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Design of Engineering Courses as a Service: Emotions, Senses and Implementation*

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Though university education is part of the service economy, there have been limited service-oriented studies on university engineering courses. Those focused largely on Kano's basic and performance needs. We used Axiomatic Design to identify two broad classes of Kano's excitement needs for engineering courses: emotional and sensory input. These needs were found to be common elements in extraordinary engineering classroom experiences. We created prototype Functional Requirements (FRs) and Design Parameters (DPs) that a course designer can use to support the insertion of these Kano excitement needs into an engineering course. We redesigned a sophomore-level open engineering course at KAIST (Korea Advanced Institute of Science and Technology). The new design was implemented and evaluated in a class with 109 students. There were statistically significant improvements in the official course evaluation scores and a separate satisfaction survey. Unusual written communications were received from about 7% of the course students. The results were replicated in subsequent semesters. The use of these broad classes of excitement needs appears to meaningfully increase student satisfaction in engineering courses. We hope that the design guidance developed can also be used to insert excitement needs into emerging learning approaches such as inverted classrooms, project based learning and MOOCs.

Keywords: engineering education; Axiomatic Design; service experience; service-oriented design; engineering of education

1. Introduction

Educational systems are vital to our modern societies and there have been many efforts to improve them. However, as highlighted in [1], the fact that education is economically classified as a service [2] is often overlooked. While some recent efforts have studied university education as a service, they largely focus on Kano's basic and performance needs.

Our goal is to identify Kano excitement needs that can exploited in the engineering classroom to delight students. We use Axiomatic Design [3, 4]. From our benchmarking, we observed that cognitive and learning style issues address basic and performance needs. However, emotional and sensory needs enable high quality courses to transcend normal expectations and reach toward the extraordinary. We develop prototype functional requirements (FRs) and design parameters (DPs) for course experiences.

The prototype FRs were used to redesign an elective sophomore-level engineering course at KAIST (Korea Advanced Institute of Science and Technology) that had been taught by the same instructor annually since 2008. The course had received good course evaluation scores averaging 4.42/5.00 from 2008–2012 and was thus meeting most basic and performance needs. The new design, focused on emotional and sensory excitement needs, was implemented in the Spring 2013 semester. The mean course evaluation score exhibited a statistically significant increase from 4.47/5.00 in 2012 to 4.67/5.00 in 2013. A separate satisfaction survey exhibited similar statistically significant improvements. Further, there were unusual written communications received from about 7% of the students in the course. Similar results were obtained in subsequent offerings of the course in 2015 and 2016.

The engineering classroom is typically approached as a means to deliver knowledge and develop skills in students. However, there is evidence (e.g., [5–8]) that extraordinary course experiences or active learning environments can have lifelong impact on student perspectives. We developed methods that can be used to create extraordinary and memorable educational experiences. While our focus is on traditional classrooms, the methods may apply to educational services such as

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inverted classrooms (e.g., [9]) and project based learning environments (e.g., [10, 11]).

The paper is organized as follows. Relevant literature and contribution are reviewed in Section 2. In Section 3, stakeholder needs and benchmarking are discussed. In Section 4, the prototype FRs and DPs are provided. The redesign of a course at KAIST is discussed in Section 5. In Section 6, we statistically evaluate the new course design (including replication). Concluding remarks are provided in Section 7.

Some of the discussion and design ideas in this paper first appeared in abbreviated conference form in [12]. Many new results and commentary are included here. Section 5 is significantly expanded relative to the content in [12] and provides stepwise guidance for developing FRs and DPs as well as additional commentary. Section 6 includes statistical analyses and results that were not available in [12]. There are many more references.

2. Relevant literature and contribution

In this section, traditional and service-oriented efforts in education are discussed, along with formal design methods that have been used for service.

2.1 Educational literature

There is a vast body of work on education. In the traditional literature, two essential ideas are knowledge taxonomies (e.g., [13]) and learning styles [14]. We discuss them in the sequel and include them in our prototype FRs.

There have been more recent efforts that focus on the role of emotions in education and highlight that emotions play a fundamental part of the educational experience ([2]). Theories on the manner in which emotion can influence the learning process have been considered. For example, in [1], three motivational theories were considered and the authors argued that emotion is an essential component of motivation and instructional interactions. Much work has investigated how negative emotions, such as shame, and their opposites, such as pride, can influence learners. See, for example, [3, 4]. It is clear from the literature that emotions influence the process of learning; see, for example, [5]. Some efforts have been specifically directed toward interpreting the role of emotions in adult learners. In [6], for example, the authors suggest that learners can understand their own feelings toward learning specific topics, or in general, through means such as story-telling and dance.

It is clear that emotions play a key role in education and should be considered in course design.

2.2 Service perspectives in education

As part of the service economy, the tools of service science are applicable to engineering education. While tools such as SERVQUAL (e.g., [21, 22]) and SERVPERF (e.g., [23, 24]) have been used for education (e.g., [25, 26]), they focus on identifying problems. As we seek to design education as a service, needs identification methods such as the Kano needs model [27] are most relevant.

[28] and [29] conducted Kano needs classification for university courses. [30] combined many service-oriented methods including a relative of SERVQUAL, Kano needs and QFD to develop an eleven step procedure for improving teaching quality in classrooms. Their focus was on improving courses to achieve good quality via basic and performance needs.

[30–32] studied a few Kano excitement needs for university courses. These included humor and enthusiasm, which are known to be effective tools for the classroom; e.g., [6, 33, 34].

2.3 Formal design in services

General design methods for services have been proposed, e.g., [35–37]. The work of [36] suggested propositions that guide the development of experience-oriented services. Their discussion on emotional connection and sensory experience support our conclusions. Formal design methods were used to improve customer satisfaction in university education. Quality Function Deployment (QFD) (e.g., [38] or [39]) was used in [40–44]. They focused on basic and performance needs. General design approaches for university education have been pursued, e.g. [45, 46]. User-centered design methods have somewhat recently been used with great success; e.g. [47, 48].

We focus on the use of Axiomatic Design (AD) for engineering education. AD provides a scientific method for design; e.g. [4, 5]. [49, 50] used AD to develop a course and an on-line education platform for mechanical design courses. [51, 52] were the first to apply AD to general education systems. They developed FRs for basic and performance needs including grading, content, and lecture. We build upon them here.

2.4 Contribution

Excepting a few studies, such as [30–32], the service-oriented efforts to improve university classroom experiences have focused on Kano's basic and performance needs. The focus in [30] was to develop a method that can be used to improve courses toward good performance. In [31], some specific Kano excitement needs were identified for the classroom. In [32], a few classroom excitement needs were identified and optimization methods were used to identify the correct intensity for the needs.

Our goal is to help transform a good engineering classroom so that it rises above the ordinary. We use AD as it is considered by some to be helpful for creating new and distinct conceptual designs [53].

Our contributions follow. We:

- Observe that strong emotions and senses are common threads in extraordinary lectures and services (Section 3);
- Develop prototype FRs and DPs for service oriented engineering courses (Section 4);
- Discuss how emotional and sensory FRs can be used in an existing course (Section 5.1);
- Redesign an existing engineering course to include these service-oriented FRs (Sections 5.2 and 5.3); and
- Discuss the implementation of the new design and review the statistical significance of the results (Section 6).

3. Stakeholders and benchmarking

We use Axiomatic Design (AD) [4, 5]. Following a stakeholder analysis and benchmarking process, we identified 259 Customer Needs (CNs). These needs were used to construct prototype FRs that can in turn be used to develop DPs. We next review the CNs and mention key findings.

3.1 Background research

Many resources were considered. We mention them and highlight key observations.

3.1.1 Source material

Students, professors, teaching assistants, course designers, accreditors, department staff, university administration, educational researchers, parents and society itself are all stakeholders of an engineering course. To identify the stakeholder concerns, we considered nine categories of source material:

- Materials from famous traditional courses ([9]) and acclaimed on-line lectures (e.g., [6, 54]);
- University student surveys;
- Prior course evaluation survey scores and comments;
- Interviews with the Dean of Education at KAIST;
- Interviews with professors who have received excellent teaching awards from KAIST;
- Articles and videos about teaching (e.g., [55]);
- Books on teaching authored by celebrated professors ([8, 56–58]);
- Guidelines for presentations ([59–63]) including the use of surprise, emotions and visuals;
- Academic literature on service ([27, 64-67]) and education; and
- Academic literature on emotions/senses (including [68]).

3.1.2 Key observations

Knowledge taxonomies and learning styles are fundamental. Less traditional goals are emerging, e.g., [69]. [26, 56–57] focused on the student experience and considered the student as a customer.

Certain courses exploit the emotions of surprise or amazement. Donald Goldstein at the University of Pittsburgh uses a variety of costumes [56]. In Walter Lewin's MIT physics course [6], he rides on a huge pendulum, "risks" having his head crushed, fires a golf ball from a gun and rides on a tricycle powered by fire extinguisher. Randy Pausch destroyed a fax machine with a sledgehammer in his course [8]. Dudley Herschbach has used philosophy quotes to motivate his chemistry course at Harvard [56]. The explosive reaction caused by combining alkali metals with water is very surprising [70]. These are much like the "star moments" suggested by the study of TED talks in [63].

Other emotions have been used as well. Humor is well known to improve student outcomes; e.g., [33, 34]. In Colman McCarthy's course at the University of Maryland [9], horror and pity have been used to express the plight of animals.

A common thread that weaves through these extraordinary educational experiences is the deep exploitation of emotion. Emotion is a key component of other services such as theatre, literature, movies and music. In that context, depth of emotion plays a significant role in determining customer satisfaction [71]. Customer service representatives, such as those at banks or call centers, use intentionally cheerful voice and facial expressions to manipulate customer emotions [72]. The process of transferring one's emotional state is referred to as emotional contagion in [73]. Emotions are considered important in experience-oriented services [36].

Senses are used in these courses to magnify the effect of the desired emotion. The loud demolition of the fax machine [8], explosion caused by alkali metals and water [70] and arresting images of the skinned cattle [9] significantly increased the effectiveness of the desired emotion. Stimulation of senses has also been used to improve general service delivery. Restaurant ambience and meal appearance increase customer satisfaction. Scent is commonly used in retail environments to influence customers and develop brand loyalty [74]. Popcorn and soft drinks are essential elements for some theatre customers. Sensory experience design is highlighted as important in [36].

We do not conduct a Kano needs classification for all emotions and senses. However, the literature suggests that they would be classified as excitement needs. In [30], "multimedia application", "comfortable environment" and "rapport" were identified as excitement needs. "Friendly communication" between professor and students was identified in [29]. In [32], "humorous professor", "candy", "professor enjoys teaching", and "personal connection" were identified as excitement needs among others. These directly or indirectly relate to emotions or senses. As such, there is support for the consideration of these broad categories of needs as excitement needs.

The use of emotions and senses appears to be a hallmark of extraordinary university courses. This dovetails with suggestions for presentations in general, e.g., [59–63]. However, emotions and senses have been used in an ad hoc fashion. We provide guidelines to insert emotion and senses into a course so that it may rise beyond an ordinary experience.

3.2 CNs

From the background research and stakeholder analysis, we developed a list of 259 distinct Customer Needs (CNs). (While they are omitted here for brevity, they are available from the authors upon request.) These motivated our functional requirements structure. We next provide an overview of key categories.

3.2.1 Cognitive domains for learning

In traditional course design, cognitive domains should be selected. In [13], the cognitive domains are: knowledge, comprehension, application, analysis, synthesis, and evaluation. These are generally considered as a hierarchy with knowledge at the bottom and evaluation at the pinnacle.

In undergraduate engineering education, the higher cognitive domains have been emphasized by Accreditation Board for Engineering and Technology (ABET) requirement of freshman design and senior design projects; e.g., [75–77]. Lab and design activities are commonly included in university engineering education and target the application and analysis domains; e.g., [78, 79].

The development of the cognitive domains will be explicitly included in our prototype FRs for an engineering course. These FRs target the usual course content and follow the approach of [51].

3.2.2 Learning styles

Students may have different learning styles. While there is much debate on learning styles, [14] provides seven categories: visual, aural, interactive, haptic, kinesthetic, olfactory, and print. We include taste to be complete.

3.2.3 Emotions

The stimulation of emotion is a hallmark of existing extraordinary engineering courses. In [68], a hierarchy of emotions was provided. At the top level are anger, fear, joy, love, sadness and surprise. There are three layers with increasing levels of detail; see [68].

It is clear that emotions can be exploited to dramatically increase the affective connection students feel with course material. By recognizing and considering the class of all emotions as candidate tools for improving a course, a broad array of options for transforming normal material into memorable experiences becomes available. A key issue is that the emotions should be well connected to the material and serve a purpose related to it. We will discuss these points in more detail in the sequel.

3.2.4 Senses

Based on insight from extraordinary lectures and learning styles, it is essential for a course to include content that stimulates a variety of senses. The use of sensory input can magnify emotion, vibrantly illustrate a point and influence the mood of students. To encourage this, we explicitly provide mention of the candidate senses in our prototype FR and DPs. The five senses are: touch, taste, sight, smell and hearing.

The stimulation of senses can be conducted directly in relation to the course material. For example, when connecting a humanitarian application to the course material, the instructor may employ visual images (sight), short powerful text (sight), a sorrowful voice (hearing) and emotional background music (hearing) to intensify a feeling of sadness or pity. (The connection between music and emotion is discussed in, for example, [80]).

Sensory stimulation can be used in an indirect way to support the service-oriented environment. For example, fresh coffee for early students (taste and smell), clean and sparkling desks (sight), fresh scented air (smell), candy for asking a question (taste), comfortable chairs (touch) and soothing background music before class (hearing) may help to create a more receptive student. The use of sensory input to facilitate service objectives has been reported in numerous service industries, e.g., [36, 81–83].

4. Prototype FRs and DPs

In AD, FRs describe what functions the service/product must accomplish. DPs detail how those functions will be provided. FRs are a "minimum set of independent [functions] that completely characterize the functional needs of the" product or service [4]. As discussed in [5] and [31], FRs are solution neutral, clear and specific, equally important (no ranking between the FRs), structured with a logical hierarchy, mutually exclusive (independent), collectively exhaustive, stated in the positive and start with a verb.

Based on our CNs and building on the work of [49–51], we developed prototype FRs and DPs. Refer to Table 1a and 1b. They are a structured list of topics from which the designer selects the goals they seek to achieve. For those conversant with the AD methodology, these prototypes can be readily inserted into their design process. For those not well versed in AD, these can be used by simply selecting functions/solutions as desired.

In Table 1a, the notation MKT FRi21 indicates, for example, that a similar FR was proposed in [51] (MKT are the initials for the first author). The use of these will be illustrated in Section 5. The prototypes of FRs are not particularly detailed; that is, they are intentionally generic so as to be used for the design of any course. FR/DP pairs should be selected as desired.

Prototype DPs are provided for each FR and can be interpreted as a "method to provide" the FR. The course designer should select specific DPs considering the course topics and desired context. These are largely placeholders.

We now provide detailed discussion of the prototype FRs and DPs.

- FR0 ensures that students understand the overall structure of the course (i.e., how the topics in the course are interlinked). This FR is FRi22 in [51].
- FR1i ensures the material for each topic i is absorbed by the students. We locate the cognitive domains of [13] as the children of each of these FRs. Learning styles appear as the children FRs of each of the cognitive domains. They arise from

Table 1a. Prototype FRs

FR0: Establish student understanding of course knowledge (content) map (MKT FRi22)
FR0.1: Create student concept of course knowledge (content) map
FR0.2: Populate the map with the course ideas and connection
FR1: Establish cognitive domain for course
FR1i: Establish cognitive domain for topic i
FR1i.1: Establish knowledge domain for topic i
FR1i.1.1: Enable visual learning of knowledge domain for topic i
FR1i.1.2: Enable aural learning of knowledge domain for topic i
. . .
FR1i.2: Establish comprehension domain for topic i
. . .
. . .
FRA: Evaluate course quality
FRA.1: Evaluate student learning
FRA.2: Evaluate student satisfaction
FRB: Establish connection between course topic and student concerns topic
FRB.j.k: Establish connection between course topic j and student concerns topic k
FRC: Magnify the intensity of student emotions associated with specific ideas
FRC.1m: Magnify the intensity of student emotions associated with course topic m
FRC.1m.1: Magnify the intensity of student joy associated with course topic m
FRC.1m.1.1: Magnify the intensity of student joy associated with course topic m via visual aid
. . .
FRC.1m.1.6: Magnify the intensity of student joy associated with course topic m via print
FRC.1m.2: Magnify the intensity of student sadness associated with course topic m
. . .
FRC.2: Magnify the intensity of student emotions associated with ideas related to the overall course
FRC.2.1: Magnify the intensity of the student emotion (fear) associated with the possibility of a poor evaluation in the course (MKT FRi21)
FRC.2.2: . . .
. . .
FRC.3n: Magnify the intensity of student emotions associated with life topic n
FRC.3n.1: Magnify the intensity of student joy associated with life topic n
. . .
FRC.3n.2: Magnify the intensity of student sadness associated with life topic n
. . .
. . .

Table 1b. Prototype DPs

- DP0: Methods to establish student understanding of course knowledge (content) map (MKT DPi22)
  - DP0.1: Methods to create student concept of course knowledge (content) map
  - DP0.2: Methods to populate the map with the course ideas and connection

- DP1: Methods to establish cognitive domain for course
  - DP1i: Methods to establish cognitive domain for topic i
    - DP1i.1: Methods to teach knowledge of topic i exploiting learning styles
      - DP1i.1.1: Visual aids on knowledge of topic i
      - DP1i.1.2: Aural aids on knowledge of topic i
      - . . .
    - DP1i.2: Methods to make student understand knowledge of topic i exploiting learning styles
      - . . .
      - . . .

- DPA: Methods to evaluate quality
  - DPA.1: Methods to evaluate student learning
  - DPA.2: Methods to evaluate student satisfaction

- DPB: Methods to establish connection between course topic and student concerns topic
  - DPB.j.k: Methods to establish connection between course topic j and student concerns topic k

- DPC: Methods to magnify the intensity of student emotions associated with specific ideas
  - DPC.1m: Methods to magnify the intensity of student emotions associated with course topic m
    - DPC.1m.1: Methods to magnify the intensity of student joy associated with course topic m
      - DPC.1m.1.1: Vision based methods to magnify the intensity of student joy associated with course topic m
      - . . .
      - DPC.1m.1.6: Print based methods to magnify the intensity of student joy associated with course topic m
    - DPC.1m.2: Methods to magnify the intensity of student sadness associated with course topic m
      - . . .
  - DPC.2: Methods to magnify the intensity of student emotions associated with ideas related to the overall course
    - DPC.2.1: Provide penalties for failure to learn (MKT DPi21)
    - DPC.2.2: . . .
      - . . .
  - DPC.3n: Methods to magnify the intensity of student emotions associated with life topic n
    - DPC.3n.1: Methods to magnify the intensity of student joy associated with life topic n
      - . . .
    - DPC.3n.2: Methods to magnify the intensity of student sadness associated with life topic n
      - . . .
      - . . .

their inclusion as DPs of the cognitive domain FRs. This structure includes FRi3, FRi4 and FRi5 from [51].

- FRA ensures the quality of the course. This FR includes obtaining student opinions on the course and evaluation of student learning. It corresponds with FRi6 of [51].
- FRB intends to connect the course material with topics the students care about. These may include everyday materials as in FRi23 from [51] and many more.
- FRC is to intensify the emotions associated with specific ideas. The stimulation of specific emotions appears as children of FRC. The stimulation of senses appears as children of these specific emotional FRs. They arise from their inclusion as DPs of the emotion FRs. There are three categories of emotions one may seek to stimulate (see Table 1a, FRC.1, FRC.2, and FRC.3). FRi21 of [51], where emotions such as fear are connected with a particular course administration component (i.e. grades), is an example of this broad class of functions.

The prototype FRs and DPs provide generic guidance and structural placeholders. Specific DPs and topics should be selected to create a specific course. The FRs and DPs must be distributed across each lecture and throughout the semester.

5. Application to an engineering course

Here we discuss the redesign of IE200 Introduction to Operations Research, a sophomore level general elective engineering course at KAIST. In Section 5.1, we provide general guidance on how to develop emotional and sensory FRs and DPs to complement the course material. We describe a revised lecture in

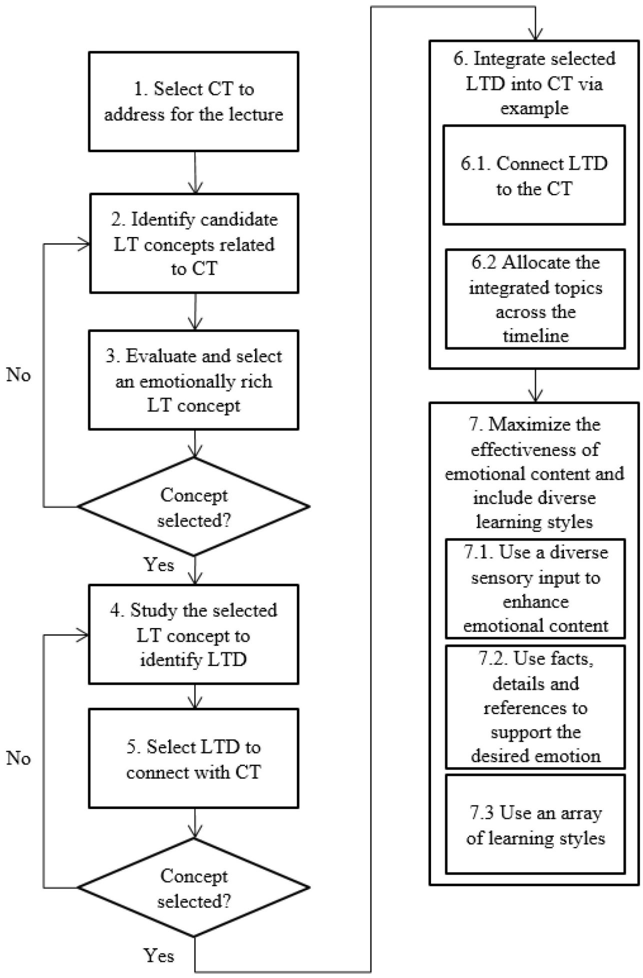

Fig. 1. Stepwise guidance for selecting FRs and developing DPs.

Section 5.2. Discussion regarding how to effectively inject emotional and sensory content with minimal time commitment is provided.

5.1 Guidance for selecting FRs and developing DPs

Figure 1 provides guidance on how to incorporate emotional and sensory content. There CT, LT and LTD are short for course topics, life topics and life topic details, respectively. LT are concepts related to issues of general concern to students (e.g., world hunger). LTD are promising related emotions, references and applications of the course material to that LT. In step 6.2, "dramatic structure of events" should be attended to as discussed in [36].

We briefly describe two examples that were used in our newly designed course.

Example 1: Optimal sandwich activity.

A classic application for linear programming is diet planning. A 30 minute activity was developed in an effort to connect the course content to diet, inspire joy and surprise and stimulate the senses of vision, taste, smell and touch. The activity developed asked the students to use their LP tools to design an optimal sandwich given ingredients (ham, cheese, jam and bread), nutritional content (e.g., protein, carbohydrates and fat content for each ingredient), preferences of the four sandwich judges and constraints on nutritional content (e.g., calorie limitation, minimal protein content, cost). The students formulated the problem and attempted to solve it by hand. The student teams were asked to make their optimal sandwich. The course teaching assistants were judges and an award was given for the best result. Students were encouraged to make more sandwiches and eat them. As the class was conducted in the morning, students (who had skipped breakfast) were hungry. The class taught an application of LP, reinforced graphical solution methods for problems with two decision variables and illustrated how difficult it can be to solve problems with more decision variables.

The process can be used in a less time consuming manner to increase the effectiveness of ordinary examples.

Example 2: Injecting emotional and sensory content into ordinary examples. Example 1 (and another detailed in Section 5.2) requires that time be set aside for the deep development of emotions and sensory input. Ordinary examples can also be enriched with little extra lecture time by overlaying sensory input and fun/surprising context. For example, consider an LP problem with two decision variables representing the number of units of type 1 product and number of units of type 2 product that are produced. Instead of using type 1 and type 2 products, weird or silly products such as the home decoration products Scary Dragon Fly and Cyber Puppy can be used. Amusing images of the product can be used. Silly sounds for each will intensify the effect. Giving physical interpretations to the production constraints also helps the students understand.

In addition, business efficiency applications can be enriched by connecting business success to better lives, improved communities (via taxes, for example) and a stronger nation (successful companies are a fundamental component of the economy).

5.2 Example of selected FRs and specified DPs

In this subsection, we provide details for an emotional and sensory learning experience. In general, all FR categories should be addressed for a course. Here we focus only on FRB and FRC. FR0 and FRA should be considered as well.

The CT is introduction to linear programming. We use food distribution as our LT which can be related to humanitarian food relief efforts. LTD include the Red Cross, surprise, joy, hungry children, empathy, sadness, and ultimately hope. We employed a surprising performance, strong emotional content and connecting examples.

The detailed FRs and DPs are provided in Appendix A and B. Here we mention some of the ideas used during the 50 minutes allocated to this class.

In the first 5 minutes of the class, a Red Cross themed food distribution skit was performed. The emotional goals were to inspire curiosity, surprise and joy (FR1.1.1, FR1.1.2, FR1.1.5). After some attention grabbing words appeared on the projection screen (DP1.1.1.1), bold highly recognizable dynamic music was played (DP1.1.3.1). The teaching team then burst into the room wearing Red Cross inspired uniforms (DP1.1.4). They distributed ''course survival kits'' to the students which included candy and the class handout for the day (DP1.1.5.1). The handout included information on linear programming network models and simple Red Cross food distribution examples. The food distribution process was conducted by two teams (DP1.2.1). One team was very inefficient while the other was highly efficient. (Both had the same resources, but used them differently.)

Examples of linear programming were studied during the 6–40 minute interval of the class. The definition of LP was given along with a simple example the students could construct in class (FR3). A simple network example that students could intuitively optimize was provided and solved by the students (DP2.1.1). A much more challenging (yet still far from realistic) example was provided that students could not solve intuitively (DP2.1.2). The difficulty of such problems and the need for algorithmic methods to solve them was thus established (DP2.1.3). This provides motivation and curiosity for the study of LPs (FR2.1).

During the 41–47 minute interval, the work conducted by food relief organizations was introduced (FR4). The manner in which optimal network distribution can enable additional food was established (FR5). During the final 3 minutes, an emotional journey was undertaken (FR6). We used pictures of hungry children and sad music to associate and amplify emotions associated with lack of food. Information on the severity of child hunger was provided in a few powerful words on the projection screen. The function was to cause the students to feel empathy for the suffering children. After, the music and presentation swung toward a message of hope regarding how engineers can help alleviate problems in the word. In this manner, we pay attention to the ''dramatic structure of events'' [36].

5.3 Comments on the redesigned material

It is important to note that this particular example intentionally devotes 15 minutes of the 50 minute class to the development of connections and emotions. On average, we devoted about 10–11 minutes of the weekly total of 150 minutes of class time to the development of deep emotions. Nevertheless, it was possible to cover all the same topics and give 90% of the examples as had been offered previously. In part, this was possible by a slightly more concise delivery of the content.

In addition, as in Example 2, it was possible to inject emotional and sensory content at minimal class time expense. This was done by layering emotions and senses over the existing examples.

Certainly, many professors wish to include as much content as possible in their course. However, the covered content in a course is often malleable. Motivation, interest and awareness of real applications can be just as valuable as covering a bit more material—perhaps more so. Thus, devoting 10% of the course time to emotional and sensory input may be helpful. A memorable course experience can last a lifetime.

6. Evaluation of the new design

The course under consideration had been offered by the authors at KAIST in Spring 2008–2012 semesters. The redesigned course was first implemented in the Spring semester of 2013, and each chapter took one to two weeks as before. About one of every three hourly lectures given weekly was designed to provide strong emotional context. The other lectures focused more on course topics with layered emotions and senses. The same course content goals were assessed and targeted.

No other factors under our control were changed. There may have been random population shifts or other unknown influences. However, the replication discussed in Section 6.3 helps to support our conclusion that the new design itself was the cause.

There were 109 undergraduate students enrolled in the course in Spring 2013. As a second year general engineering elective at KAIST, the course is open to students of any business/engineering/science major.

We consider three categories of feedback: end of semester student course evaluation survey (CES), written communication received by the instructor from the students, and an additional satisfaction survey given on the last day of class by the teaching team.

6.1 Official course evaluation surveys

The course had been taught using the previous design in the Spring semesters of 2008, 2009, 2010, 2011 and 2012. The CES uses a 1 to 5 Likert scale (higher is better). The CES average, CES standard deviation and number of valid survey respondents is provided in Table 2. The average CES prior to the redesign was 4.42/5.00. In the 2013 implementation, the average CES value increased to 4.67.

Table 2. Course evaluation survey results from 2008 to 2016

Year	Average CES	Stand Dev CES	Respondents
2008	4.45	0.54	76
2009	4.36	0.69	161
2010	4.43	0.71	163
2011	4.4	0.66	147
2012	4.47	0.59	139
2013	4.67	0.49	97
2015	4.54	0.59	100
2016	4.68	0.5	101

To assess if the newly designed course had an improved CES value, we used the one-tailed Mann-Whitney non-parametric median based hypothesis test to compare the 2012 CES scores with the 2013 CES scores. With a p value of 0.01, we accept the alternative hypothesis that the 2013 median CES score is significantly higher than in 2012.

6.2 Written comments from students

In previous semesters, the course instructor did not receive course feedback outside of the CES (which has an open ended portion). However, in 2013, the instructor received unsolicited email from 7% of the students with unusual commentary. Excerpts include: "I was really glad to learn", "I will always remember", "I was really pleased", "It was my pleasure to attend class", "I was very honoured to learn", "One of the best things that I've done this semester", "I will try hard to become a good engineer" and "I was very happy that I can participate in this class". The newly designed content seems to have had positive effect on some of the students.

Further, the character of the anonymous written comments from the official course evaluation (the same one from which the CES is obtained) seemed to shift in a similar manner. It included comments not received previously such as "I really loved this class" and "I'll miss this class".

6.3 Satisfaction survey

At the end of the 2012 and 2013 course offerings, the teaching team asked the students to complete an additional satisfaction survey (developed by the authors for this purpose). There were six questions that each used a 5 point Likert scale (higher is better); refer to Table 3.

Factor analysis on the entire 2012 and 2013 population results showed that all questions loaded strongly on a single factor. We use Cronbach's alpha as a metric for reliability of the instrument. The value of 0.878 was sufficiently high. The average satisfaction values are given in Table 4. There SAT is the average of the overall satisfaction question scores averaged over the population

Table 3. Overall satisfaction questions for 2012 and 2013 course offerings

OVERALL	Strongly disagree				Strongly agree
O1. Did the lecture presentation help you learn the course material?	1	2	3	4	5
O2. Did the lecture notes help you learn the course material?	1	2	3	4	5
O3. Do you feel that you learned a lot?	1	2	3	4	5
O4. Were you able to concentrate during the lectures?	1	2	3	4	5
O5. I am satisfied with the enjoyment outcome.	1	2	3	4	5
O6. I am satisfied with overall service.	1	2	3	4	5

Table 4. Results of SAT scores in 2012 and 2013

YEAR	Average SAT	Stand Dev SAT	Respondents
2012	4.15	0.61	111
2013	4.37	0.54	92

responding. The average SAT score increased by 0.22 from 4.15 in 2012 to 4.37 in 2013. This is similar to the average CES increase.

We conducted a one-sided non-parametric Mann-Whitney test to determine if the median of the 2013 responses exceeded the median in 2012. With p value of 0.005, the alternate hypothesis that the median of the 2013 scores is higher was accepted.

6.4 Replication

In an effort to replicate the results (after a hiatus in 2014), the new design was once again implemented in the Spring 2015 and Spring 2016 offerings of the course with the same instructor and head TA. Course evaluation results are provided in Table 2.

During the 2015 Spring semester, the MERS virus was detected in the Republic of Korea with cases in the city hosting KAIST. As a consequence, a key interactive activity (special lecture) was not provided during that semester. Despite the adverse environment, the 2015 CES average value was 4.54 (as compared to the 4.42 average from before the new design). The Mann-Whitney test provides significance relative to the 2012 offering with p value of 0.025. Written comments such as "I truly love it" and "the most fascinating class . . . in my life" were again received.

The 2016 Spring offering of the course was the same as the 2013 Spring offering in terms of learning environment (the same special lectures were offered and there were no deviations caused by external events). The instructor and head TA were the same. The 2016 CES average again returned to 4.68 (as compared to 4.42 from before the new design). The Mann-Whitney test provides significance relative to the 2012 offering with p value of 0.01. Written comments such as "if I had this course earlier this might have changed my decision [of major]", "inspiring" and "never once got tired of coming to class". We consider this a successful replication. We attribute the 0.13 difference in the average CES scores between the 2015 and 2016 offerings of the course to the removal of the interactive special lecture late in the 2015 semester due to MERS. One might interpret that difference as the value of that activity.

We consider these subsequent offerings as successful replication.

7. Concluding remarks

Using Axiomatic Design, we identified emotions and sensory input as Kano excitement needs for extraordinary engineering course service. We constructed prototype functional requirements (FRs) and design parameters (DPs) to aid the course designer to insert emotional and sensory content. We redesigned IE 200: Introduction to Operation Research at KAIST. We injected emotional and sensory context into the existing course material where possible. We created learning experiences that sought to inspire deep emotions related to the course topics. We devoted about 10–11 minutes on average of the weekly 150 minutes of class time to developing these deeper emotions. The course content learning objectives were not changed. The redesigned course was first implemented in 2013 and replication was conducted in 2015 and 2016.

The insertion of emotions and senses into the course resulted in statistically significant increases in the official university course evaluation survey (CES) and a second satisfaction survey. Further, the course instructor received unusual written communications from students that suggested they were positively influenced by the new design. The results were confirmed in 2015 and 2016. We conclude that emotional and sensory content significantly improved the quality of this course.

This work has several limitations. We only implemented the approach on one course. It is not clear if the same approach can be used for basic fundamental courses such as Calculus. The implementation compared course offerings in different years rather than in the same semester side by side. Further, we only considered the traditional lecture format.

In the future, the method should be applied to other courses with different course topics (e.g., mathematics). With modern technological advances inspiring the rise of MOOCs, it is important to determine if this direction is helpful for those largely on-line experiences. It will also be important to expand the FRs and DPs to address learning objectives beyond course content and into realms such as intrinsic motivation.

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Appendix A: Detailed FR decomposition for example class

Functional Requirements (FRs)	Time
FR1 Magnify the intensity of student emotion associated with specific idea	
1.1 Magnify the intensity of student emotions associated with life topic "Food"	
1.1.1 Magnify the intensity of student curiosity associated with life topic "Food"	
1.1.1.1 Magnify the intensity of student curiosity associated with life topic "Food" via Sight	0~0.5
1.1.2 Magnify the intensity of student surprise associated with life topic "Red Cross"	
1.1.2.1 Magnify the intensity of student surprise associated with life topic "Red Cross" via Sight	0.5~1
1.1.3 Magnify the intensity of student surprise associated with life topic "Music"	
1.1.3.1 Magnify the intensity of student surprise associated with life topic "Music" via aural style	1~1.5
1.1.4 Magnify the intensity of student surprise associated with life topic "Ordinary class"	1.5~2
1.1.5 Magnify the intensity of student joy associated with life topic "Food"	
1.1.5.1 Magnify the intensity of student joy associated with life topic "Food" via taste	2~5
1.2 Establish connection between course topic and student concerns topic	
1.2.1 Establish connection between course topic network modelling problem and student concerns topic "Food"	2~5
FR2 Magnify the intensity of student emotion associated with specific idea	
2.1 Magnify the intensity of student emotions associated with course topic	
2.1.1 Magnify the intensity of student curiosity associated with course topic "Network modeling"	5~13
2.1.2 Magnify the intensity of student curiosity associated with course topic "Network modeling"	13~20
2.1.3 Magnify the intensity of student enthusiasm associated with course topic "Operation Research"	20~23
FR3 Establish cognitive domain for course	
3.1 Establish cognitive domain for topic "Brief ideas about network modeling"	
3.1.1 Establish knowledge domain for topic "Brief ideas about network modeling"	5~23
3.2 Establish cognitive domain for topic "Concept of modelling and optimization"	
3.2.1 Establish knowledge domain for topic "Concept of modelling and optimization"	23~40
FR4 Magnify the intensity of student emotion associated with specific idea	
4.1 Magnify the intensity of student emotions associated with life topic	
4.1.1 Magnify the intensity of student curiosity associated with life topic "Emergency relief"	40~44
FR5 Establish connection between course topic and student concerns topic	
5.1 Establish connection between course topic "Optimization model" and student concerns topic "Food distribution"	44~47
FR6 Magnify the intensity of student emotion associated with specific idea	
6.1 Magnify the intensity of student emotions associated with life topic	
6.1.1 Magnify the intensity of student empathy associated with life topic "Food distribution for poor children"	
6.1.1.1 Magnify the intensity of student empathy associated with life topic "Food distribution for poor children" via visual style	47~50
6.1.1.2 Magnify the intensity of student empathy associated with life topic "Food distribution for poor children" via aural style	47~50

Appendix B: Detailed DP decomposition for example class

Design Parameters (DPs)	Time
DP1 Methods to magnify the intensity of student emotions associated with specific ideas	
1.1 Methods to magnify the intensity of student emotions associated with life topic "Food"	
1.1.1 Methods to magnify the intensity of student curiosity associated with life topic "Food"	
1.1.1.1 Ridicule words about hunger and no person	0~0.5
1.1.2 Methods to magnify the intensity of student surprise associated with life topic "Red Cross"	
1.1.2.1 Red Cross Sign on screen	0.5~1
1.1.3 Methods to magnify the intensity of student surprise associated with life topic "Music"	
1.1.3.1 Music from movie "Pirate of Caribbean"	1~1.5
1.1.4 Sudden appearing of professor and TAs with Red Cross costume	1.5~2
1.1.5 Methods to magnify the intensity of student joy associated with life topic "Food"	
1.1.5.1 Giving candies	2~5
1.2 Methods to establish connection between course topic and student concerns topic	
1.2.1 Two different ways of distributing candies (efficient & inefficient)	2~5

<u>**DP2**</u> Methods to magnify the intensity of student emotion associated with specific idea	
2.1 Methods to magnify the intensity of student emotions associated with course topic	
2.1.1 Simple network in-class activity which can be solved easily	5~13
2.1.2 Complex network in-class activity which cannot solved by simple calculation	13~20
2.1.3 Introduction to the reason that why students should learn OR (to solve complex problem)	20~23
<u>**DP3**</u> Methods to establish cognitive domain for course	
3.1 Methods to establish cognitive domain for topic "Brief ideas about network modeling"	
3.1.1 Two in-class activities about network modeling	5~23
3.2 Methods to establish cognitive domain for topic "Concept of modelling and optimization"	
3.2.1 Simple explanation about problems and optimization modelling	23~40
<u>**DP4**</u> Methods to magnify the intensity of student emotion associated with specific idea	
4.1 Methods to magnify the intensity of student emotions associated with life topic	
4.1.1 Introduction to the organization helping poor children	40~44
<u>**DP5**</u> Methods to establish connection between course topic and student concerns topic	
5.1 Explain about trade-off between food distribution and fixed budget	44~47
<u>**DP6**</u> Methods to magnify the intensity of student emotion associated with specific idea	
6.1 Methods to magnify the intensity of student emotions associated with life topic	
6.1.1 Methods to magnify the intensity of student empathy associated with life topic "Food distribution for poor children"	
6.1.1.1 Emotional slides composed of picture of poor children and hope filled message about how engineers can contribute to saving them	47~50
6.1.1.2 Emotional music start from sad melody and become hopeful	47~50