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EXPECTATION MANAGEMENT IN A GLOBAL COLLABORATION PROJECT USING A DETERMINISTIC DESIGN APPROACH

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ABSTRACT

Expectation management in product engineering design aims at setting achievable goals for both customers and designers, while leaving room for creativity and passion. This is especially challenging in the global workplace. Using an example of a design project, the Dental Headrest project (DHR), this paper reviews how expectations were managed in a successful, collaborative project between the University of Tokushima (UT) and Massachusetts Institute of Technology (MIT).

The goal of the project was to design an innovative mechanism for the positioning a dental chair headrest so satisfy both the needs of a patient for comfort and a clinician for flexibility and access. The design team was formed with six students from the MIT MechE's Precision Machine Design class, while the challenge proposed by a UT team of dentists and design engineers.

The team followed a deterministic design procedure inducing understating the challenge and reviewing prior art, strategy and concept generation, detailed module design and fabrication and testing, culminating in presentation and documentation. Through the process was coordinated by online communication and collaborative working spaces which ensured real-time information transfer between the continents. The conclusion was a face-to-face meeting between the two institutions.

This DHR project resulted in an innovative design of headrest adjusting mechanism that was implemented in a prototype. Moreover, the students, faculty and clinicians benefitted from the experience of innovative design collaboration in a multidisciplinary, global team.

1 INTRODUCTION

Managing the expectations of both clients and designers is an essential part of every product design and development project, necessary in order to set attainable goals, while retaining space for passion and creativity. The "best designed" product will be deemed a failure if it does not satisfy the customer's true needs, which may not always be clearly expressed. Likewise, as the designer shares his experience and expectations this can broaden the solution space and catalyze the client to consider new possibilities. In truth, a well-executed process can make the combined dreams of both the customers and designers come true.

How does a designer systematically imagine and think about what a customer wants to his/her design? An answer to this question is to follow a deterministic design approach [Slocum 1992], which is taught in the MIT Precision Machine Design (PMD) class, number 2.75, and has proven to be effective as evidenced by many successful class projects [MA 2006]. This emphasizes a systematic, clear decision making process that continually seeks to minimize risk, as opposed to shoot from the hip design, while extracting the maximum from creative designers [Slocum 2005].

Clear communication within the design team and with the client is essential and in today's global workplace this poses challenges of time zones, languages and cultures. Using an example of design project, the Dental Headrest (DHR) project, this paper reviews how the management of expectations were controlled as part of an international, multidisciplinary global

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collaboration between the University of Tokushima (UT) and Massachusetts Institute of Technology (MIT).

First, this paper presents a brief overview of the PMD class, the deterministic design methodology, and the two types of supporting tools, namely PREP (Peer Review Evaluation Process) and FRDPARRC table [Graham 2007]. Then the paper covers the specific exemplary DHR project, which includes behind-the-scene commentary, and presents the results of this global collaboration.

2 MIT PRECISION MACHINE DESIGN CLASS OVERVIEW

This class delivers both a project-based engineering experience to students and solutions to real clients, while focusing on best engineering practices and fundamental design principles. The goal is to emulate a fast paced, professional R&D environment, where there is no room for excuses [DeLoughyry 1995]. The hypothesis in designing this course is that with advanced students, who are well on their way to becoming practicing engineers, collaborative projects aimed at solving real challenges can effectively advance both learning and research for students, clinicians and instructors.

To this end, since 2004 Boston area clinician-investigators have been paired with small teams of graduate and senior undergraduate students to develop proof-of-concept prototype medical devices for unaddressed clinical challenges. Each summer project proposals are solicited from the local medical community and a subset selected, based upon the potential to create novel hardware, for “pitching” to the class in the first week. Students make the ultimate selections and self-form into 3 – 6 person project teams. Then, partnering with their clinicians, teams begin a 14 week, industry modeled design process which is roughly broken into three parts:

1. Detailed problem understanding and investigation of prior art, followed by brainstorming of basic strategies for achieving the desired Functional Requirements (FR).
2. Selection of best strategy and development of concept embodiments, selection of the best, modularization of design and identification of the most critical module (MCM).
3. Detailed design, fabrication of parts, system assembly, testing, debugging and documentation and presentation.

A useful (and fun) tool implemented in the class is the FRDPARRC table, which partners with the deterministic design process. Each Functional Requirement (FR) leads to specific design parameters (DP), such as required torques, backed up by analysis (A) and referenced (R) information. However, then students are asked to investigate the possible risks (R) of failure and for each develop countermeasures (C).

Lectures on advanced mechanical design are delivered in conjunction with the design process during the first two thirds of the semester; the final third is focused entirely on completing and testing the prototype device. Teams receive a $3-4,000 purchasing and fabrication budget which is overseen by their team mentor.

Course instructors meet weekly with each team and serve as project managers/design consultants/mentors, demanding focus and passion. Documentation is emphasized and it is critical that team member and mentors maintain a notebook in which they record their contributions. A key element is the Peer Review Evaluation Process (PREP) which specifies that team members should first brainstorm/design individually and then, as a group, review each others’ ideas. PREP is an important catalyst of making the any design process more efficient by reducing the amount of discussion needed to converge on an idea.

An online Wiki is used as a collaboration and archiving tool. Students are encouraged to upload scanned notebook sketches, written test results, photos and videos as the design process progresses. This not only ensures intra team communication, but allows mentors to participate, regardless of geographic location [Wallece 1997 & 1998]. Three in-class design review presentations allow for the entire class to participate in the collaboration process [Bourne 2005].

Teams complete the semester by demonstrating their working prototype to an academic, clinical and industry audience and documenting their project with a publication quality research paper, which they are then encouraged to submit to a conference or a journal. Recently, the course model has been successfully extended to encompass other industry sponsored challenges.

Projects initiated in the course have generated pending patents, peer-reviewed publications, senior and graduate theses, and several funded start-up ventures. Both course alumni and their TAs often go on to work as mechanical designers in the medical device industry while research conducted in the course has helped clinicians advance their careers.

Table 1: Course Design Process Schedule

	Discovery		Design Engineering		Building & Testing
1	Opening	6	Select *Strategy* Identify FRs	10	Fabricate MCM Demo. MCM
2	**Clinician presentations** Form teams	7	*Brainstorm 3 Concepts* Bench-level prototype Select *Concept*	11	Fab. other modules **Present final design**
3	Define problem Review prior art	8	Begin solid model **Present 3 *Concepts***	12	Complete fabrication Integrate modules
4	Brainstorm *Strategies* Bench level experiment	9	Identify *most critical module* (MCM) & supporting modules	13	Complete prototype Test! Debug. Test!
5	**Present 3 *Strategies***			14	**Present Prototype** Document

3. DENTAL HEADREST PROJECT

3.1. PROPOSAL BACKGROUND

The first joint project between UT and MIT was conducted in 2005 and centered on the challenge of designing a robotic dental mill to precisely shape teeth to receive crowns [Ito 2007 & 2008]. The project was proposed to the PMD class as a part of the Dental Engineering joint research at UT and a novel prototype was successfully built within the 14 week class. Critical to the success of the project was the colocation of a UT faculty member at MIT during the whole semester, who mentored the project closely. In addition, a local dentist leant his enthusiastic support.

When international collaboration was again suggested, the authors again decided to collaborate in the space of dental technology, however this time it was not possible to locate a UT faculty member at MIT and, in addition, the MIT surgeon who originally helped with the milling machine project already left MIT and could not help with the project. Thus emerged the proposal to conduct a global collaboration experiment where the project sponsors would be in Japan and the design team in Cambridge.

Since project is competitive, with the final decision being made by the students, the discussion focused on getting not only practical topics but also topics in which students would be interested. As a result, two proposals were discussed with the MIT course staff: A dental wire bending machine and a multiple degree of freedom (DOF) dental headrest.

Wire bending for dental treatment is manually performed by a skillful dental technician, therefor it was proposed to design a table-top, computer controlled, dental wire bending machine. However, even though the idea of dental wire bending machine looked new, industrial 3D wire bending machines exist and simply creating a scaled-down version would not be seen as new and exciting by students. The other reason is feasibility.

The other proposal for the creation of a new dental headrest was also reviewed carefully by both MIT and UT course staff. A brief review of prior dental headrest technology indicated that there was room for a new direction. The following comments from Dr. Ed Seldin, retired from MIT's campus health service, convinced the team of the feasibility of DHR project:

"There are some good headrests out there and simpler designs seem to trump more complex ones in the field. There might be a high-end market for a headrest with the capacity to store the spatial coordinates for the positioning of patients of record - perhaps a menu of positions based on the procedure being undertaken and the dental location. The problem with most headrests is a lack of effective dampening, with jerky movement and loss of head support during some adjustments of position, especially with anesthetized or sedated patients. I have had occasion to envision a hydraulically actuated headrest coupled with a haptic interface/ joy stick controller and digital memory. "

The project was presented to the class in September 2011 and selected by a team who decided to call themselves "Smoothmotion," which gives an indication of their most important FR.

3.2. OVERVIEW OF DHR PROJECT

Correct patient head position is important for patient and clinician comfort and, ultimately, greatly affects the outcomes of dental treatments. The headrests of dental chairs should be designed to securely support the patient's head position while allowing frequent adjustments by the clinician. However, typical headrests in current dental chairs only permit adjustment about 3 DOF, which is not enough to satisfy the actual requirements of both patients and doctors, when considering ergonomics issues as well as clinical practices. Figure 1 shows the typical motions which are extension and tilt. The headrest can be extended along the neck axis by pressing the button and locked in position by releasing the button when the desired adjustment is reached. A lever at the headrest neck is used to release and lock position adjustment. Operation on headrest position adjustment requires both hands of the operator.

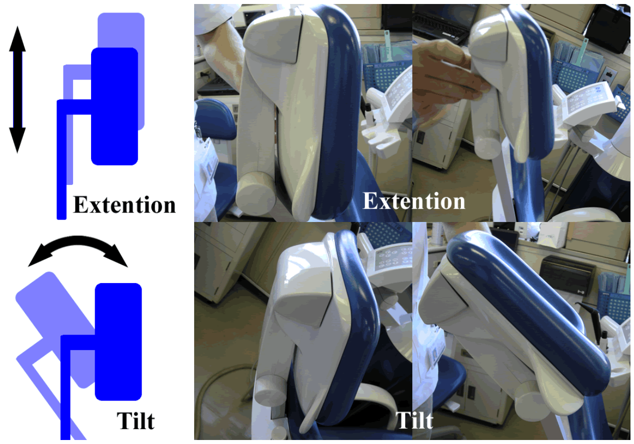

Figure 1: Typical headrest motion

Furthermore, positioning mechanisms often have too much friction in the joints so motion resolution can be limited and motion jerky. Clinicians desire to adjust the head position in an intuitive manner with an easy lock and release, was well as provide much more comfort to the patients. The main functional requirements initially identified were :

- Smooth positioning: The headrest should move easily from position to position with no apparent singularities.
- Quick and Easy position lock/release: A single action should release the mechanism to enable its repositioning.
- Stable and precise positioning: Once the position is fixed, it should be locked firmly and securely.
- Head position sensing: Position sensing might be required in order to implement a computer controlled dental treatment support system. This was not a mandatory requirement.

These customer requirements were provided to the MIT team by UT team and careful discussions were made to develop a shared understanding among the members of both teams. The resulting mission statement of DHR project was: *To develop a dental chair headrest with intuitive, continuous, and smooth adjustability, which facilitates head positioning that is comfortable for both patient and dentist.*

3.3. GLOBAL COLLABORATION ON DHR PROJECT

The DHR project was conducted as an international collaboration between UT and MIT. The MIT student team was composed of six undergraduate students from Department of Mechanical Engineering at MIT under the supervision of the MIT course staff. The UT team was composed of Graduate students of Department of Dentistry under the supervision of UT staff from Department of Dentistry as well as Mechanical Engineering. Additional support was provided by Dr. Grace Collura, head of MIT campus dental service, who provided medical user input to the MIT team.

Even though DHR project was an international project, the project schedule and procedure followed that of all the other class projects.

The only difference from other 2.75 projects was that Smoothmotion team and UT clinicians were located on opposite sides of the globe. Therefore, weekly regular project meeting between MIT/UT teams were held using video conference and email, and data/information was shared via the secure MIT Wiki site. This occurred in addition to the regular weekly regular meetings between the MIT student team and staff and in class presentations.

3.4. DHR PROJECT FINAL PROTOTYPE

The project was conducted based on the deterministic design methodology, which is taught in 2.75 class, and the final prototype was designed/built at the end of the semester, of which photo is shown in Figure 2.

The core idea of the proposed design is based on jamming media technology with headrest ergonomics to provide a headrest that is intuitive, continuous and smooth, facilitating comfortable head positioning for both patient and dentist. The headrest uses a vacuum regulation system to achieve rigidity in an otherwise flowing media which allows six degrees of freedom to the headrest. The headrest consists of two main modules, or a extension module and a bag joint. The extension module provides one degree of freedom in extension along the neck's axis. The bag-joint, which is continuously adjustable, provides the remaining five degrees of freedom, including three rotations and two translations. An ergonomically friendly handle allows one handed control of the system, which a dual button release ensures a firm grip on the handle before the vacuum on the system is released and structure lose rigidity.

According to the demonstration video clips, the UT team confirmed that the customer requirements given by UT were mostly fulfilled in the prototype. Two kinds of design updates, or extension mechanism and single hand operation, were also implemented in the final prototype as discussed in the final meeting. However, direct feedbacks of bench-level experiments which show the stiffness longevity and instantaneous force behavior could not be confirmed in the video clips. Therefore, UT team concluded that attendance at the final meeting was the only solution to confirm ergonomic function.

Figure 2: Final Prototype

The final class presentation was held in December, 2011 at MIT campus, hosting all of the team members, clinicians, teaching staffs and invited guests. The presentation covered the 5 final presentations from the energy focused topics and 9 final presentations from the medical focused topics.

4. EXPECTATIONS IN EACH STAGE OF THE DETERMINISTIC DESIGN PROCESS

Deterministic design methodology played a key role in design and project management of DHR project. If a design concept could not be rapidly verified by analysis or experiment, it was dropped from consideration.

4.1. PROJECT TEAM FORMATION TO MANAGE EXPECTATIONS IN PROBLEM UNDERSTANDING

A presentation covering the overview of projects, explaining their problems and significance was presented to students by clinicians in the beginning of 2.75 class. Considering the clinicians' presentations, the students select the projects on which they would want to work and form teams. This procedure provides two advantages. Each team selects a favorite project which helps to increase the motivation of the student team. In addition, clinician take great care to present their product desires so that their problem will be selected by one of the teams. As a result, the matching of student team and a clinician(s) increases the motivation on both sides, and leads to the better teamwork activity [Byrd 1995; Dertouzos 1989; Simon 1996] through out the semester.

This matching structure applied to the DHR project as well and worked effectively to share common understanding, considering the expectations on each side towards the common goal. One of the characteristic features of the DHR project was that it was an international collaboration project across the globe between the two different cultures, institutions and languages. Therefore, both teams tried to understand each other's expectations, both technical and professional. This expectation understanding worked effectively towards the success of DHR project.

4.2. SCHEDULE EXPECTATION FOR THE GLOBAL DHR PROJECT

At the time of project proposal presentation, no UT staff could be in residence at MIT, so UT staff prepared a presentation and MIT staff made the presentation in the class. After the project was selected, MIT and UT teams worked together.

A regular weekly meeting was held using a video conference system (Skype) between the campus of MIT and the two separate campuses of UT, which means that a three site-connection was used. The time difference between UT and MIT is 13 hours during summer and 14 hours during winter. When the project started, a regular meeting was scheduled at 8:30JST or 19:30EST on weekly basis. Even though MIT team members attended the meeting, it was hard for UT team members to regularly attend the meeting because of the conflict of other local meetings and clinical schedules.

Even though the time difference is one of the difficulties to overcome in global collaboration, MIT/UT teams generally managed the difference very well. However, one episode happened in November. Generally, both MIT/UT team members were on-line and waited for the starting time 5-10 min. prior to the meeting time in every week. However, one day in November, the UT team did not find the MIT members on-line even after 15 min. passed without any notice or e-mail messages, which had never happened before. There was no reply to an inquiry message sent by UT team to MIT team. If an attendee does not appear in the meeting at the time of appointment, the meeting may be automatically cancelled in most of the cases. However, UT team had a feeling that there must be a reason why the MIT team did not show up because the meeting was expected. 30 min. later, a message delivered from MIT team to UT team, explaining the time change of 1 hour delay due to daylight savings time, which is an uncommon custom for the UT team in Japan. Expectation in the DHR project time schedule worked appropriately to comply with the delay of meeting time one hour later.

4.3. PROBLEM UNDERSTANDING AND FUNCTIONAL REQUIREMENT IDENTIFICATION

The project desires were shared among the team composed of students and clinicians, but it was hard to share details over the video conference, and this is where the Wiki helped greatly. The MIT/UT team shared, for example, pictures of existing headrests in the UT hospital, brochures of dental chair products, and video clips showing a simulated scene of UT hospital. Even though the clinicians at UT did not use the definition of functional requirements, what is required in the clinic was clearly presented to MIT team. The video clip presentation proved to be the most effective method to show the requirements, even though its preparation took much time and effort.

After sharing the basic idea of problem in the project, further web based meetings made the functional requirements clear to the SmoothMotion team so it could work on its design.

Smoothmotion team expectation: The team used as a benchmark a current product on the market made by Sirona, which is very flexible in adjusting. Their goal was to design a more flexible and innovative product.

UT expectation: Research topic proposal was based on clinical experiences and the UT team was not aware of the Sirona product at the time of proposal.. When UT reviewed the benchmark product presented by MIT team, it was confirmed that the adjustable movement of SIRONA is good but does not fully satisfy the requirements.

For both sides, the expectation was it should be possible to design an innovative new dental headrest.

4.4. MANAGEMENT OF EXPECTATION IN DESIGN STRATEGIES AND CONCEPTS

In deterministic design, the methods can be applied at each step along the way. Smoothmotion team followed the step of deterministic design ranging from coarse to fine, creating possible strategies, concepts, module and component.

As a result, the team proposed three concepts, which are ball joint, hexapod, and jamming.

Figure 3: Proposed concept: ball-joint

The first concept, based on ball joints [Drutchas 1991], is similar to the bone structure of an arm with shoulder and elbow joints replaced with ball and pin joints, respectively. The serial mechanism achieves the required range of motion through combination of rotations allowed by the joints. Figure 3 shows the example image of this concept.

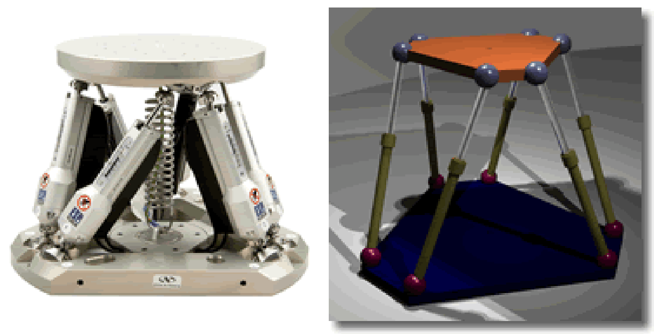

Figure 4: Proposed concept: hexapod

The second concept, a hexapod [Newport 2009], supports the headrest by six links working in parallel, allowing triangulation of three points in space while deterministically defining a plane. Figure 4 shows the example image of this concept.

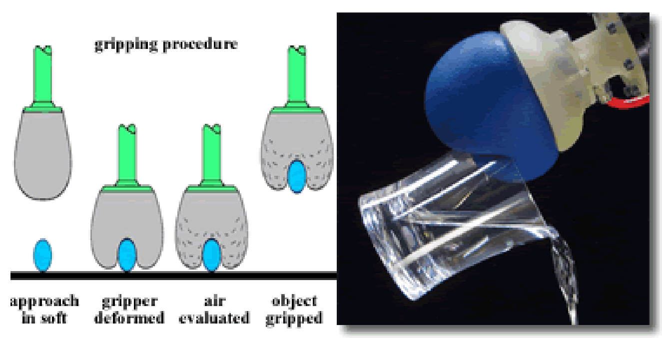

Figure 5: Proposed concept: media jamming

The third concept, based media jamming [Brown et al. 2010], uses granular media subject to a critical compressive stress to form a pseudo-solid. It is possible to rapidly switch a cleverly designed support from free-forming and freely adjustable to rigid, pseudo-solid by just applying an appropriate vacuum. Figure 5 shows the example image of this concept applying to robotic arm gripper.

Smoothmotion team built three concept prototypes based on these initial concepts, and posted them to the Wiki for the

UT team to review prior to an on-line design reviews. Power point slides and descriptive explanations were first used to share the idea among the MIT/UT teams. However, it was very hard to share the concept ideas with slides. Therefore, just as UT team did in problem presentation, video clips of physical sketch models were prepared by the MIT team and shared with UT team. Since the motion of the headrest is critical to understand the proposed concepts, video clips worked effectively. In this way, design reviews of the concepts were undertaken by MIT/UT team members. Questions posed by the UT team included:

Q1) According to the video, hexapod and ball-joint types are too bulky and it may become a problem in clinical operation. The size of Jamming type looks like the most suitable one judging from the video clips.

The sketch model prototypes recorded in the video clips were made to show the mechanism idea. Therefore the SmoothMotion team did not pay too much attention to appearance and size. However, the clinicians of UT team saw the mechanism and also focused on the expected final imaginary product from the video clip.

This led to a perception of unmet needs. The expectation at the concept model stage of SmoothMotion was somehow different from that of UT, which thought a misunderstand occurring. However, the comments from the UT team provided what is required, or expected by the customer to the SmoothMotion team, which then worked successfully to share their idea of customer expectations in the DHR project team. Back-and-forth discussions include:

Q2) We cannot see the locking mechanism of Jamming type. Please explain to us about that.

UT Expectation: Locking mechanism is critical and expected to be implemented.

Q3) Is it possible to install a lock button on the back of the headrest, as is similar to the existing headrest?

UT Expectation: Usability of simple operation is expected.

Q4) Would it be possible to make downsizing of the connecting part between the chair and headrest? The ideal size would be similar to the existing headrest.(this is related to 1))

UT Expectation: Compact design is expected.

Q5) The level of compressor noise sounds larger that the current level. Would it be possible to decrease the noise level and keep it much quiet?

UT Expectation: Comfortability for both doctors and patients are expected.

Q6) Please show us the actual adjustable area in each prototype.

UT Expectation: Functional requirement fulfillment is expected.

Q7) As far as we can see from the videos, jamming type is the most favorable one.

UT Expectation: Innovative idea and compact design are expected.

4.5. MANAGEMENT OF EXPECTATION IN PROTOTYPE SYSTEM

Based on the best concept selected, SmoothMotion built a working prototype and presented it to UT team by way of video clip demonstration. It was confirmed that the prototype basically met the functional requirements given by UT team. However, the following two points were found be inadequate: extension mechanism and single hand operation.

Since the extension mechanism of 100mm translation along the neck axis was a required specification, the implementation of this mechanism was requested. Even though the final presentation was scheduled in 2 weeks ahead, SmoothMotion team decided to work on the implementation of that function. Reviewing the feasible candidate design ideas considering the project time limit, an additional linear sliding mechanism was designed to make the extension and added to the prototype.

The prototype on the video clip also showed two-hand operation for position adjustment because of the multiple buttons to control the vacuum lock of the media. After additional engineering work was completed on the prototype, a single hand operation was realized.

The expectation of the UT team was well understood by the SmoothMotion team, not only through the design to manufacturing stage, but also in the rework on the final prototype. It was recognized that the SmoothMotion team tried to meet the expectations of the UT team and the UT team believed that the SmoothMotion team could comply with its expectations. At first, the UT team was not aware of the deterministic design process used, the SmoothMotion team followed the deterministic design process, which helped to achieve the goals of the project, and thus helped the UT team to also learn the deterministic design process.

4.6. EXPECTATION OF OFF-LINE MEETING TO FIND AN UNSOLVABLE SOLUTIONS ON-LINE

Mechanism and function were mostly understood by using video clips along with figures, photos, written descriptions and oral explanations. However, the following points were not well understood by the UT team.

According to the bench-level experiment, the headrest becomes very stiff after vacuum is applied and could support the patient head appropriately. However, how long does it keep the same stiffness? Does the stiffness decrease over time? When an impulse force is applied to the headrest, which could occur during clinical treatment, what would happen?

As for the single hand operation to adjust the headrest position, which is one of the critical requirements, the operation looked possible. However, how easy it is to make adjustment? How long does it take the vacuum to make the headrest stiff after adjustment?

Both the MIT and UT teams expected to carry out the DHR project online as far as they could. On the other hand, they also expected have an off-line meeting to directly share the project achievements. In the event of difficult understanding on-line, one of the solutions is to hold an off-line meeting.

4.7. EXPECTATION TO MEET IN THE FINAL PRESENTATION

The 2.75 final presentations were held at MIT in December 2011, where the teams demonstrated prototypes to the class, instructors and invited visitors who signed non-disclosure forms so IP rights could be maintained before patents were applied for if required. In the session, teams (including clinicians) respond to questions from the audience, and audience feedback is formally provided to teams.

In order to clarify the questions mentioned in the previous section, a UT staff attended the final presentation. Since this was the first face-to-face meeting, both the team and UT were quite excited to share ideas, review, experiences, and results. Even if audio-video communication and information/data sharing is available over the network, face-to-face meetings cannot be replaced by any other media, which was recognized in the final presentation. In the end it is hard to share a teambuilding meal or toast via the internet!

5 CONCLUSIONS

This paper presented the case study of dental headrest design project under international collaboration between the University of Tokushima and Massachusetts Institute of Technology. The project was conducted based on managed expectations and deterministic design, starting from design strategy, followed by concept design, module design and engineering, prototype building and test, and design reviews. This paper showed how expectation management was well organized and was used successfully during of the development of the DHR project, which has led the project to success in terms of product development as well as PBL-based education [Sheppard 1998]. Deterministic design is taught in 2.75 as a methodology towards engineering design. However, this project showed that deterministic design approach could also work effectively on project management in a global collaboration project between two different cultures. The effectiveness of the approach was proved by the success of DHR project, which achieved the final goal of innovative design on dental headrest within a limited time allotment with highly satisfying the customer requirements.

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