FatCombat: A Health Video Game for Education and Promotion of the Recommended Fat Intake Among Children

Ismael Edrein Espinosa-Curiel*, Edgar Pozas-Bogarin*, Janeth Aguilar-Partida*, Maryleidi Hernández-Arvizu*
and Edwin Emeth Delgado-Pérez†
* CICESE-UT3
Andador 10 #109, Ciudad del Conocimiento, 63197, Tepic, Nayarit, México
Email: ecuriel@cicese.mx, pozas@cicese.mx, amara@cicese.mx, maryleidi@cicese.mx
†Center for Studies and Research in Behavior
Universidad de Guadalajara (UdG)
Francisco de Quevedo 180 Arcos Vallarta, 44130, Guadalajara, Jalisco, México
Email: emeth.delgado@gmail.com

***Abstract*—Overweight and obesity are frequently assumed to be the result of an energy imbalance caused by an excess in calories and fat intake. To help children learn about the different types of fat and their intake recommendations, we developed the health video game *FatCombat* (FC). In this game, players go inside the bodies of children to help them eat healthily by respecting fat intake recommendations. As a result of their actions, the heart can stay healthy and generate a constant flow of blood to the children's bodies. FC is based on knowledge of fat intake and integrates a set of behavior change techniques related to cognitive and behavioral theories used in children's health interventions. In this paper, we describe the design process for FC and report the results of a pilot study to evaluate the effect of FC on the knowledge children have of fat and to evaluate the user experience of FC players. Players of FC improved their knowledge of fats and the game provided high levels enjoyment.**

Keywords–Health video game; Children; Fat intake recommendations; Learning; Fat intake change.

I. INTRODUCTION

The prevalence of childhood overweight and obesity has reached alarming levels, affecting virtually all socio-economic groups, irrespective of sex and ethnicity, of both developed and developing countries [1]. Childhood obesity can profoundly affect children's physical health, social, and emotional well-being and self-esteem [2]–[4]. It can also contribute to increased premature mortality [5]. Childhood obesity is a multifactorial problem; however, it is frequently assumed to be the result of an energy imbalance caused by an excess in fat intake in children [5]. One possible solution to this problem is to eliminate as much fat as possible from children's diets; however, children need fat for adequate growth (e.g., it helps them absorb vitamins and minerals, provides fuel and insulates the body). Therefore, instead of reducing fat intake, to have adequate growth, children must learn how to intake the daily recommended amount of the four types of fat. Different fats have different effects on the body. While saturated and trans fats can raise blood cholesterol levels and increase the chance of getting heart disease, monounsaturated and polyunsaturated fats have several health benefits. In addition, children need to identify the types of fat contained in the food they usually consume in order to be more selective and improve their fat intake habits.

Health video games are an emerging strategy that can help fulfill these objectives of learning and changing behavior. These types of video games are innovative and enticing methods for attracting attention, educating, and promoting changes in the knowledge, attitudes and behaviors of players [6], [7]. The literature indicates that health video games can have positive effects on nutritional knowledge, physical activity, and eating attitudes and behaviors of children [6]–[8]. In particular, this type of video games can help children to increase their knowledge regarding nutrition definitions and eating rules [9], the five most important macronutrients of foods [10], and the U.S. Department of Agriculture MyPlate guidelines [11]. This type of game can also help increase the intake of healthy food, such as vegetables, fruits, legumes, and white meat [12]–[14], and reduce the intake of unhealthy food, such as sugar-containing snacks and beverages and processed snacks [13], [15], [16].

Some of the current nutrition health video games for children include knowledge related to fats. The video game "Fit, Food, Fun", for instance, includes a mini game structured like a quiz that compares protein, fat, carbohydrates, or calories between two food items. It also includes a mini game designed to estimate the content of sugar, fat, or salt in food [9]. Similarly, the video game "Alien Health" encourages students to discourse about the somewhat similar food items and to make an optimal choice, taking into account the protein, fats, carbohydrates, fiber, and vitamins/minerals of the food [10], [11]. In the game 'Fitter Critters", the player is responsible for the health of a virtual pet (Critter) and needs to complete quests to learn how food and activity choices influence their Critter's behavior and health. By choosing healthy foods without surpassing the fat, sugar, and caloric allotment, the Critter becomes healthier and is sick less [17]. The game "Creature 101" includes a mini game to learn about the role of taste, sugar, and fat in our diets. It also includes a mini game related to food and nutrition facts about sugar and fat contents of commonly consumed beverages and snacks [15]. In the "NutritionBuddy" video game, players collect food to make a well energy-balanced combination of food and beverages by keeping carbohydrates, fats, and proteins within the recommended limits [18].

II. PRESENT STUDY

Although the health video games described above include knowledge related to fats, to the best of our knowledge, there is not an explicit game designed to educate children about the

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different types of fat and their effects in the body, the daily fat intake recommendations for children, and the type and amount of fat that have the food frequently consumed by children. Therefore, we developed *FatCombat* (FC), a health video game that focuses on helping children understand and apply the nutritional concepts related to fats mentioned above. The FC elements and mechanics are based on nutrition knowledge and Behavior Change Techniques (BCT). FC is part of IFitKids, a platform that integrates nutrition mini games and components related to psychology, nutrition, and physical activity. In this paper, we describe the design process of FC and how BCTs were operationalized into the game elements to induce changes in the fat intake of players. We also describe the results of a pilot study to evaluate the effect of FC on the fat knowledge of children and to evaluate the user experience and usability of the game.

We organize this paper as follows. Section III describes the methodology we used to design FC. In Section IV, we describe our proposed health video game. Section V describes the evaluation of FC. Section VI reports the results of a pilot study to evaluate the effect of FC on the knowledge children have of fat and to evaluate the user experience of FC. Section VII discusses our findings. Finally, Section VIII provides some concluding remarks and some research directions for future work.

III. GAME DESIGN

To design FC, we used an iterative game design methodology based on the work of Macklin and Sharp [19]. Our methodology consisted of the following five steps (see Figure 1): (1) learning and behavioral change planning; (2) game design; (3) prototype development; (4) play-testing; and (5) evaluation. We conducted three cycles until we obtained the version of FC evaluated in this study. Next, we describe the activities conducted in each step.

- In Step 1, we conducted a literature review to position FC in the specialized serious game literature (e.g., [20]–[22]) and nutrition knowledge. In addition, we conducted several multidisciplinary design sessions with two nutritionists and a psychologist to establish and improve the learning objectives, target behaviors, behavior change objectives, and BCTs that could be integrated into the gameplay elements to support the behavior change objectives.
- In Step 2, we conducted multidisciplinary design sessions with the participation of two nutritionists, one psychologist, one expert on human-computer interaction, and three game designers. The session aimed to propose design ideas and game rules and mechanisms and define how to include the nutritional concepts and implement the selected BCTs into the gameplay elements. Based on these activities, we designed high-fidelity prototypes. We conducted 4, 2, and 2 multidisciplinary design sessions in cycles 1, 2, and 3, respectively. The number of sessions is higher in the first cycle because this is when we go from the idea to have a working prototype.
- In Step 3, we implemented in the video game engine Unity® a high-fidelity prototype based on the game design obtained in the previous step.

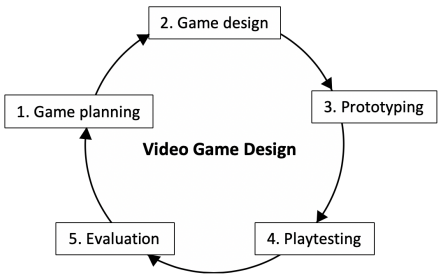

Figure 1. Process of designing FC

- In Step 4, children played with the prototype and later participated in a focus group where they were encouraged to talk about their game experience (e.g., instructions, activities, challenges, game flow, human-computer interaction, and amount of fun) and to draw new game elements or features. Some suggestions from cycle 1 were to improve the explanation of fats, the tutorial, the health indicators, and the feedback messages, as well as to clarify the mission and emphasize the role of fats in the game mechanics. The suggestions for improving and changing cycles 2 and 3 were to add a map, add difficulty levels, increase the reward coins, make the heart interactive, and add more fun elements. In cycles 1, 2, and 3 there were 6, 12, and 10 children participating, respectively. The age range of all participants was 8 to 11 years. Different children participated in each cycle. The playing duration was 10, 15, and 15 minutes for cycles 1, 2, and 3, respectively.
- Finally, in Step 5, we conducted a multidisciplinary session with the same participants of the Step 2 session to discuss and analyze the obtained results, the changes suggested for the game and the new requirements obtained in the previous step, and we elaborated a set of recommendations to improve the usability, enjoyment, player experience, game mechanics, game elements, and learning and behavior change strategies.

IV. FATCOMBAT

Players have to fill out a "welcome form", which creates a user-tailored profile, and then they are allowed to start playing. The requested data are gender and age in years and months. This information is used to estimate the recommended energy consumption, and based on this information, estimate the total number of grams of fat and the amount of each type of fat. FC includes a configuration section, where players log-in, play through the game's story, select and buy avatars, and select the next level from a map. In addition, FC includes an educational section, where the players learn about the importance of fat for adequate growth, the four types of fat and their effects on the body, fat intake recommendations, and the predominant types of fat contained in popular food (see Figure 2, top left and top right screens). Players should see this tutorial completely the first time they play. Then, they can see it again if they want to review the explanation. This section also includes a tutorial that explains the game goal, how to play the game, the game

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Figure 2. FatCombat's screens.

options and elements, the indicators, and the results section (see Figure 2, bottom-right screen).

A. Active playing

We designed FC as an active game to make it more fun, improve the user experience, and promote light physical activity [23]. Active games require physical activity beyond that of conventional hand-held games and rely on technology that tracks body movements or reactions for game progress [24]. FC players must perform basic physical movements, such as squats, jumps, lateral body movements, and arm movements to pick up the food. They also need to perform kicks and punches to prevent the avatars of trans and saturated fats from delivering food to the heart. To follow the body movements of the players, FC uses the Microsoft Kinect V2® sensor.

B. FC gameplay

The adventure of FC takes place in HealthyTown, a city controlled by a group of evil chefs who added fats that come to life within the children's bodies to the food. Dr. Yokuro Kokoro, the chief scientist of the city, realizes what is going on, so he assigns a secret agent (the player) the mission to go inside the bodies of children and help their hearts eat healthy, respecting the intake recommendations for calories, total fat, trans fats, saturated fats, monounsaturated fats, and polyunsaturated fats. The Food and Agriculture Organization of the United Nations (FAO) proposed the following daily fat intake recommendations for children aged between 2 and 18 years old [25]:

- Between 25% and 35% of Kcal should come from fat.
- Up to 1% of Kcal should come from trans fats;
- Up to 8% of Kcal should come from saturated fats;
- From 6% to 11% of Kcal should come from or polyunsaturated fats;
- The intake of monounsaturated fat depends on the total fat intake and the characteristics of dietary fat. Analyzing the possible combinations of fat consumption, we calculated that the recommended consumption range is from 5% to 29% of Kcal.

C. FC mechanics

In the game, food appears randomly, and players must decide whether the heart should consume it or not. For each food, the game shows a real picture and a tag that specifies the type and amount of fat that the food contains. The game has a database of 400 foods frequently consumed by Mexican children. The food included in the database was selected from interviews with children from 8 to 11 years of age and the opinion of two nutritionists. The fat quantity of the foods was obtained from the Mexican equivalent food system [26]. To make their decision, players must take into account the type and amount of fat that the food contains and the fat already consumed by the heart, which is specified in fat bars. In alignment with the recommendations mentioned previously, we integrated into the game six variables that influence gameplay (see Figure 2, middle screen). These variables are "total calories", "total fat", "trans fats", "saturated fats, "monounsaturated fats" and "polyunsaturated fats". A bar displayed on the user interface serves as a visualization of the "variables" levels, and each bar has an exclusive range depending on the variable.

When the player feeds the heart with food that contains saturated or trans fat, yellow or pinks fats will appear in the veins and the bars of these fats will increase. When the player feeds the heart with food that contains monounsaturated or polyunsaturated fats, green or blue fats will appear in the veins and, since these fats help clean the trans and monounsaturated fats, some yellow and pink fats will disappear and their bars will drop. The blood flow in the veins is determined by the amount of fat they have. Therefore, the more fat, the less blood flow. When the blood flow is low, it is reflected in the facial expressions of the heart. In addition, the avatars of the saturated and trans fats randomly appear and try to give the heart food with their type of fat (see Figure 2, bottom-left screen). For example, the saturated fats avatar gives the heart a dish of beef, and the trans fats avatar gives the heart a chocolate cake. The player must determine if the heart should be allowed to eat these foods. If the player does not want the heart to consume such food, he or she must defeat those fats by kicking or hitting them. FC has other scenarios in which questions related to fats, types of fat, and the types of fats present in popular food appear randomly. The player earns coins if he or she answers the questions correctly.

We included a curve of increasing difficulty across the 10 levels of the game to encourage players to have fun through the end of the video game. The learning objectives of the levels are incremental. For example, at level 3, in addition to the objective of level 3, players must meet the objectives of levels 2 and 1. The game levels are as follows:

- Level 1. Players need to ensure that the total calories and fat intake are within the recommended ranges.

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- Level 2. Players have to prevent the heart from intaking food with trans fats.
- Level 3. Players need to ensure that the intake of saturated fats is less than the maximum amount allowed.
- Levels 4 and 5. Players need to ensure that the intake of monounsaturated and polyunsaturated fats is within the recommended range.
- Levels 6 and 7. The hints about the types and amounts of fat in the foods are hidden.
- Levels 8, 9, and 10. The bars showing saturated, monounsaturated, and polyunsaturated fats are hidden, and only the grams consumed are shown.

If the player meets the objective of the levels, he or she earns points and moves on to the next level. On the contrary, if he or she loses, the level must be repeated.

D. Behavioral change techniques

We integrated a set of BCTs in the gameplay elements of FC to induce changes in the fat intake behaviors of players. Figure 3 explicitly shows the relationship between the BCTs used and the gameplay elements. A BCT is defined as "an observable, replicable, and irreducible component of an intervention designed to alter or redirect causal processes that regulate behavior; that is, a technique is proposed to be an "active ingredient" [27]. BCTs are based on constructs of theories frequently used in health interventions, such as behavioral theory, cognitive theory, control theory, theory of planned behavior, and social cognitive theory. BCTs can be used alone, but the combination of several BCTs is frequently critical for effectiveness [28]. The BCTs integrated into the game show empirical evidence of the game's efficacy in aiding weight loss and addressing other kinds of dietary problems in children [29]. In the game, we integrated BCTs related to the explanation of the natural consequences of fat intake in order to shape knowledge by providing instructions on how to perform the planned behaviors. The game also provides an environment to substitute and practice new behaviors and includes game mechanisms to instigate the selected behaviors. To support the practice of the behaviors, FC includes prompts and clues that are reduced or eliminated in the last levels of the game. In addition, to guide the activities, the game includes goal setting, review, feedback and monitoring. The game also includes rewards to immediately reinforce short-term actions (e.g., maintain the blood flow) and long-term actions, such as level completion. The reward follows an incremental scheme. Finally, the game includes other elements associated with learning and behavior change, such as vicarious consequences, social comparison, and the player being centered as a role model. The work of Michie et al. [27] provides a broad definition of the BCTs operationalized in FC.

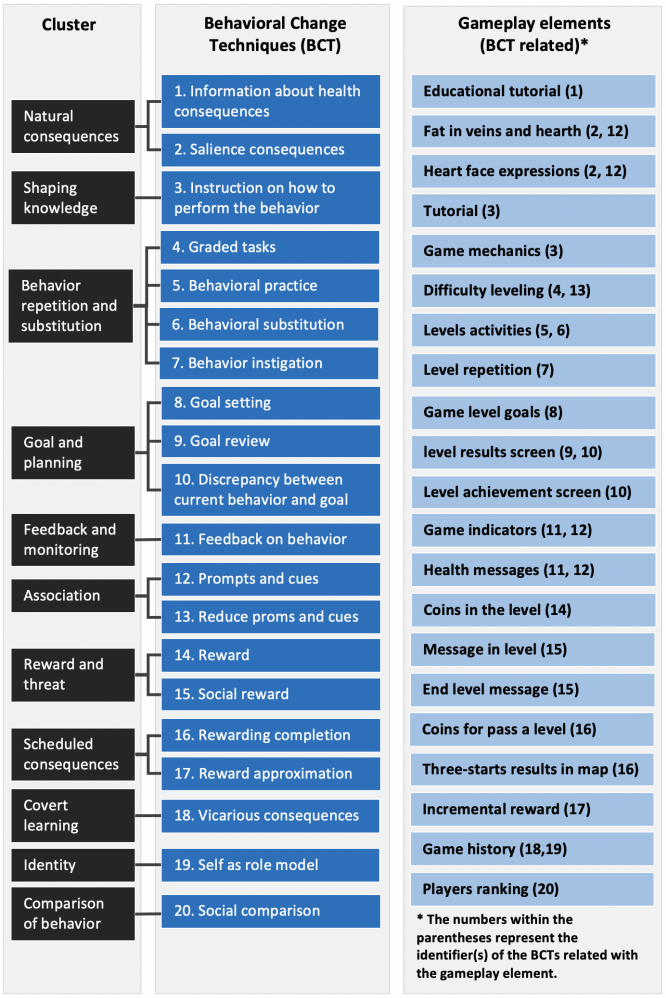

Figure 3. BCTs operationalized in the gameplay elements of FC

V. GAME EVALUATION

We conducted a pilot study to evaluate whether the game helps improve the children's knowledge about fats and to examine the user experience of the players. Although FC was also designed to generate changes in fat intake attitudes and behaviors related to players, we did not evaluate this due to the short duration of the evaluation study. A longer-term study is required to evaluate changes in the fat intake attitudes and behaviors of players. A total of 13 children (n=5 girls, n=8 boys) aged 8-10 (mean age 9.6, SD 1.12 years) from a primary school voluntarily participated in the experiment. Of the participants, 50% of the girls and 70% of the boys were overweight or obese. Before collecting the data, we obtained written authorization from school authorities and written consent from the parents for the children to take part in the study. Later, we applied a fat knowledge questionnaire. The questionnaire included seven general fat questions with 5 response options (e.g., *What is the type of fat that is solid at room temperature and is found in animal foods?*) and 10 questions about the types of fat various foods contain (e.g., *What type of fat does avocado mainly contain?*). Later, over a period of 25 days, the participants conducted six game sessions, with an average of 35 minutes per session (one session every two days). The total average time that the children played was 3.5 h. When the students finished the game sessions, we applied the fat knowledge questionnaire and a user experience questionnaire. The user experience questionnaire was based on two validated questionnaires [30], [31] and had 47 items grouped into 13 categories. For each item, we asked the participants to indicate on a 5-point Likert-type scale ranging from (1) "Totally disagree" to (5) "Totally agree" the level to which they believe the game accomplishes each of the

TABLE I. FAT KNOWLEDGE PRETEST AND POSTTEST RESULTS

Correct responses	*Mean*	*SD*[a]	*P*[b]
pretest	5.1	4.5	0.038
posttest	8.9	4.6	

[a] Standard deviation

[b] P value of<0.05 was considered to be statistically significant

questionnaire statements.

VI. RESULTS

We compared the pretest and posttest levels of fat knowledge using the Wilcoxon signed-rank sum test. We used the Statistical Package for the Social Sciences (SPSS) version 25 software [32] to conduct the statistical analysis. From the statistical analysis results (see Table I), we identified that the players significantly improved their fat knowledge after playing the game (P=0.038). In relation to user experience, for each category, Table II, shows the number of items, an example of the statement, the median and interquartile range, and the percentage of participants who agreed that the game fulfills the statements in that category. The agreement percentage represents the result of dividing the number of responses with an evaluation of 4 or 5 by the total number of responses. The game received a median score of 4 or above in all dimensions, which reflects high levels of user experience, enjoyment, and usability. Most of the participants agreed that FC is fun and easy to use; has a clear story, goals, and dialogues; provides useful feedback; and has pleasing sounds and graphics. Another significant result is that most of the players agreed that the game adapts the difficulty to their capacity and skills, stimulates their curiosity, and allows them to be imaginative. They also agreed that the game helped improve their knowledge and constantly motivated them to advance to the next stage or level. These characteristics provide them with a good amount of immersion because most of the players agreed that they forgot about the passage of time, became unaware of their surroundings while playing the game, and could not wait to play again.

VII. DISCUSSION

To best our knowledge, FC is the only nutrition health video game explicitly designed for education on and the promotion of the recommended fat intake among children. The obtained results show that children significantly improved their knowledge of fat after playing FC. The video games that include some knowledge about fat have also obtained favorable results in knowledge improvement and behavior change. The video game "Creature 101" [15] helped children to improve their eating behaviors, and the video games "Fit, Food, Fun" [9], "Alien Health" [10], [11] and "Fitter Critters" [17] helped to improve the general nutrition knowledge of children. However, because none of these studies evaluated the effect of the video game on children's knowledge about fats, we cannot be made a comparison against the results obtained by FC. The study conducted by Holzmann et al. [9] is the only that includes some questions to evaluate fat knowledge of children; however, they reported that players obtained a lower score in the knowledge of fat and oil after play the video game. These results are encouraging for further research on the ability of FC to teach about fats and improve fat eating.

Moreover, the high user experience and usability results of FC were in line with results from other health video games for children. These studies reported satisfaction and usability ratings ranging from 4.11 to 4.52 on a 5-point scale [13], [17], [33] which are similar than ratings observed in the present study. As satisfaction and usability appear to be correlated with knowledge gained, the high user experience and usability of FC has implications for its ability to impact fat knowledge. Two areas of improvement for the video game are autonomy and visual aesthetics because these were the subscales with the lowest rating. The first refers to the control that the players felt in the game elements and the support provided to players in the game so that they would know what the next steps in the game were. The second relates to the quality of the game's graphics and whether the players like them and find them pleasant. One limitation of this study is that it was conducted in a single school and with only a few participants. However, given that the objective of this study was not to generalize our findings but to achieve an overall impression of the usability of FC, we consider our results to be valuable for researchers exploring the design context of this type of serious game.

VIII. CONCLUSION AND FUTURE WORK

In this paper, we present *FatCombat* (FC), an active health video game used for educating and promoting the adequate intake of different types of fat among children. Additionally, we describe how a multidisciplinary team used an iterative game design methodology to design FC. Finally, we describe how BCTs were operationalized into FC gameplay to induce changes in the fat intake of the players. These contributions can help game designers design new serious games for nutritional education and for encouraging changes in eating behaviors of children. From a pilot study, we identified that players of FC improved their knowledge of fats. In addition, we identified that the game provides high levels of user experience, enjoyment, and usability. For future work, we are planning to conduct additional design cycles in which parents, teachers, and children will be involved as co-designers to improve game design. In addition, we are planning to conduct a comparative study of using FC versus the traditional lecture way. Finally, we are planning to conduct a randomized controlled trial to evaluate more in-depth the effectiveness of FC to support player learning about fats and to evaluate its effects on fat intake intentions, fat intake auto-efficacy, and fat intake behaviors.

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TABLE II. USER EXPERIENCE RESULTS

#	*Category*	*Items*	*Question example*	*Median(IQR)*	*Agreement*
1	Goal clarity	2	The overall game goals were presented clearly.	5(1)	81% (21/26)
2	Feedback	3	I received feedback on my progress in the game.	5(1)	79% (31/39)
3	Challenge	3	The level of challenge in the game was adequate for me.	5(1)	77% (30/39)
4	Autonomy	2	I felt a sense of control in the game.	4(2)	65% (17/26)
5	Immersion	4	I cannot wait to play again	5(2)	71% (37/52)
6	Knowledge improvement	3	I understood the basic ideas of the knowledge taught in the game.	5(1)	77% (30/39)
7	Playability/Usability	9	I think it is easy to learn how to play the game.	5(2)	72% (84/117)
8	Narratives	3	I enjoyed the story provided by the game.	5(1.5)	74% (29/39)
9	Enjoyment	3	I think the game is fun.	5(1.5)	74% (29/39)
10	Creative freedom	3	I feel that my curiosity has been stimulated as a result of playing the game.	5(1)	77% (30/39)
11	Audio aesthetics	3	I enjoyed the sound effects in the game.	5(1)	79% (31/39)
12	Personal gratification	4	I am very focused on how to achieve the game's goals and get the rewards.	4(2)	77% (40/52)
13	Visual aesthetics	3	I enjoyed the game's graphics.	4(2)	62% (24/39)

Data are expressed as the median (interquartile range) of the participants' scores. The scores are (1) "Strongly disagree"; (2) "Agree", (3) "Undecided", (4) "Agree", (5) "Strongly agree".

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