as the key problem. Through surveys to patients and oral care providers, I identified two areas of focus: communication between oral care providers and patients and preventative maintenance education. I chose these areas because they focused on all three stakeholders: the patient, dentist, and dental hygienist.

To gain a better understanding of these different stakeholders and the workflow of a dental visit, I interviewed two dentists and a registered dental hygienist. These interviews provided me with an understanding of daily events, patient classification, the roles each stakeholder holds during a visit, and terminology used in the field. In addition, I conducted surveys with patients to find out what they value during a visit to a dental office. Using the information gained from the interviews and surveys, I identified five opportunities for applying a design: stakeholder interaction time, patient's lifetime, in office dialogue, displays and recording information, and engagement. I chose the three categories of the

patient's lifetime, in office dialogue, and engagement as the areas that could most benefit from connected devices at home and in the dental office to create tangible methods of communication during an office visit.

There are three potential project areas within these three categories: home monitoring, office visualizations, and procedure management. Instead of choosing a single area, I combined the three to propose a new system: Cloudent. Cloudent addresses all three problem areas by filling the gap between dental visits through quantifying oral hygiene and communication between the patient and dental office via connected devices and data collection. For the system to be implemented, I applied Neuringer's attributes for self-experimentation (Neuringer 1981) and patient motivation through the design of a Home Oral Care Kit and a dental office mouth model. I believe that applying self-experimentation and Mageau's traits of the coach-athlete relationship (Mageau 2003) to the Cloudent system will increase connectivity between oral care providers and the patient. While technology used in home care and communication devices at the dental office will change over time, this quantified, connected system for motivating patients will remain relevant.

The design addresses what the possible devices could be and how the patient can interact with them. While the design shows the potential form and user interaction, the design does not address the current technological state on the types of electrical components necessary to produce these products. For example, current intraoral scanners are still large and require a large processor; however, I believe over time this technology will become more compact and can be used by a consumer.

Key Collaborators

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Cohanim Smileworks
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I envision dental offices adopting Cloudent to view patient data and communicate with patients. Cloudent provides a solution to the problem of the lack of connectivity between oral care providers and patients through connected devices and Tangible User Interface.

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Appendix

Dentist Patient Survey

Question One:

Do you work in the dental field such as a dentist, dental hygienist or assistant?

Answer Choices	Responses
Yes	2 (4.17%)
No	46 (95.83%)
Total	48

Question Two:

How long has it been since your last dentist appointment?

Answer Choices	Responses
0-6 Months	42 (93.33%)
7-12 Months	1 (2.22%)
Over 12 Months	2 (4.44%)
Total	45

Question Three:

What best describes the type of appointment you last had?

Answer Choices	Responses
A. Regular cleaning and check-up	37 (82.22%)
B. For a specific issue (ex: toothache, broken tooth, etc.)	5 (11.11%)
C. You were visiting a new dentist	1 (2.22%)
Both A and B	2 (4.44%)
Total	45

Question Four:

How long have you been seeing your dentist?

Answer Choices	Responses
A new dentist	5 (11.11%)
0 to 5 years	17 (37.78%)
6 to 10 years	8 (17.78%)
Over 10 years	15 (33.33%)
Total	45

Question Four:

How long have you been seeing your dentist?

Answer Choices	Responses
A new dentist	5 (11.11%)
0 to 5 years	17 (37.78%)
6 to 10 years	8 (17.78%)
Over 10 years	15 (33.33%)
Total	45

Question Five:

How comfortable do you feel asking your dentist about dental issues?

Answer Choices	Responses
Very comfortable	38 (84.44%)
Neutral	3 (6.67%)
Comfortable if asked leading questions	3 (6.67%)
Not comfortable	1 (22.22%)
Total	45

Question Six:

How comfortable do you feel asking your dentist about dental issues?

Answer Choices	Responses
Very comfortable	38 (84.44%)
Neutral	3 (6.67%)
Comfortable if asked leading questions	3 (6.67%)
Not comfortable	1 (22.22%)
Total	45

Question Six:

Please rank what you feel is the most important to least important about a dental visit. One is the most important, six is the least important

- a. Preventative maintenance education (examples: brushing teeth, flossing, braces cleaning, etc.)
- b. Viewing x-rays and images of your teeth as it pertains to your health
- c. Understanding what the doctor, hygienist, or assistant is trying to convey
- d. Pain management during visit
- e. Being physically comfortable in chair
- f. Understanding your mouth health

	1	2	3	4	5	6	Total	Score
Understanding what the doctor, hygienist, or assistant is trying to convey	9 (20.93%)	11 (58.58%)	11 (25.58%)	5 (11.63%)	6 (13.95%)	1 (2.33%)	43	4.21
Understanding your mouth health	8 (18.18%)	6 (13.64%)	15 (34.09%)	6 (13.64%)	7 (15.91%)	2 (4.55%)	44	3.91
Pain management during visit	13 (29.55%)	7 (15.91%)	2 (4.55%)	9 (20.45%)	8 (18.18%)	5 (11.36%)	44	3.84
Preventative maintenance education (examples: brushing teeth, flossing, braces cleaning, etc.)	14 (32.56%)	3 (6.98%)	2 (4.65%)	8 (18.60%)	4 (9.30%)	12 (27.91%)	43	3.51
Viewing x-rays and images of your teeth as it pertains to your health	1 (2.27%)	6 (13.64%)	10 (22.73%)	9 (20.45%)	11 (25.00%)	7 (15.91%)	44	3.00
Being physically comfortable in chair	0 (0.00%)	10 (23.26%)	4 (9.30%)	6 (13.95%)	7 (16.28%)	16 (37.21%)	43	2.65

Question Seven:

From the previous question, please explain your number 1 choice (why is this most important to you?).

It's not just the chair but the entire experience. I need something to distract me. I would prefer to listen to music or watch a video, while sitting there.

It is important to be educated first in how to take care of your teeth to move forward in your mouth health.

If it is important to my health it's very important that I understand what they are telling me, in terms I can understand, so I can make appropriate decisions or changes as needed.

Maintenance is very important.

I don't like pain.

Especially if it's a routine visit, I don't want to be uncomfortable or have pain. If the hygienist is not delicate or pays no heed to my discomfort level as they clean and scale, it's just a terrible experience for me.

I would like to have issues caught as soon as possible, sometimes before a problem is more easily visible without x-ray.

I go to the dentist to stay healthy - understanding the status of my dental health is paramount.

My physical health is often reflected in the overall condition of my mouth, i.e. gums, jaw, teeth roots.

I hate going to the dentist in general and it is very physically uncomfortable to have all those tools and hands crammed into my mouth. Visits can be painful, and I'd like to avoid this as my first priority.

Pain hurts!

Going to the dentist makes me nervous, I don't want to be in pain so that's most important to me.

The skill of the dental hygienist in cleaning my teeth efficiently while not causing me too much discomfort is of primary importance to me.

Understanding is key to improving my own health.

Understanding what is going on with my mouth health means that I can pro-actively monitor things and change things that I am doing wrong, or improve my habits.

I have had a lot of dental work as a child (teeth pulled and ortho work) and the pain issue has been difficult to overcome since that time.

If my oral health conditions change and it is not readily apparent to me, I want to know and understand the issues

Preventative maintenance is the surest way of avoiding further pain and suffering at the hands of the dental drill! I like to have the Dentist rate how I am doing at my maintenance to ensure I am not missing anything.

I want to know the best way to maintain the health of my teeth, what issues might exist, and how to improve my dental health.

Just want to be sure nothing is "wrong".

I'm a big wuss.

I need to understand what my dentist or hygienist is trying to tell me as it pertains to my teeth so I can make the best decisions for my health.

To learn what I can do to keep my teeth healthy

Prevention is the first step to ensuring that I don't have more serious dental issues pop up.

To make sure that I am healthy

Preventing is wiser than fixing a problem after it happens.

I believe if you know preventative treatments you can avoid worst problems

as i understand it, dental health can have a huge impact on your overall physical health

Dislike having a painful experience no matter what

Teeth is a very important issue for me. Having healthy teeth is for my health issue.

Having a low tolerance for pain, if the visit is a painful one, I would not look forward to returning.

Prevention is always the best medicine.

Because I'm weak against pain.

Understanding what the dentist and hygienist have to say provides the basis for my decisions regarding my dental health.

I know that if my mouth/teeth/gums are healthy, that won't contribute/will reduce my exposure to other diseases in the rest of my body. So I make sure to take care of my teeth and get dental regular checkups.

If I don't understand what they are explaining then I don't know the severity of the issue or what needs to be addressed.

I don't like pain

I am the one who will live with the consequences of my oral health :) It's important that I understand what I need to do to have healthy teeth.

If I don't understand my own oral health or the reasons for the recommendations given, I'm not motivated to maintain good oral hygiene after my visit. And I've had a lot of cavities so want to avoid any more!

I want to know if my teeth and mouth are healthy and if not, what I need to do to make it so.

Knowledge and purpose of what is being done. More than these six, the most important to me is the technical preciseness, fluidity of movement

and swiftness of the dentist.

I am most comfortable (less fear and stress) when I understand the situation, whether it is good news or bad.

I like to know what I can do to keep my mouth healthy so things don't become a bigger issue. Regarding seat comfort: this would have ranked a lot higher when I was pregnant!

It's important to me to learn what I should do differently or what I should continue to do to keep my teeth healthy and cavity-free. I like learning about new methods or technology they use to clean my teeth, too.

Dental Survey

Question One:

What best describes your role?

Answer Choices	Responses
Dentist	5 (45.45%)
Dental Assistant	1 (9.09%)
Dental Hygienist	2 (18.18%)
Dental - Office	3 (27.27%)
Other (please specify)	0 (0.00%)
Total	11

Question Two:

How long have you been in the dental industry?

Answer Choices	Responses
0 to 5 years	2 (18.18%)
6 to 10 years	2 (18.18%)
11 to 15 years	1 (9.09%)
Over 15 years	6 (54.54%)
Total	11

Question Three:

What technology or methods do you use to communicate to patients about preventative maintenance, health issues, etc., in the office? If possible, please name specific tools used.

Intraoral camera, digital X-rays, periodically take BP, drawings, photos on iPad, verbal explanations, and videos

Discussion, showing and explaining patient's x-rays to them, drawing pictures.

Verbal communication, demonstration on models of the mouth, drawings done chair-side with the patient, patient hand outs.

Intraoral camera photos, iPad app, books, website, models

SOLUTIONREACH, all in one patient communication. By text email or phone.

Verbal communication, digital radiographs on a portable pad, 3D models, brochures.

Show models of teeth, night guards, xrays, intraoral photos

We use adentrix computer system, and solution reach for emails, appointment reminders, text, and dentrix for xrays

X-rays, intraoral cameras, emails, website, electronic communication system, brochures and other printed information

Intra-oral cameras, x-rays, digital photos, study models, brochures

Oral hygiene product demos (eg. Sonicare, waterpik), internet (pictures or youtube videos), x-rays viewed on dentrix program

Question Four:

What is frustrating or problematic about current communication technology methods?

I have used various computer programs both animated and those using actors. Customizing them is cumbersome. Seems to take up to much time with the patient

Limited time with the patient to explain sometimes complex concepts.

Lack of efficiency, inadequate visuals, other models available are expensive. I know that patients will often not read the hand outs unless very motivated.

The app has been my favorite because I can manually toggle the switch to stop at certain points. Most just played videos and had a voice over.

Nothing, the best we have found so far!

The frustration isn't the tech (when it's functioning properly), it's the limited time available to explain to patients their needs.

Unsure if patient truly understands concept

Question Five:

What type of ongoing education do you participate in?

General dentistry con-ed

Continuing education lectures. Guest lectures brought in to our clinic. Home study on pertinent subjects.

CE lectures through UW Continuing Dental Education and WSDA (Washington State Dental Association), including the Pacific Northwest Dental Conference

All types of continuing education –mostly surgery related.

Richardson Group.

Dental association conferences, specialized continuing education courses, online courses.

CE regarding periodontal care, emergency care, CPR, communicating with patients

Question Six:

I would love for you to continue being part of my research. If you would like to participate further, please provide me with your contact information below. This will not be shared outside of my research.

I received four responses from this question.