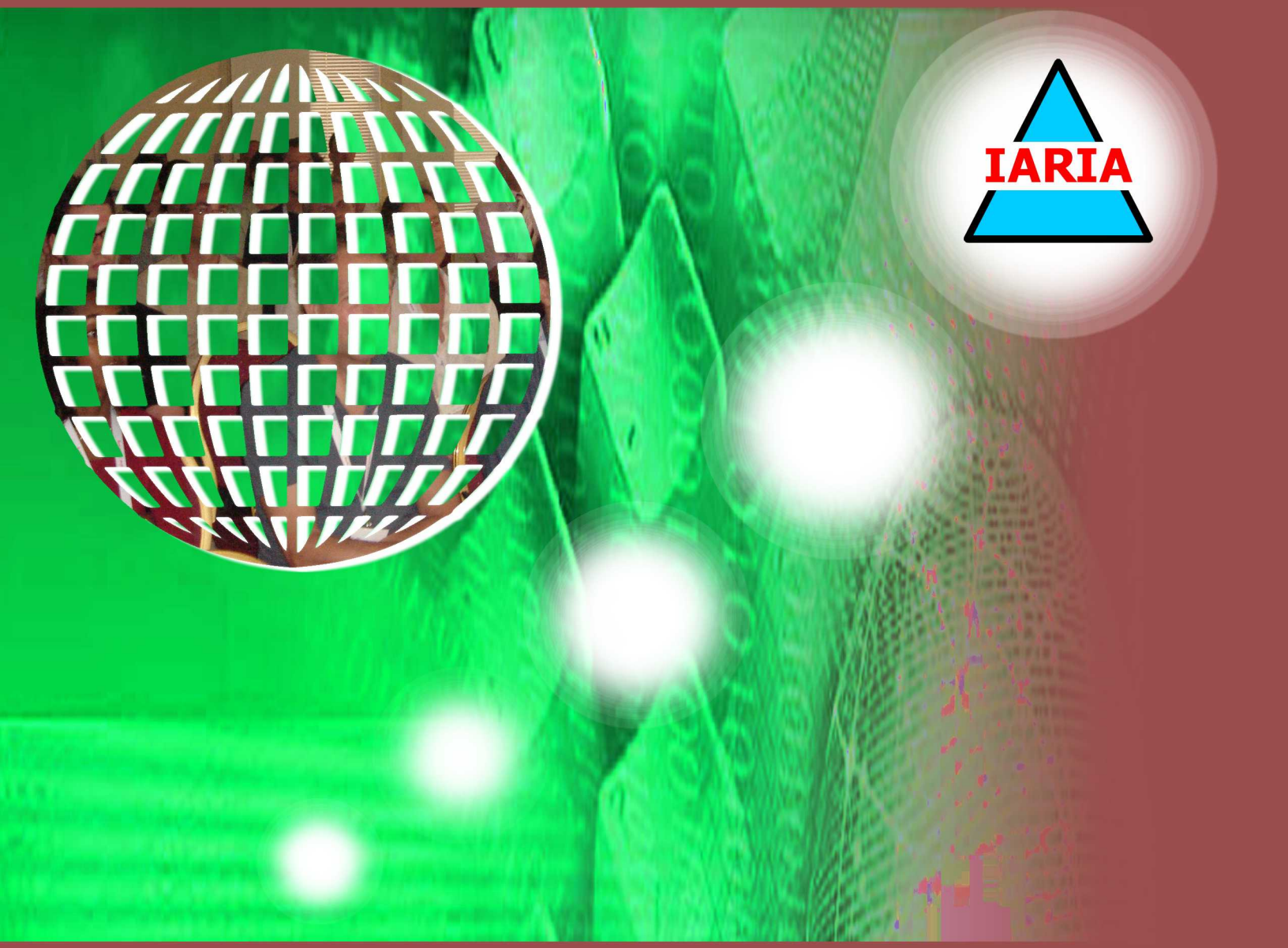
International Journal on Advances in Life Sciences



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Gender Differences in IT Adoption & Gestural Communication

Science Behind Stereotypes & Implications on Human Computer Interaction

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Abstract— **This paper reviews gender differences in gestural communication and perception of Information Technology (IT) and investigates gender differences in basic hand gestures for the design of user-centric and gender-adaptive systems. If males and females associate themselves differently with technology, being masculine and feminine, then this would have a strong impact on their adoption of IT and would require the development of gender-adaptive gesture-recognition systems, devices and applications. In this paper, we present empirical studies to demonstrate gender differences in the perception of technology as well as gestural communication. We have conducted a survey with 20 male and 20 female participants and found differences in the perception of the gender of technology. Our association with IT may be driven by the way we identify ourselves with the gender of technology. If there are differences in the way we process information and males and females use different system architectures, then the development of gender-adaptive systems would increase the acceptance of technology. We have also analysed natural hand gestures to identify what type of gestures are used in gestural communication, using video analysis and annotation. We have conducted an experiment involving 10 male and 10 female Australian adults. We have asked the participants to describe an object using hand gestures and speech. We have found gender differences in the perception of IT, as well as types, frequency and occurrences of hand gestures. Drawing conclusions from these comparisons, we discuss the potential effects of gender differences in the design of multimodal interfaces as well as the necessity of developing gender-adaptive systems in Human Computer Interaction (HCI).**

Keywords- gesture analysis; gender differences; human computer interaction; consumer research; perception of technology.

I. INTRODUCTION

Gender differences have long been debated in a number of disciplines such as education, sociology, psychology, neuroscience, and medicine. In this article, we provide a debate on this controversial issue and the science behind stereotypes. Our goal is to draw parallels between the perception of the gender of Information Technology (IT) and gender differences in our interest in so-called masculine and feminine technologies, as we believe to motivate females' interest in IT, we must start developing feminine technologies that females feel more associated with.

Gender differences in gestural communication [1] have been studied by many researchers, leaving much unclear regarding the implications on Human Computer Interaction (HCI). As shown by Nasser and Kavakli [2], culture has an impact on gestures, but these stereotypes may be incorrect. Nasser and Kavakli [2] have shown that Anglo-Saxons uses gestures more than Latin-Americans but since the frequency of gestures is higher in Latin-Americans, this gives an impression as if they use more gestures. In fact, Latin-Americans use faster but less gestures.

Our aim in this paper is to look into another stereotype and investigate gender differences in gestural communication between males and females in order to develop personalized interfaces. To identify gender differences in the perception of IT as well as gestural communication, we defined two hypotheses to test:

(1) Users' gender and their computer experience have a significant effect on the perception of the gender of IT.

(2) Gender differences in gestural communication have a significant influence on user association and the perceived gender of technology and in return these may affect the acceptance of technology.

Our association with IT may be driven by the way we identify ourselves with the gender of technology. There may be gender differences in the way we process information, as well as our perception regarding the masculinity and femininity of the technology. If males and females use different system architectures to process information, the development of gender-adaptive systems would increase the acceptance of technology.

The paper is structured as follows: Section I presents a debate on the influence of gender on technology adoption and gestural communication in HCI. Section II reviews summary of related works regarding gestures and gender differences in gestural communication. Section III describes the methodologies used. Section IV addresses the survey on the perception of IT and the experiments on the use of hand gestures. Section V goes into finer details with respect to the analysis of the data collected. Section VI presents the findings. The conclusions close the article.

II. GENDER DIFFERENCES IN TECHNOLOGY ADOPTION & GESTURAL COMMUNICATION

In this section, we will look into gender differences specifically in IT adoption and gestural communication.

A. The Influence of Gender on IT Adoption

The influence of gender on IT adoption has received a significant amount of attention. In USA, Internet use at various locations increased over time among females relative to males. In 1997 and 1998, females were less likely to use the Internet anywhere or at home than males, but they were more likely to do so by 2001 [3]. Among those who work, females remained less likely than males to use the Internet at work, but the gender gap narrowed over time. People who are employed are more likely than the non-employed to use the Internet at home or anywhere, else with nonworking females the least likely to use the Internet. What drives the change in the statistics? Is it the development of feminine technologies?

As stated in previous studies, the uptake of technology and acceptance of IT has been relatively slow by female users until the introduction of more feminine and gesture-based technologies such as smart-phones and tablets. Two-thirds of U.S. consumers own smartphones today [4], with slightly more women owning one than men [5]. Does association with the gender of technology have anything to do with the adoption of technology? This is still an open research question.

Recent statistics show that females use technology differently than males [6]. Females not only use social media more often than males, but they use it in different ways and to access different kinds of information and entertainment. For example, females use social media for staying in touch, blogging and sharing and researching how-to information, while males use social media for business and dating more than females do. LinkedIn is the only social platform that males use more than females.

Regarding the differences between males and females on the usage of social networks, Tüfekçi [7] similarly found that females are more likely to use social networks to keep in touch with friends either living nearby or in other schools, while males are more likely to use social networks to find potential friends and find people with have similar interests [8]. However, males tend to make new relationships in social networks more than females do. Tüfekçi [7] suggested that females are more social than males and they demonstrate differences in communication styles. Females use social networks, such as Facebook for maintaining existing relationships, academic purposes and following agenda more than males, while males use Facebook for making new relationships at a rate higher than females.

The gender gap is lessening as more people are exposed to using technology, but most researchers support the idea that social influences play a much stronger role in technology adoption for females than males [9]. Males appear to be more strongly influenced by their own attitudes toward using new technology, while female's decisions tend to be driven by their perception of others' beliefs that they should or should not adopt the technology [10]. These findings are consistent across income, education, and computer self-efficacy levels. Similarly, Mazman et al. [29] found in 300 prospective teachers (including 234 females and 66 males) that the social influence on females were significantly higher than males in the use of a technological innovation.

On the other hand, the technology adoption is potentially influenced by the tendency of females to assess their technical skills lower than males [11]. Regarding the adoption of technology, ECAR [9] conducted a survey to identify early and later adopters. Mainstream adopters refer to the people stating that they usually use new technologies when most people they know do. Figure 1 shows that about half (49.3%) of the respondents in [9] identify themselves as mainstream adopters, while the percentages drop off for earlier and later adoption categories. The figure demonstrates that 57% of mainstream adopters are females. 33% of the male respondents see themselves as early adopters and 18.7% as innovators (52.0% in total), while just a quarter of females (25.6%) choose these categories.

Which best describes you?	ECAR Descriptor
I am skeptical of new technologies and use them only when I have to.	Laggard
I am usually one of the last people I know to use new technologies.	Late adopter
I usually use new technologies when most people I know do.	Mainstream adopter
I like new technologies and use them before most people I know.	Early adopter
I love new technologies and am among the first to experiment with and use them.	Innovator

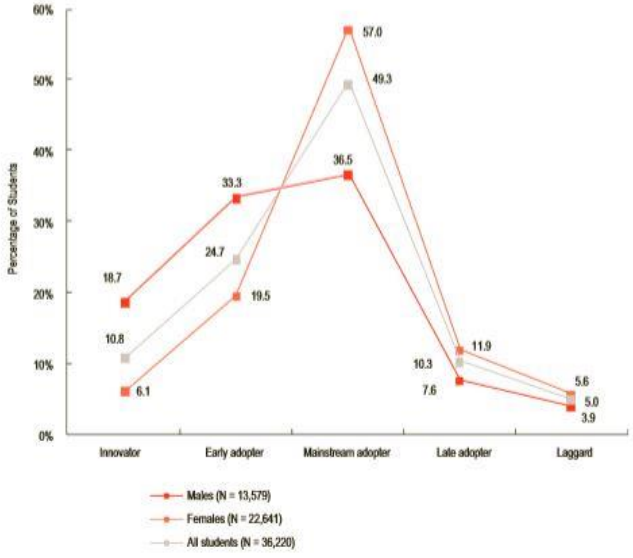

Figure 1. Technology adoption by gender [9]

The adoption of new technologies does not only depend on the gender, but also other social and cultural characteristics. There may be other unobserved non-gender differences that may impact adoption such as access and quality of resources for females. For example, regarding

peanut production in Eastern Uganda, Tanellari et al. [12] found that female farmers are less likely to adopt technology than male farmers. Furthermore, they found that females living in female-headed households are less likely to adopt new varieties than females or males living in male-headed households. Their analysis reveals that there are different dynamics between female and male-headed households when it comes to decision making with regard to peanut production.

Studies on the perception of IT show that although males and females in the United States have similar experiences with computers, females have an advantage in typing [13]. Workers in general state that they have more experience with computers than non-workers, and, in particular, working females have been using computers for more years than working men. Nonworking females state that they have less experience with computers than working females. However, there seems to be no perceived difference in the use of computers between nonworking and working men.

B. Gestural Communication

Human Computer Interaction (HCI) is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use. One of the primary goals of HCI is to target the design of user-centric and adaptive systems as well as personalization of devices and applications. Adaptive systems refer to interactive systems adapting their behavior to individual users based on the information acquired about them, the context of use and the environment. Therefore, personalization of devices and applications requires a careful analysis of gender differences to be widely accepted by anyone in the community.

HCI systems have evolved significantly starting from the use of mouse input [14] to multimodal systems integrating speech recognition, head and eye-tracking technologies, and static and dynamic hand gestures. Humans have an inherent need to use gestures, as they complement our ideas. To such an extent that humans are known to gesture even when talking on the phone. Gestures are considered as sign languages to externalize human thoughts.

The level of communication between users and their electronic devices has been largely limited to a pointing interface. As computers and technologies become increasingly integrated into our lives, the demand for technology has increased expanding into new sectors, as seen with the new apps and wider use of the smart phones and tablets. This brings the emphasis on the richness of communication conveyed by gestures as the new media of interaction. As a result, computer vision algorithms have improved, since the first VideoDesk [15], which was only detecting the user's fingers and thumb. Today, it is possible to recognize and respond to the whole body posture [16]. Hand posture detection has been used to give commands to the computer and robotics systems [17, 18] to give mobility to the people in wheelchairs. Hand rotation and movement indicate the parameters to give commands to these systems.

Regarding the individual differences in cognitive processing, controversial views exist. Herlitz et al. [19] state that there are gender differences in verbal, quantitative and visuospatial ability in human cognition. A general view is that males outperform females on visuospatial tasks and females outperform males on verbal fluency. Males show significantly higher mean scores on the arithmetical computations, arithmetical reasoning, and spatial cognition [20]. However, some researchers believe that although there are gender differences in our cognitive abilities (verbal, quantitative, visuospatial) these are quite small, and therefore, insignificant [21]. How small the gender differences in gestural communication and what their effects are on multimodal system design remain to be answered.

It was suggested by Kramer [22] that females more often use facial expression and hand gestures to express their thoughts than males. Regarding nonverbal communication, there are differences between females and males. Females use more expressions and nonverbal behaviors than males. Females are more skilled at sending and receiving nonverbal messages [23]. Males are louder and more interruptive and display more nervous, defluent behaviors. The differences in the mean use of hand gestures are also statistically significant in a social bar setting [24]. Males are likely to use their hands to express themselves and they rely on more obvious gestures. Females, on the other hand, present more subtle gestures and they restrain and exhibit deferential gestures [25].

Regarding hand preferences, Saucier and Elias [26] reveal that the number of gestures made with the right hand during speech is significantly higher for males, however, during listening, the number of gestures made with left hand is significantly higher. This may imply separate parts of brain being employed for processing information for different tasks. There is no evidence regarding the females left or right handed gestures which are associated with right and left sides of brain respectively. However, some other studies state there are no significant differences in the degree of hand preference between pointing gestures produced along with speech and gestures produced on their own [27]. This implies that different parts of brain are used in information processing for performing different tasks.

Cocher and Vauclair investigated the processes underlying gestural communication in children [27] and adults [28] by examining hand shapes and hand preference patterns associated with different types of gestures. They presented several communicative situations eliciting pointing gestures and symbolic gestures to 81 participants in an experiment in [27]. They found some differences in hand shapes depending on the function of pointing: contrary to results reported in children, the proportion of index-finger gestures was higher in imperative situations than in declarative situations. The distance between the gesturer and the referent was also found to influence hand shapes, proximal pointing being more frequently associated with index-finger gestures than distal pointing. The comparison of hand preferences revealed a greater right-sided asymmetry for declarative pointing than for non-

communicative activities, whereas there was no difference between imperative pointing and non-communicative activities, or between symbolic gestures and non-communicative activities.

Investigation of tangible HCI technologies suggests that it is important to be cognisant of gender with respect to the interactions they facilitate [30]. However, no specific studies address whether any gender differences are present in the use of gestures or hand preferences, while people communicate with computer systems.

III. GESTURE CLASSIFICATION

The most recognized classification for hand gestures is the one established by McNeill in [31]. McNeill classifies gestures as seen in Table I. Gestures have also been classified according to their purpose. They could be goal-oriented (change of position, shape), indirect manipulation (set, stop), empty handed gestures (wave, snap, point, take), and haptic exploration (touch, stoke, knock).

A. Gesture Types

McNeill [31] identified the gestures types as summarized in Table I.

TABLE I. CLASSIFICATION OF GESTURE TYPES

Gesture	Function	Linguistic example
Iconic	Resembles that which is being talked about	Flapping arms like wings when talking about a bird
Metaphoric	Abstractly pictorial; loosely suggests that which is being talked about	Making a box shape with hands when talking about a room.
Beat	Gestures with only two phases (up/down, in/out) indexing the word or phrase it accompanies as being significant	Rhythmic arm movement used to add emphasis
Deictic	Gestures pointing to something or somebody either in concrete or abstract	Pointing while giving directions

Iconic. Iconic gestures are identified as actual picturing, as if drawing. Therefore, if a participant mentions the word "square" and draw a square, it is considered an iconic gesture.

Beat. Beat gestures are generated by context and marked a gesture or transition. A beat gesture is identified, for example, if a person describes the back of a chair and stresses staying back and the hands are put a bit forwards. These are mainly low energy low kinetic gestures.

Repetition. Repetition gestures are part of beat gestures, but are counted separately.

Deictic. Deictic gestures correspond to pointing, but they do not include gestures performed purely with the index fingers. Pointing gestures are normally accompanied by words like "there" or "left" for example.

Metaphoric. Metaphoric gestures represent conceptual subjects. They may represent an abstract concept such as "old" or "retro". A user would not use these as an actual depiction, but they may use them to supplement a word or enhance the meaning of another gesture.

Junk. Junk gestures are identified as gestures without a particular meaning. This could be a gesture that the user takes back (a "mistake") or some transition movements.

B. Gesture Segmentation

The technique mostly used for gesture analysis is gesture and speech alignment. In practice, gestures are identified as atomic parts or as a sequence of hand shape [32] (the latter being harder to measure). Normally, the gesture coders are guided by the endpoint localization to perform the segmentation and recognition. The reality is that the spatio-temporal variation comes from the fact that not only do different people move in different ways, but also even repeated motions by the same subject may vary [33]. The issues here are speed and endpoints, making it challenging to know when a gesture ends and when another begins.

Within different technologies, there are different methods for detecting a candidate cut. For example, in video games they are based on three criteria: abnormal velocity, a static gesture, and severe curvature [34]. Li and Greenspan [33] focus on how the endpoints are located asking participants to repeat various actions several times in order to document the variances. These variances, they claim, are useful for identifying the range of a given gesture, and therefore a better identification. This way, to build a gesture model, a gesture representation must be repeated at a single moderate speed. Gesture model does not have to be perfect.

IV. METHODOLOGY

This section covers the explanations of the methodologies we used in the project. The methodology used for counting gesture frequency, types and occurrence is the same as the methodology used in [2] for addressing cultural stereotypes in gestural communication. Nasser and Kavakli [2] stated that the culture has an impact on the frequency, types and occurrences of certain gestures and this could be explained by Hofstede's cultural dimensions [35]. This methodology was also used by Kavakli and Chen [1] and Liu and Kavakli [36] for addressing gender differences in information and cognitive processing respectively.

A. Survey

The goal of the survey is to explore the gender differences in the perception of Information Technology (IT). This survey was carried out in the early stages of the project to help us understand the general perception of males and females regarding IT. 20 participants joined our survey on the perception of IT. The age range of participants was 25-30 years old. They came from Asian and Australian backgrounds. They were either professional or university students. For the purpose of this survey, we collected the results from the participants based on 21 questions regarding their perception of using electronic devices in their daily lives as well as internet usage.

B. *Video Analysis*

We used the video annotation tool ANVIL [37] for video analysis. ANVIL offers multi-layered annotation based on a user-defined coding scheme (Figure 2). Special features offered by ANVIL are the tracks for time stamp, coding facilities on video footages and a project tool for managing a collection of annotation files. Gestures are separated by pauses. A pause is defined as a temporary stop in action or speech. The purpose of this pause is to eliminate the period of inactivity from the actual gesture time. This pause could appear at the beginning of a video, when the participant explains what he or she might do, or when the participant states that he or she has ended the action. ANVIL permits the creation of a track on the time line where gestures are segmented and coded.

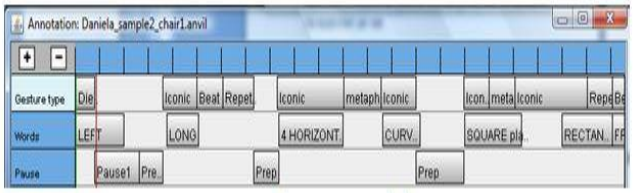

Figure 2. ANVIL annotation track

In video analysis, we used the gesture classification defined by McNeill [31] as used in [1] and Table I. All participants used words to accompany their gestures, even if they were not instructed to do so.

C. *Experiments*

18 participants including 8 males and 10 females joined the experiment. The participants were divided into two groups. The participants were the ones who did the survey before the experiment. Their age range was 25-30 years old. They were from Australian or Asian backgrounds. The participants were either employed or unemployed. We have chosen a group of males and females with English as their native language. We explained the task to the participants. They were asked to describe a particular object (Figure 3).

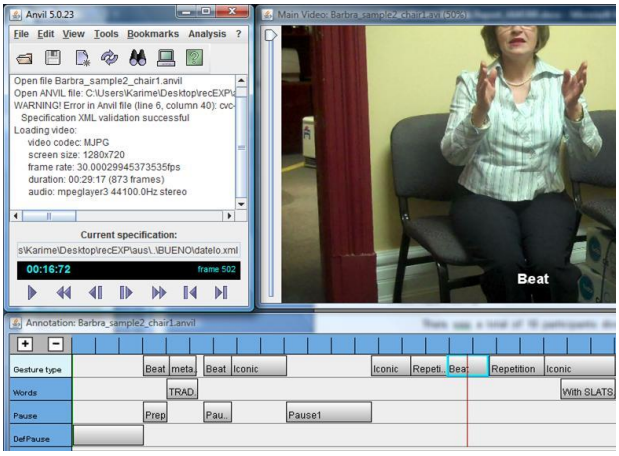

Figure 3. A snapshot from the experiments

We used a camera to record each participant. During the experiment, all participants were given the task to describe a chair, the participants were also instructed to describe the chair as if they were describing the object to someone who cannot see it as if they were in a videoconferencing session. They were encouraged to use both hands and as many gestures as possible.

V. RESULTS

This section covers the results of survey and experiments.

A. *Survey Results and Demographics*

Analysing the survey, we found that all male participants perceive themselves as having more experience with computers than female participants. According to Table II, 80% of male participants state that they have more than 10 years of experience in using IT, while the rest opts for 6-9 years. The trend is reverse in females with 86% stating that they have 6-9 years of experience in using IT and 13% with more than 10 years. According to Table II, either males start using technological devices perhaps earlier than females or they consider themselves having higher level of computer experience than females.

TABLE II. PERCEIVED COMPUTER EXPERIENCE

experience of using computer	Male(%)	Female(%)
less than 3 years	0	0
3-6 years	0	0
6-9 years	0.2	0.86
more than 10 years	0.8	0.13

As seen in Table III, most females consider themselves as beginners in computer use (92%), which indicates that they use computers at a basic level, such as internet browsing, typing etc. However, most males (92%) consider themselves as intermediate or professional users of computer.

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TABLE III. PERCEIVED COMPUTER SKILLS

level of computer skill	Male (%)	Female (%)
Beginner	6	92
Intermediate	26	13
Professional	66	0

According to Table IV, 53.3% of males spend more than 6 hours on a computer each day; however, none of the females opts for that. At most, 33.3% of females spend 4-6 hours on a computer each day. This daily experience of using computers seems to have a significant influence on the perception of IT. Perhaps, as a result of this, males feel more confident in using computers than females or at least they state that it is the case.

TABLE IV. COMPUTER TIME

Average time spend on computer each day	Male (%)	Female (%)
Less than 1 hour	0	0
1-3 hours	26.6	66.6
4-6 hours	20	33.3
More than 6 hours	53.3	0

More interestingly, we asked participants in the survey what the gender of their IT device is (i.e., desktop, mobile, laptop or tablet, and the internet) and compared the responses of females to males. Table V demonsrates the perceived gender of IT device overall including males and females. According to this table, while desktop computers seem to be perceived as a more masculine technology (43.3%), mobile phones are perceived more feminine (50%). Laptops have no gender (68%), neither does the Internet (73%).

TABLE V. PERCEIVED GENDER OF IT DEVICE

	Desktop (%)	Mobile Phone (%)	Laptop (%)	Internet (%)
Masculine	43.3	6.6	8	10
Neutral	33.3	43.3	68	73
Feminine	23.3	50	24	16

However, when comparisons are drawn between males and females as in Table VI and Table VII, we found that there are gender differences in the perception of the gender of IT. We found that all male participants consider the internet with no gender at all. Majority of males think that their IT device has no gender. Still, if there is a gender associated with it, their desktop is masculine (40%), but mobile phones (20%) and laptops are feminine technologies (14.2%) for males.

TABLE VI. PERCEIVED GENDER OF IT DEVICE BY MALES

men	Desktop (%)	Mobile Phone (%)	Laptop (%)	Internet (%)
Masculine	40	13.3	7.1	0
Neutral	53.3	66.6	78	100
Feminine	6.6	20	14.2	0

More than 86.6% of females think that their desktop has a gender (while more than half of these think that their desktop is masculine, the other half think that it is feminine). Their perception of mobile technology is primarily feminine (80%), but their laptop (36.3%) and Internet (33.3%) are partially feminine, while majority of them think that their laptop and internet has no gender.

TABLE VII. PERCEIVED GENDER OF IT DEVICE BY FEMALES

women	Desktop (%)	Mobile Phone (%)	Laptop (%)	Internet (%)
Masculine	46.6	0	9	20
Neutral	13.3	20	54.5	46.6
Feminine	40	80	36.3	33.3

These findings imply that males show a tendency to objectify the technology and they do not seem to see the personality or gender behind their IT device. For them, an IT device is an object and nothing more than that. Whereas a large proportion of females seem to perceive a personality and gender associated with their IT device. These differences between males and females may be the driving force behind their use of technology.

B. Video Analysis Results

We used ANVIL video annotation tool to analyse the video records of the experiments. We used seconds as the measuring unit for time. In total, we collected 8 males and 10 females' gestures, but only the ones with better expression and comprehension of the task were chosen for analysis. Therefore, the final selection was 5 for each gender group. There are a total of 157 gestures in this experiment.

In 5 male participants, the average duration of video is 1min 28 sec and the longest video footage is 1:50 minutes. The total number of gestures in the video records is 72. Male participants used only 4 gesture types in the description of the chair in our experiment. According to Figure 4, the use of iconic gesture type is 50%, then followed by deictic, junk and beat gesture types. We found higher number of deictic and junk gestures 17% each in males video protocols. We also found that male participants did not use metaphoric gestures during the description, and only 3 males performed a metaphoric gesture.

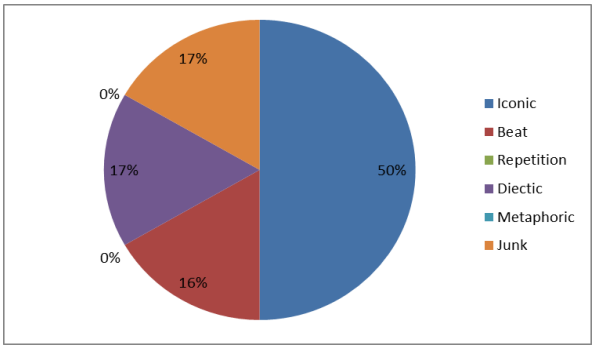

Figure 4. Gesture types used by males

In female participants, the average duration of video is 1 min 48 sec and the longest video is 2:10 minutes. The total number of gestures in the video is 84. Female participants

used all 7 types of gestures in the description of the chair in our experiment. According to Figure 5, the iconic gestures were more than 56% in the females' video records, followed by deictic, junk metaphoric, repetition and junk gestures. The beat gestures are used the least by females.

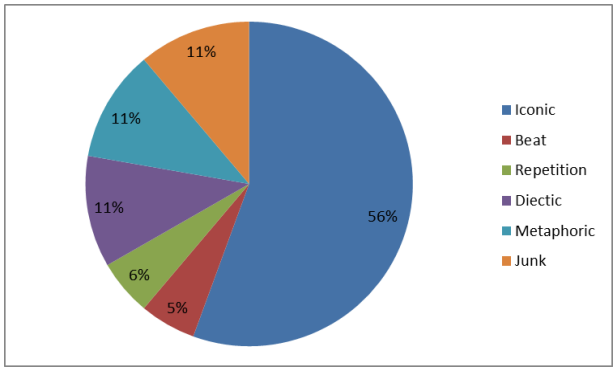

Figure 5. Gesture types used by females

C. Comparative Analysis

The most significant finding in both genders for a gesture based interface design is the ratio of iconic gestures as these are the most frequent gesture types in both protocols (50% for males and 56% for females). Both males and females use junk gestures but the portion of junk gestures is smaller in females (11% vs 17%). Comparing Figure 4 and Figure 5, we found that male participants only use 4 types' gestures out of 7. However, females make use of all 7 types. Some female participants would even use metaphoric gestures. We found that females are more diversified compared to males in their gesture types. Table VIII presents comparative analysis results.

TABLE VIII. COMPARISONS

	Total video duration	Avg video duration	Total num.of gestures	Avg gestures per participant	SD	Total gesture time	Ave gesture time	Frequency
Male	384 sec	76.80 sec	72	14.4	8.24	128 sec	25.6 sec	1.78
Female	444 sec	88.75 sec	84	16.8	9.12	201 sec	40.2 sec	2.39

Analysing the results in Table VIII, we found that females use more gestures in a longer period (84 vs 72 gestures and 1:48 vs 1:28 seconds on average). The frequency of gestures is higher in females (2.39 vs 1.78). On the other hand, males perform less number of gestures in a shorter time frame (25.6 sec vs 40.2sec). The total duration of video is larger in female participants. The video records comprise both gestures and speech. Females' descriptions are longer. The total gesture time is nearly as twice as male participants in females.

Detailed description of the abbreviations defined in Table VI can be listed as follows as in Nasser and Kavakli [2]:

Total video duration: The total video duration is measured as the sum of total duration of each participant.

Average video duration: The average video duration is measured as the number of total video duration divided by the number of the participants.

Total number of gestures: The total number of gestures is measured as the sum of the total gestures of each participant used in the video.

Average gestures per participant: The average gesture per participants is measured as the number of total gestures performed by the participants divided by the number of the participants. This way we get the average gestures performance for each gender.

Total gesture time: The total gesture time in the video records.

Average gesture time: The average gesture time is measured as the number of total gesture time divided by the number of the participants.

Frequency: The frequency is measured as the number of gestures performed by a participant divided by the gesture time period of the same participant. This way we get the gestures per second and it will help assess speed of gesture performance and point out what gestures are most significant for the gesture recognition system.

D. Structural Analysis Results

To analyse gender differences in the functional description of a chair, we divided the sample chair into different parts (Figure 6): seat, back, bars and legs. Each part is connected to another part. In Figure 6, we found gender differences in the descriptions of the functional parts of a chair. Functional parts of a chair were described before in [38]. In [38], Kavakli et al. found that chairs are externalized and drawn by fine arts students using a functional description as a mental image.

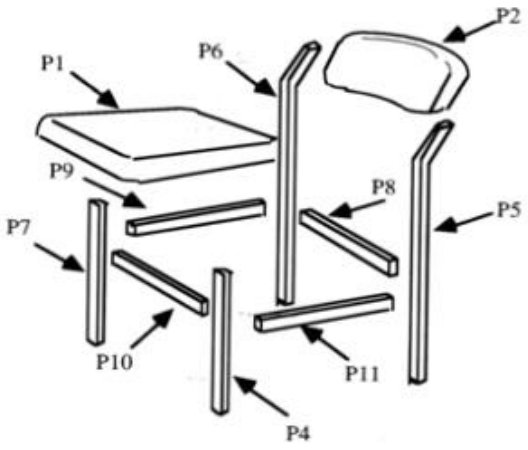

Figure 6. Parts of a chair as used in [38]

The number of males and females describing the specific parts of the chair is demonstrated in Figure 7 following a part based description. Overall, 2 males vs 3 females describe Part1, 3 males vs 1 female Part2, 2 males vs 4 females Part4 and 5, 0 males vs 4 females Part5 and 6, 1 male vs 4 females Part6 and 7, 2 males vs 5 females Part8 and 9, 0 males vs 4 females Part9 and 10, and 0 males vs 4 females Part10 and 11. We found referral to 10 parts of the chair in males vs 29 in females.

We also observed that females' seem to more systematically refer to a structural description in their description. For example, first they tend to describe the leg followed by the other legs, then they start pointing out the rungs, the seat and back of the chair. However, males' description of these functional parts is random.

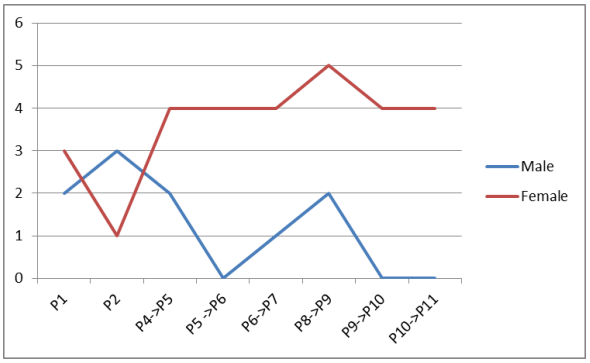

Figure 7. Number of participants describing functional parts of a chair

VI. Conclusion and Future Work

Our motivation to examine gender differences originates from ubiquitous system development for gesture recognition [16] suggesting the use of gender-adaptive systems in HCI [36]. Gender differences found in psychology, computer science, marketing, neuroscience, education, and economics that strongly suggest that males and females solve problems, communicate, and process information differently. In this study, we defined two hypotheses to test:

(1) Users' gender and their computer experience have a significant effect on the perception of the gender of IT.

(2) Gender differences in gestural communication have a significant influence on user association and the perceived gender of technology and in return these may affect the acceptance of technology.

Regarding Hypothesis 1, there are gender differences in the perception of the gender of IT. While desktop computers seem to be perceived as a more masculine technology (43.3%), mobile phones are perceived more feminine (50%). Laptops have no gender (68%), neither does the Internet (73%). When comparisons are drawn between males and females, all male participants consider the Internet with no gender at all. Majority of males think that their IT device has no gender. Still, if there is a gender associated with it, desktop is masculine (40%), mobile phone (20%) and laptop are feminine technologies (14.2%). On the contrary, more than 86.6% of females think that their desktop has a gender. Their perception of mobile technology is primarily feminine (80%) but their laptop (36.3%) and internet (33.3%) are partially feminine, while majority of them think that their laptop and internet has no gender.

These findings imply that while males show a tendency to objectify the technology, and do not seem to expect to find a personality or gender behind their IT device, a large proportion of females seem to perceive a personality and gender associated with their IT device. These differences between males and females may be the driving force behind their adoption of IT.

We also found that 53.3% of males spend more than 6 hours on a computer each day, however, only 33.3% of females spend 4- 6 hours on a computer each day. Perhaps, as a result of this, most females consider themselves as beginners in computer use (92%), however, most males (92%) consider themselves as intermediate or professional users of computer.

Regarding Hypothesis 2, there are gender differences in the use of gestures. We found male participants only use 4 types' gestures out of 7. However, females make use of all 7 types. Females seem to be more diversified compared to males in their gesture types. We found higher number of deictic and junk gestures (17% each) in males' video protocols, as well as no use of metaphoric gestures. Iconic gestures are the most frequently used gestures in both protocols (50% for males and 56% for females). The beat gestures are used the least by females. Both males and females use plenty of junk gestures but the portion of junk gestures is smaller in females (11% vs 17%). Females use more gestures in a longer period (84 vs 72 gestures and 1:48 vs 1:28 seconds on average). Frequency of gestures is higher in females (2.39 vs 1.78).

We also found gender differences in the functional description of a chair, referring to differences in mental imagery. Females refer to functional parts 3 times as much as males. This implies that males and females may employ different cognitive processing methods. Females tend to describe the chairs following a part based description and referring to a structural description. However, males' description of these functional parts seems to be random.

User association with IT may be driven by the way humans process information. If there are gender differences in the way we process information and males and females use different system architectures, then the development of gender-adaptive systems would increase the acceptance of technology.

There is also supporting evidence in behavioral research that there are gender differences in cognitive spatial abilities [39-41]. These may directly impact the ability to perceive, interpret, and cognitively process spatial properties and spatial relationships of visual objects [42]. Males have less computer anxiety [43]. Future research studies should investigate not only psychological but also physiological aspects of gender differences in information processing. In this article, we have presented that these differences may be the reason for females being not so interested in a masculine

technology. To motivate females' interest in IT, we must start developing feminine technologies that females feel more associated with as demonstrated in this article.

It is important to state that these are only pilot studies. Future studies require a larger sample size and must focus on the consistency of the annotations using independent coders.

It would be useful to collect psycho-physiological feedback to verify these results, such as EEG data sets. Further, research may also investigate the combined effects of gender and culture on gesture performance.

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Sports Medical App to Support the Health and Fitness of Workers

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***Abstract*—This paper describes the development and first version of an eHealth system for sports physicians who support employees in improving their health and fitness. Regular physical activity improves quality of life and has various health benefits. Companies have an interest in the health and fitness of their employees. For employers it is important to encourage this in a safe way. To this end, the sports physicians of Isala Hospital in Zwolle, The Netherlands, offer sports medical examination and guidance programs to companies. The sports physicians wanted to use smartphone technology to improve and expand their services. It was important for them to have all the client data stored confidentially in one database under their own supervision, e.g., to perform scientific analyses. Since not all details of the end product were clear at the start of the project, an incremental and iterative development method was used. In this way, a prototype online and mobile data tracking system is developed that makes it possible (among others) to: give employees access to their sports medical examinations results with personalized standard values; insert goals that are advised by the sport physicians; use a heart rate sensor and a smartphone application (app) for training data entry by the employees themselves; import data from other sports apps; compute individual 's heart rate zones and energy use of a training based on sports medical test results. A focus group session with sports physicians have been performed to evaluate the prototype and to discuss extensions. Important enhancements include periodical entry of health data and comparing sports activities with the Dutch Standard for Healthy Exercise and the Fit Standard. We present the approach we have chosen and the functionalities of the first prototype of the system, which typically make it an application that supports sports medical services.**

Keywords - sports medicine; employees; exercise; evidence based; application.

I. INTRODUCTION

This paper describes the foundation, development and first version of an eHealth system for sports physicians who support employees of companies in improving their health and fitness [1].

Sports Medicine is the medical specialty that focuses on promoting, safeguarding and restoring the health of people who (want to) sport or exercise. It also aims to promote and restore the health of people with chronic conditions through sports or exercise. For both facets, the balance between specific physical load and capacity are explicitly taken into account [2].

Regular physical activity improves quality of life and has various health benefits [3][4]. However, about one third of the adult Dutch population does not meet the Dutch Standard for Healthy Exercise for their age group [5][6], which prescribes 30 minutes of moderate activity at least 5 days per week (for 18 – 55 years olds) [7]. This evidence-based standard focuses on maintaining health in the long term. Further, only a quarter of the Dutch population aged 19 years and older meets the Fit Standard [6], which prescribes 20 minutes of vigorous activity at least 3 days per week [7]. This standard focuses on maintaining physical fitness in terms of endurance, strength and coordination.

Companies have an interest in the health and fitness of employees as this may have an effect on sickness absenteeism and productivity. This is especially relevant nowadays because of the ageing of the working population. Besides, the increase of screen work contributes to non-compliance with the guidelines for sufficient exercise. Employers may want to actively maintain or even improve their employees' health and fitness. A company could present itself as a good employer to offer its employees counseling by sports physicians as part of occupational health care and fringe benefits. Moreover, sporting together can improve interaction between employees of different departments resulting in better cooperation and increased innovation. However, for employers it is important to encourage this in a safe and responsible way.

The sports medicine department of Isala in Zwolle, The Netherlands, performs sports medical examinations and guidance for groups of employees of external companies with the aim of encouraging movement and improving the health of the workers. Participants are periodically examined and supervised regarding their training and health during a year. With the aid of the physician, each participant determines his own goal. To this end, employers can choose specific sporting events in which their employees can participate at the end of the year, such as a half marathon or bike ride. Participants receive an individual report with advice and the companies receive a general management report.

Until recently, only data of the sports medical examinations were locally stored in individual files per participant. This had several major drawbacks: a) participants could not see their own data, b) training

activities of participants were not included, c) health parameters of the participants could not be followed during the training period, d) it was not clear whether the individual goals were met, and e) it was not possible to analyze data at group level and set up management reports.

The method of data storage of medical examinations and the way of guiding participants needed renewal. The sports physicians wanted to use smartphone technology to improve and expand their services. They wanted more insight in the progress of health and fitness status of the participants, and to provide the participants themselves with meaningful and motivational information. It was important for them to have all the data stored confidentially in one database under their own supervision. To that end, we looked for an online data tracking system that should provide:

1. Own, central, confidential, secure and adequate data storage;
2. User-friendly and reliable data entry by the sports medicine staff;
3. Appropriate authorizations for different types of users;
4. Insertion of goals and training schedules by participant, trainer or sports physician;
5. Use of sensors and apps for data entry by participants themselves;
6. Low-threshold use by the (sometimes, at the start) inactive and sedentary participants;
7. Possibility to import data collected with other sports apps by the (sometimes) more athletic participants.
8. Participants meaningful insight in:
    a. their own sports medical examination results, compared to their age and sex adjusted standard values;
    b. their training sessions;
    c. progress in training and health parameters compared to:
        i. Dutch Standard for Healthy Exercise for their age group;
        ii. their personalized goals;
        iii. results of their (company) peers.
9. Automatic feedback to individual participants to stimulate or warn;
10. Contact between participants and sports physician or trainer;
11. Automated standard analyzes and (management) reports;
12. Basis for scientific sports medical research.

The sport physicians searched by asking colleagues and on the internet for systems that met these requirements. A system that fully supported the sports physicians' guidance model was not found.

Therefore, the sports physicians contacted the research group ICT-innovations in Health Care of Windesheim University of Applied Sciences, Zwolle, The Netherlands. Together they started a project. The primary objective was to build a system that met all the requirements of the sports physicians and made use of new technology in the field of monitoring and communication of sports and health parameters, such as web services, database servers, sensors, apps and smartphone technology. The secondary objective was to provide an appropriate model for monitoring of ambulatory patients by other medical specialties of the hospital. Furthermore, we wanted to encourage knowledge exchange between the hospital and the university of applied sciences and to stimulate the development and use of technology for the benefit of health and healthcare. Finally, we wanted to make IT students acquainted with, and train them for a position in the field of medical informatics. The project was named Hightech4SportsMedicine.

In Section II, we will present the approach that we have chosen in order to develop the system. In Section III, we show the results of the State of the Art study and the functionality of the first prototype of the system. In Section IV, we give an overview of the results of the focus group session with sports physicians. In Section V, we discuss the work that has to be done in the future.

II. APPROACH

In this section, the approach is presented that have been chosen in order to develop the system.

A. State of the Art

We performed a brief literature review on systems that were available for, or can be related to sports physicians and athletes to share their training progress, training experiences and health parameters to support medical guidance. The findings provided input for the system to build.

B. Integration with education

We deploy IT students to develop the system. In this way, we give the students the opportunity to develop skills in the field of medical informatics. The school of Information Technology and the research group ICT-Innovations in Health Care have expressed the intention to give students the opportunity to participate in the project in the context of the minor App Development. Different groups of students will be provided this opportunity during four consecutive semesters. The school will provide additional and customized education and guidance, and contribute to the continuity of the project. Three IT students have developed a first basic version of the central database for a data-tracking system. Two times three other students have consecutively developed the system so far and worked on an app with sensors for the employees.

C. Agile / Scrum

Many things in this project were and are still unclear. Research to investigate the needs, desires and possibilities form a major part of this project. Therefore, an ease of communication and social integration with the stakeholders and end users are heavily desirable. Besides, working iteratively and incrementally makes it possible to quickly obtain the advantage of new insights because the planning and the priorities can be easily adjusted once new information becomes available. Also, good control and coordination mechanisms are important for delivering usable

increments. Scrum [8] provided us with the needed instruments to clarify the needs and manage the project. It also provides defined meetings and activities and gives structure and clarity for the team and stakeholders.

The role of the students regarding the important elements of Scrum is:

1) Product backlog

The product backlog is basically a prioritized list of features that the customer wants, described using the customer's terminology. The IT students together with the product owner (a sports physician) are responsible for setting up the product backlog document and managing it.

2) Sprint planning

A scrum sprint is a confined to a regular, repeatable work cycle. Sprint planning is a critical meeting. The functionality to be delivered in the sprint is planned at this meeting. The IT students plan this meeting and invite the product owner to attend the meeting. They discuss the product backlog and decide which functionality is to be delivered in the next sprint, taking the following factors into consideration:

- The sprint length;
- The available capacity and resources;
- The priority and importance of the functionality;
- The scope of the functionality;
- The time estimate for the functionality.

The meeting results in a sprint backlog document. The IT students ensure that all the privies are provided with a copy of the sprint backlog document.

3) Sprint

The sprint is the heart of Scrum. Within the sprint the needed functionality is implemented, tested, integrated and accepted. To make the feedback cycles short and effective enough, the sprint is limited to two weeks. The IT students start the sprint with making an appropriate design. The design should fit the overall architecture of the software. The IT students distribute the functionality to be implemented among them. Regardless who is implementing the functionality, all the IT students are responsible for the performed work. Working in this way should enhance the team spirit and ensure the distribution of knowledge. The sprint is closed with a sprint review. In the sprint review the IT students demonstrate the work done within the sprint and get the performed work accepted by the stakeholders. The functionality that has not been accepted by the stakeholders or finished by the IT students will be put back in the product backlog. For a delivered functionality to be accepted, it should satisfy a set of rules that has been defined by the IT students and the product owner. This set of rules is called a Definition of Done. After the sprint review, the IT students plan the next sprint planning meeting to start the scrum cycle again.

D. Focus group

After a presentation of the prototype, we conducted a focus group meeting with six sports physicians (in training) and one physician assistant to identify what enhancements are important to them.

III. RESULTS

In this section, we show the results of the State of the Art study and the functionality of the first prototype of the system.

A. State of the Art

There are information systems that support sports physicians in recording patient data and are thus in fact electronic patient records (EPRs). However, these EPRs do not usually give patients access to their data. Besides, there are no specific EPRs for sports medicine. Additionally, there are apps that support the physician or athlete in the diagnosis and treatment of a specific sports injury. Examples are the "Medical iRehab AnkleSprain" [9] and the "Medical iRehab Tennis Elbow" [10]. Furthermore, there are countless apps for athletes focusing on the monitoring of training and health parameters, whether or not equipped with training schedules and advice. We found, however, no systems specifically aimed at sports medical examination, advice and guidance where the main objective is to assist employees or other participants in safe sports practice and promoting health and fitness. Moreover, the systems found showed no alignment of data collection by the athletes and the information needs of the sports physicians, no fitting with the care processes of the physicians and no provision of an own, secure and insightful database for management reports and scientific analysis. Mosa et al. [11] searched MEDLINE to identify articles that discussed the design, development, evaluation, or use of smartphone-based software for healthcare professionals, medical or nursing students, or patients. There were no articles about applications for sports medical physicians or their clients.

Researchers of the University of Florida concluded in a recent review that very few of popular free apps for physical activity were evidence-based and met the guidelines from the American College of Sports Medicine [12]. This makes it difficult, especially for beginners, to follow a safe and physiologically sound progression in their exercise regimen.

Another review also demonstrated a shortage of evidence-based physical activity apps [13]. The authors underscore the need for development of evidence-informed mobile apps and highlight the opportunity to develop evidence-informed mobile apps that can be used clinically to enhance health outcomes. They further state that: "*social integration features (e.g., sharing and connecting with others) as well as technological features (e.g., pairing with peripheral health devices) may offer the greatest potential to enhance health outcomes among clients prescribed healthy physical activity behaviors*".

Kranz et al. [14] did a comparative review of smartphone apps for health and fitness. The authors learned that there was a great potential for improvement in usability, instruction quality and fostering long-term motivation. Feedback adds to long-term motivation by giving insight in singular exercises and in the history of training to see that regular training 'pays off'.

Powel et al. [15] state that the mHealth app industry is still in its infancy, but that its future looks bright. *"However,*

the potential of apps will only be realized if patients and clinicians trust apps, if apps are known to be effective, and if apps can communicate securely and meaningfully with EHRs and personal health records…"

Rabin et al. [16] recruited 15 sedentary adults to test three currently available physical activity smartphone apps. Users appeared to have specific preferences, including automatic tracking of physical activity, track progress toward physical activity goals, apps being flexible enough to be used with several types of physical activity, user friendly interfaces (e.g., a one-click main page) and goal-setting and problem-solving features.

Middelweerd et al. [17] explored Dutch students' preferences regarding a physical activity application for smartphones. Participants preferred apps that coach and motivate them, which provide tailored feedback toward personally set goals and that allow competition with friends. In another study, Middelweerd et al. [18] rated apps based on an established taxonomy of 23 behavior change techniques used in interventions. The study demonstrated that apps promoting physical activity applied on average 5 out of the 23 possible behavior change techniques. Techniques such as self-monitoring, providing feedback on performance, and goal-setting were used most frequently. The authors conclude that apps can substantially be improved regarding the number of applied techniques.

Bert et al. [19] underline the crucial role of physicians in the management of patients, and therefore, the smartphones should play only a complementary role in the health management of individual patients.

From this extensive review can be learned that (among other things) it is important to provide insight into health status and degree of movement whereby personified standard values, recommendations and feedback are based on evidence as applied by sports physicians.

B. The Architecture

In order to be able to build a first version of the system and to be able to expand the functionality, the following architecture is used. This includes:

1) Central database

A centralized database where monitoring data and health measurements will be saved. No personal data will be saved that can be directly or indirectly linked to physical persons. The database will also give the possibility for retrieving data for management reports as well as scientific analysis.

2) Web Services

For achieving data quality and data security, secure web services are built. They are a set of functionalities, which is used for data entry and data retrieval. It forms the only entry point to the central database.

3) User applications

In this context, the term user applications refers to the applications that could be used by the end users for data entry and data retrieval, and for communication between participants and sports physicians. A web site is built for this goal and a native (iOS) mobile application is being implemented.

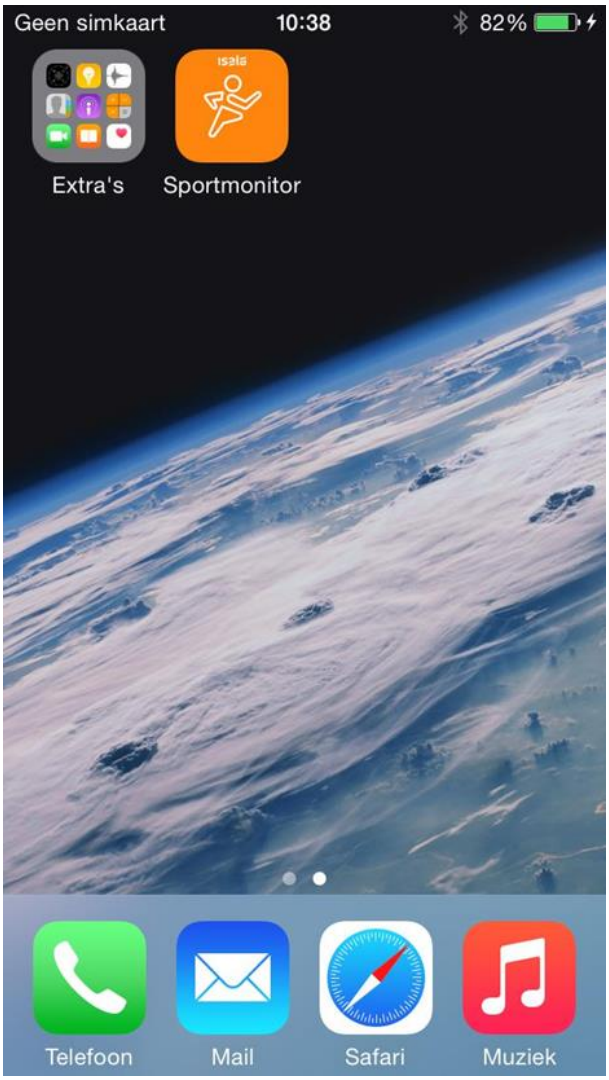

Figure 1. App icon Isala Sportmonitor

4) Sensors

The system makes use of the GPS system of the iPhone in order to determine location, route, distance and speed. A chest strap based heart rate sensor with Bluetooth Low Energy (LE) connectivity is used [20]. Bluetooth LE is a feature of the latest Bluetooth specification, Bluetooth 4.0.

C. Data quality

Data quality is achieved by working with value limits for data entry, automatic alerts when capturing improbable values and automatic calculation of values from other values, e.g., BMI from length and weight, and body fat percentage from multiple skinfold measurements.

D. Sports Medicine App with Sensor

A first, but not yet complete version of the app has been developed for the iPhone. This version allows participants to see their sports medical test results like peak expiratory

flow, cholesterol level, fat percentage, orthopedic tests, maximum heart rate, electrocardiogram, etc. Further, trainings data like type of sports, duration, distance, speed, route, heart rate zones and energy consumption have been implemented.

This paragraph demonstrates the app developed so far. The app for the end users is self-evident in Dutch. Figure 1 shows the icon designed in the house style of Isala hospital.

When the app is opened for the first time, the app is requesting permission to send messages. The app needs this permission to send reminder messages during a workout. Further, the user must agree with the terms of use before the app can be used. The app can work completely offline unless the app is used for the first time. In that case, or if obtained a new password, it is necessary to log in with an internet connection.

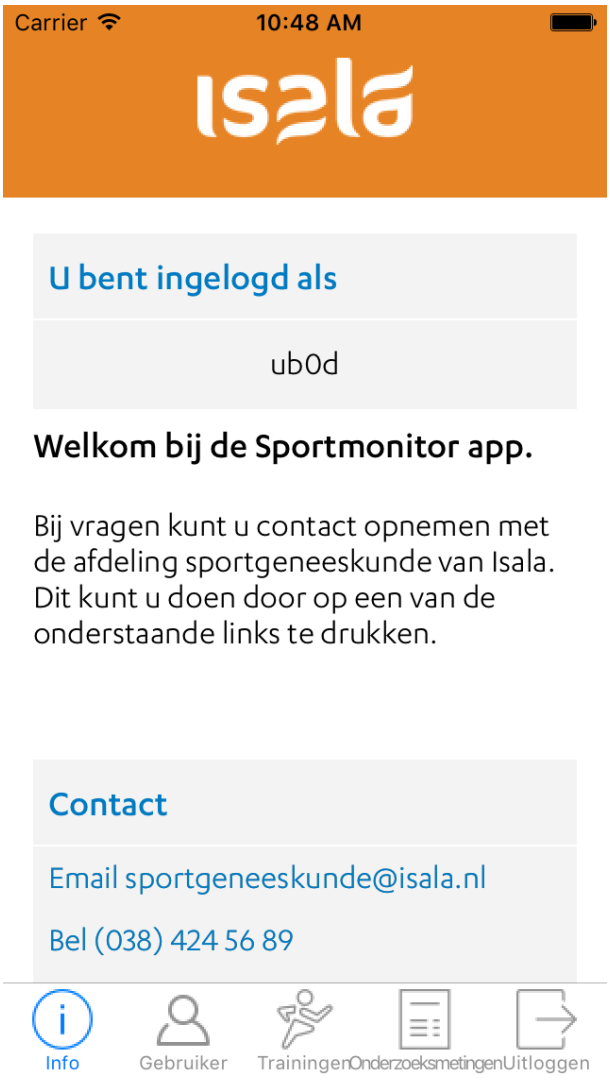

Figure 2. Contact information of the department of Sports Medicine after logging in, with email address, telephone number and link to website.

Figure 3. Example of sports medical test results; first page. “Conclusie” = conclusion; “Metingen” = measures; “Geslacht” = gender; “Leeftijd” = age; “Gewicht” = weight; “Lengte” = Length; BMI = Body Mass Index; grey circle: neutral value; orange circle: low health risk.

To use the app, it is necessary to log in with a username and password. If the user is logged in, all data in the app can be viewed. To prevent that someone else can view the data, each time when viewing confidential information the user will have to enter the password again. In this manner, the further anonymous data cannot be linked to the owner of the phone, e.g., in case of theft or loss of the phone.

Figure 2 shows the first page after logging in. The first page presents the contact information of the department of sports medicine of the Isala hospital.

When pressing "Onderzoeksmetingen", a list is presented of all sports medical examinations that have been conducted for the user with their dates. When subsequently a sports medical examination is touched, the results of all the tests of that sports medical examination come into view

(Figure 3). At the top is the conclusion of the sports physician, followed by all the test values. By means of scrolling, the rest of the values can be seen (Figure 4).

After each measurement with value, a colored circle is shown, which may indicate what the result of this measurement means in comparison to an evidence-based (and sometimes age and sex adjusted) standard that is used by the sports physicians. When there is no standard available or not relevant for a measurement, the circle is grey.

When there is a standard available, a green circle means a 'normal', healthy value; an orange circle means low health risk and a red circle means high health risk.

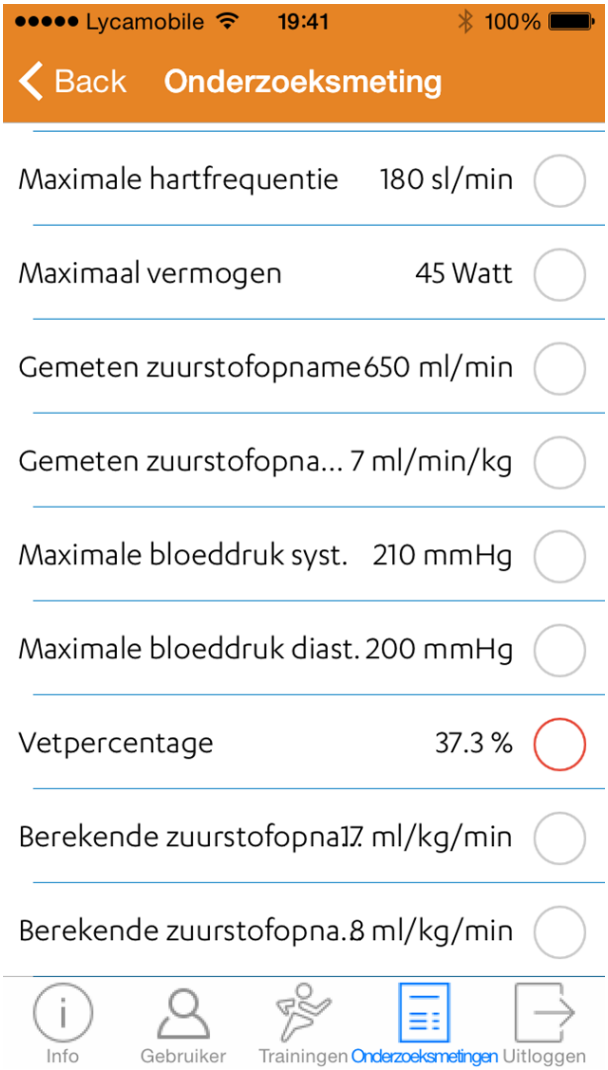

Figure 4. Example of sports medical test results; second page. "Vetpercentage" = fat percentage based on skinfold measures; red circle: high health risk.

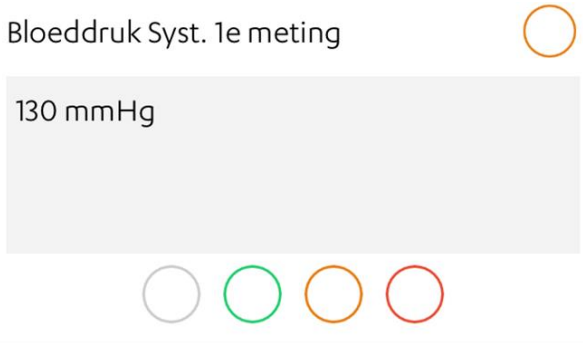

Figure 5. Insight in one's own health data compared to standard values. "Bloeddruk Syst. 1e meting" = systolic blood pressure in rest, first measurement. Here the participant has a somewhat elevated systolic blood pressure. The text in the grey area says (in Dutch): "*The orange icon indicates that you fall within the limits of the mildly abnormal standard values. Value between the: 130.0 and 140.0.*"

To see what standard values apply to a particular test result, the test result can be unfold, see Figure 5. All circles subsequently appear below the measurement. Pressing a circle will show the (age and sex adjusted) standard values that are associated with that color. In this manner a user can compare his own value with healthy, 'normal' values.

The app offers the user the possibility to set a rest pulse and maximum pulse by himself if he believes that recent measurements more accurately reflect the current physical condition than the ones that were done earlier by the sports physician (Figure 6). If, later, a new medical sports examination will take place, the new measurements then contains the most recent and accurate values. If a new measurement recorded by sport physicians is detected, a popup will appear that asks the user if he wants to use the latest measurement by the sports physician. By clicking the 'OK' button, the user's custom measurements will be overwritten by the measurements from the sports physician.

Accurate rest and maximum pulse are important since they are used to compute energy use of (mountain) biking and heart rate zones (all sports).

Figure 6. More accurate or recent values for heart rate at rest ("Hartslag bij rust") and maximum heart rate ("Maximale hartslag") filled in by the participant to replace earlier measures by the sport physician.

To calculate the energy usage for (mountain) biking there are four values necessary. These values are:

- rest pulse;
- max pulse;
- average heart rate astrand;
- power astrand.

The average heart rate astrand and power astrand are inferred from the submaximal cycle test as part of the sports medical examination.

The app has the functionality to set a goal. When the user decides to set a goal he needs to fill in at least the end date, sport and distance (Figure 7). When the goal has all the required values, it will be saved locally first. If the user has an internet connection it will also be pushed to the online database. Every time the users load the goal view, it will check for unsynced data in the local database. If any exists, it will try to sync this data. If the user decides to switch off his goal, he will be faced with a popup where the user can state that he achieved his goal. Behind the scenes, the system automatically checks whether in a training session the goal is met.

A comprehensive summary of a training can be retrieved. Under "Details", various details about a training are shown (Figure 8), such as the start date, start time, stop time, duration, kind of sport, energy use, distance, average speed, maximum heart rate and average heart rate. There is also a field with the note specified after the training by the user.

Under "Route", the route of the training will be displayed on a map (Figure 9). To check the start or end point, the red dots in the map have to be pressed. A small window will open in the sphere and shall indicate whether it is a start or end point.

Figure 7. Activated goal and progress evaluation. The bar under "Voortgang" shows the extent to which a goal is reached. "Einddatum" = end data; "Sport" = sport; "Hardlopen" = running; "Afstand" = distance, and "Tijd" = time.

Figure 8. Summary details of a training. "Startdatum" = start date; "Starttijd" = start time; "Eindtijd"= stop time; "Duur training" = duration; "Sport" = kind of sport; "Energieverbruik" = energy use; "Afstand" = distance; "Gem. Snelheid" = average speed; "Max. hartslag" = maximum heart rate; "Gem. Hartslag" = average heart rate; "Opmerking" = note (by the user about the training).

The diagram shows the speed curve. When tapping a measuring point in the diagram, the location on the map corresponding with that point on the diagram is shown by means of the red dot. A small window will open in which the exact speed at that location is shown. If a heart rate sensor is used, also a chart for the heart rate (in beats per minute: bpm) is presented. Tapping a measuring point makes also the heart rate visible at that point (Figure 10).

The diagram shows initially the curves of a complete training. By zooming in, the progress of the training can be viewed in more detail. Zooming in is done by putting a finger down and select the desired selection by rubbing to the left or right (see Figure 10). Zooming out is done by rubbing out a finger from some point. The user can also swipe (left or right rubbing) to move one set to the left or right.

By tapping on the top right arrows button on the map, a full screen map appears. The moment the user clicks again on the arrow, the map reduces back to its original size.

Under "Zones" the total number of minutes of the workout in a certain heart rate zone is given in a chart (Figure 11). When touching a column, the total number of minutes in that zone is shown. Each zone represents a certain training intensity. The heart rate zones are based on user's heart rate at rest and maximal heart rate and are thus determined individually and professionally.

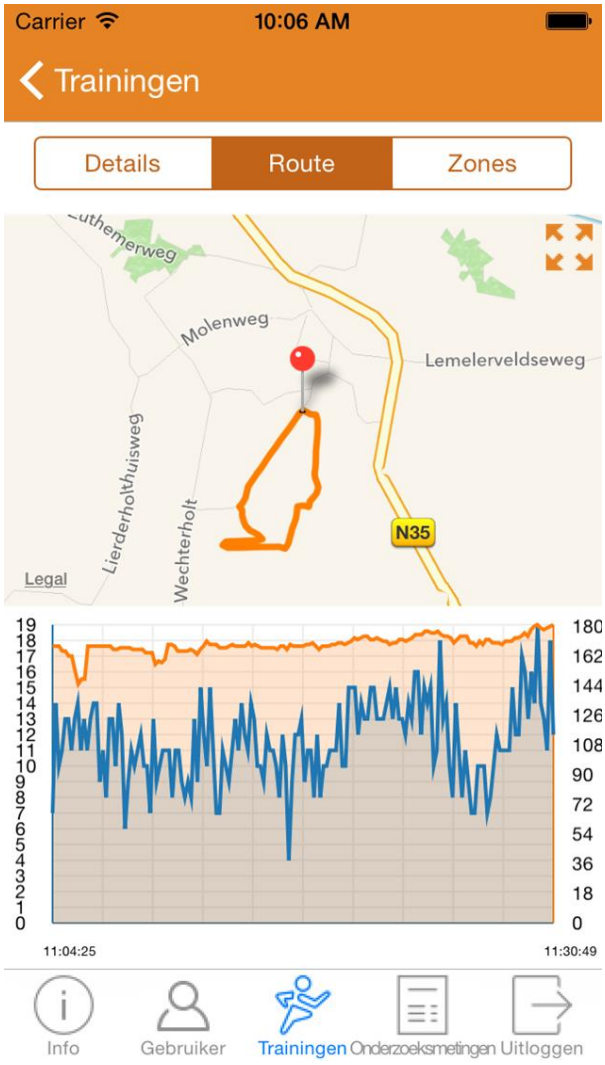

Figure 9. Detailed training overview by default. Left scale and blue line: speed (km/h); Right scale and orange line: heart rate (bpm). When tapping a measuring point in the diagram, the location at that point is shown on the map by the red bullet.

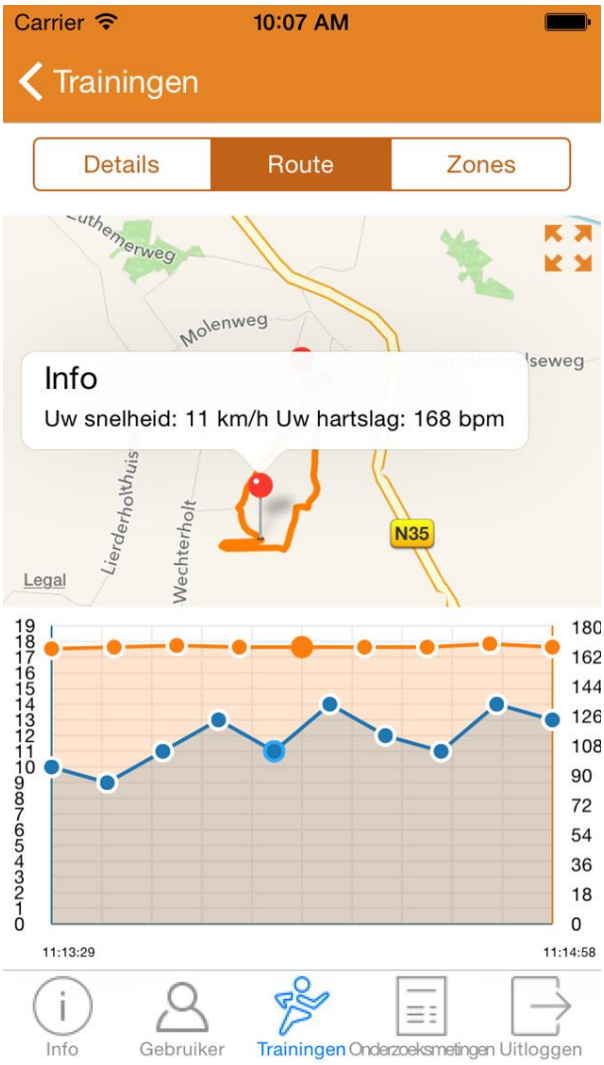

Figure 10. Detailed training overview zoomed in. Left scale and blue line: speed (km/h); Right scale and orange line: heart rate (bpm). When tapping a measuring point in the diagram, the location at that point is shown on the map by the red bullet. You can also see the speed and heart rate at that point.

Figure 12 shows statistical feedback information for the user: totals over a chosen period and graphics with totals per week. Totals of duration, distance and energy use can be sport specific or applied to all sports combined.

In order to get a complete overview, an important feature is the option to import data from other, popular sport apps. A quick inventory gave the following results:

- Runkeeper: exports data, but only from the website;
- Strava: exports data, but only from the website;
- Endomondo: does not export data;
- Runtastic: exports data, but only from the website;
- Nike+: does not export data.

The importance is reflected by the following user story: *"As a user, I might have been using another sports app to track my sport activities. To get a complete picture, I would like to import the data from those workouts into the Sportmonitor website, so I have all my workouts in one place. Then afterwards I could import them from the website into the app, so I have them available there".*

Exporting data from other sport apps (if possible) happens through the websites of the services. The exported files are of the type GPX, which stands for "GPS Exchange Format". The advantage is that most services use this format, so only one importer had to be written to be able to import data from all these services into the app.

A participant wishing to import his data into the Sportmonitor app, have to use the Sportmonitor website. Then inside the app itself, the online workouts can be imported into the local database of the app.

For some sport apps (like Runkeeper and Strava), it is possible to export the data automatically via an API. The use of APIs ensures that data are automatically sent from one party to another party.

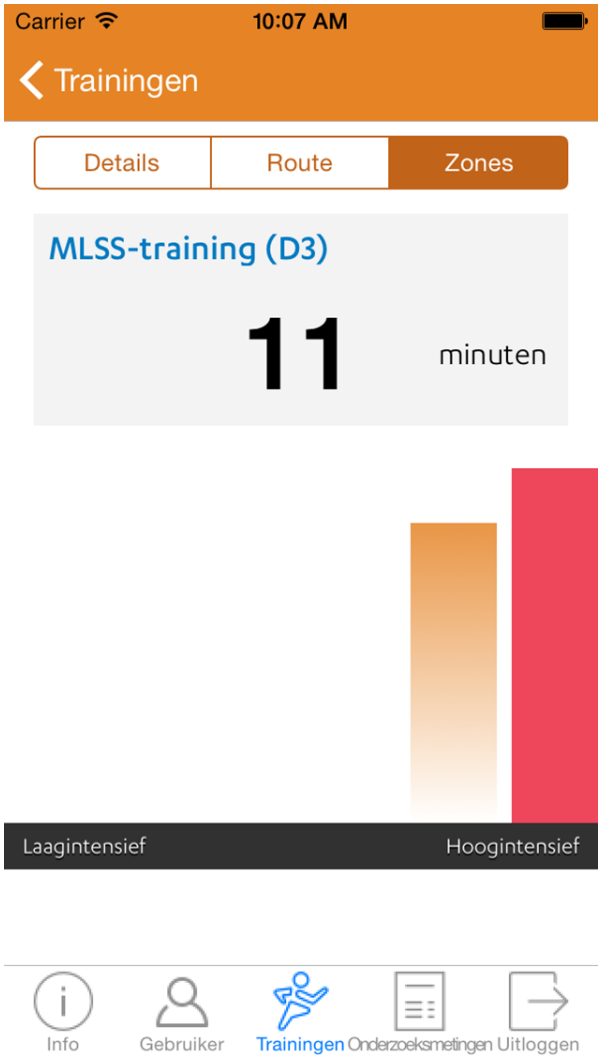

Figure 11. Heart rate zones from low intensive to high intensive of a training session, showing type of training and total number of minutes of workout in a zone when touching the corresponding column.

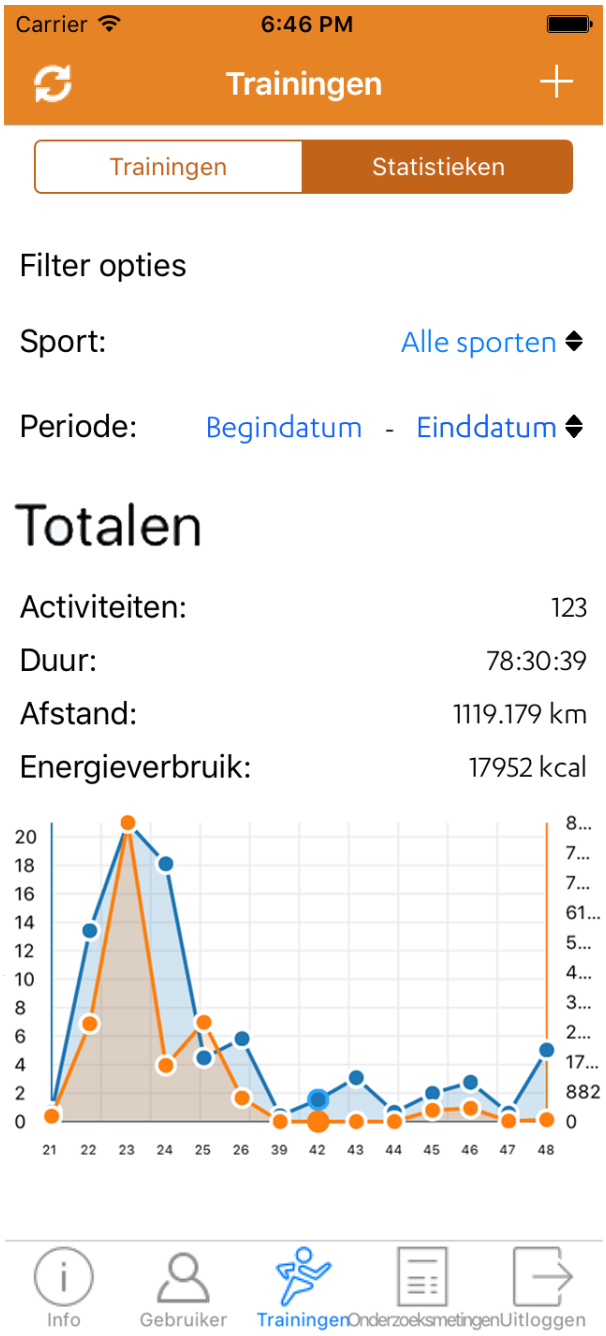

Figure 12. Statistics overview."Totalen" = totals (over the complete or a selected period); "Activiteiten" = activities; "Duur" = duration; "Energieverbruik" = energy use. The graph shows total numbers per week. Left scale and blue line indicates duration (in hours); right scale and orange line indicates energy use (in kcal.). The data are based on experimental use during the development of the application and therefore do not always reflect realistic numbers. In the future, totals per week will be visual compared to the Dutch Standard for Healthy Exercise and the Fit Standard.

IV. FOCUS GROUP

In the focus group meeting with six sports physicians (in training) and one physician assistant, the following enhancements important to them were identified:

First of all, the for the sport physicians most important function of the Sportmonitor is to stimulate people to exercise sufficient and in a healthy and pleasant way. Therefore, it is important that the Sportmonitor:

- Is a clear sport medical app
  - It incorporates sports medical test results with:
    - biometry;
    - standard values;
    - specific advise;
    - heart rate zones / energy use.
- Forms a low threshold to use, especially for sedentary and inactive people.
- Stimulates by means of:
  - Positive feedback;
  - Interesting, nice insight in own training sessions.
- Gives the participants insight in their exercises in terms of training duration and intensity on a weekly basis in comparison with the Dutch Standard for Healthy Exercise and the Fit Standard.
- Samples periodically health data in order to be able to signal overtraining and health issues, especially:
  - Sleep Quality
    - How well did you sleep this week? (VAS 0-10);
  - Wellness
    - How well do you feel? (Vas 0-10);
    - Fitness / wellbeing (POMS);
  - Heart rate at Rest;
  - Rate of Perceived Exertion (RPE, 6-20 Borg Scale)
    - after training (how strenuous was the training?);
    - before training (how well are you recovered?);
  - Weight (BMI automatically computed).
- Inserts goals advised by the physicians.
- Has a clear structure, and a more attractive and more convenient navigation.
- Can support other business cases
  - Application to other target groups, however not tailored towards diseases, but to stimulate exercise, e.g.:
    - Obese children;
    - Chronically ill patients;
    - Chronically tired patients;
    - Elderly;
  - Corporation with (dependent on target group):
    - Occupational health physicians;
    - Fitness centers;
    - Sport clubs;
    - Trainers / Life style coaches;
    - Other medical specialties;
    - Health insurance companies.

V. Conclusion and Future Work

No information system could be found on the market that supports the sports medical guidance model of the sports physicians of Isala in all its facets. Therefore, we started an innovative project. A system was built using new technologies. The innovation mainly concerns the integration of the use of apps, sensors, web services, smartphone technology and a database server with a feedback function to participants/employees, sports physicians and employers in one sports medical guidance program and not as separate parts. This makes it possible in the future to link advised training programs to actual training and health data in the course of time for large groups of participants who are employees and mostly recreational, non-performance-oriented athletes.

The system gives participants insight in their sports medical test results compared to their age and sex adjusted standard values. Test results are automatically used to compute personalized heart rate zones and energy use. Total duration and energy use of sports activities per week will be evaluated against the scientifically based Dutch Standard for Healthy Exercise and Fit Norm in future. Also, periodical entry of health data will be implemented. The sport physicians see in the system opportunities to corporate with fitness centers and sport clubs or trainers and to apply it to other target groups such as chronically tired or ill patients and elderly persons for whom it can also be very beneficial to sport. Since the Sportmonitor is a tailored business application, management and maintenance of the application is an important issue for the hospital.

An evaluation study is planned in which we want to evaluate the value of the system in terms of routine use of the system, satisfaction of end users and compliance to training programs. Once the database is filled with sufficient data, we hope to scientifically evaluate the effectiveness in terms of health, fitness and goal achievement of several sport medical advices and do subgroup analyses.

Acknowledgment

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We also thank IT students Kay van Bree, Joep Kemperman and Patrick Wobben for the development of the first version of the central database of the Sport Monitor in the context of their mid-internship, and Wisam Bahnam, Maikel Gommans, Thomas Visch, Samuel Fonseca, Trinco Ingels and Ron Jonkers for their work on the apps and sensors in the context of the minor App Development.

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Video-recorded Observations of Surgical Telementoring

Approaching collaboration among laparoscopic surgeons using videoconference

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Abstract — **In northern Norway, laparoscopic surgeons under training use videoconferencing to access expert surgeons. Videoconferencing as a tool for collaboration and knowledge sharing overcomes the distance between expert mentors and mentees and might improve surgical training. Understanding of videoconferencing in surgical practice is limited, and the educational and clinical benefits of telementoring should be explored. Over a three-year period, from 2015 to 2017, we will undertake an qualitative, explorative study using video-recorded observations of interactions. Our objective is to examine collaboration in surgical training, seeking an in-depth understanding of the non-technical aspects or social processes of collaboration in surgical training. Here we discuss how video-recorded studies may contribute to the understanding of the interactions between mentors and mentees and how to use video for approaching this practice. We discuss the use of video-recorded observations and present a fixed and a flexible design for collecting video recordings. Experiences from 8 real-time cases and one simulation of collaboration using videoconferencing in the operating theatre reflect the optimality of the flexible design, which allows following the dynamic of the surgical team. The results reveal a number of resources that are important both for interactions during surgical (tele)mentoring and for the camera position.**

Keywords - collaboration; surgical training; telementoring; videoconference; interaction; video-recorded observations.

I. INTRODUCTION

Approaching surgeons to explore the social processes of collaboration during training in the operation theater has several obstacles. When gaining access to the operation, the researcher needs to be prepared for the spoken and visual aspects and even the smell of the operating theater. Masks cover the surgeons' faces, the sounds of the machines make it difficult to hear spoken words, and the sterile zone creates a boundary, limiting how closely the researcher can approach the surgical activity. When observing daily activity, it is easy to take actions for granted or focus too narrowly. Video recordings allow us to capture, play back, and re-frame the activity. This paper is an extended version of a paper for the conference eTelemed in which, we outlined the objectives of the Collaboration in Surgical Training (CoaST) study and the qualitative design. We conclude by presenting a design for collecting video recordings to explore surgical training [1]. Here, we extend previous work with experiences from real-time cases and a simulation that reflects the use of video for approaching surgical practice.

In general, surgeons must have six years of education, training, and clinical practice. The clinical practice involves hands-on training, during which, the training surgeons (mentees) are instructed by expert surgeons (mentors).

Access to mentors for the purpose of education presents a problem to many hospitals. Improving access to mentors in surgical training could be accomplished by implementing videoconferencing (VC) telementoring as a tool for knowledge sharing. VC has the ability to overcome the geographic distance between mentors and mentees and allow for organization and full concentration on training locally and at a distance.

In surgical practice, procedures are often challenging. Unexpected issues arise and can lead to a point of no return, where decisions must be made in the moment [2]. The skills of the surgeon and the collaborating operating team are a prerequisite for a good surgical outcome [3][4]. Thus, collaboration and training in team performance are important in surgical practice. Optimal teamwork is essential whether mentors and mentees are located in the same room or they are located at a distance. VC for telementoring is well suited for collaborating and overcoming issues related to distance [5]. However, a recent review of surgical telementoring reported the limited understanding of VC in surgical practice. The review concluded that while focus has been given to piloting the technology, little attention has been paid to the educational and clinical benefits of telementoring [6]. Studies report that surgical mentoring through VC provides opportunities to alter surgical practice and offers patients the best expertise in surgical treatment without geographic limitations [7]. However, little in-depth understanding of the non-technical aspects or social processes of collaboration in surgical training exists.

During the CoaST project, we will examine the current organization of surgical training and the use of VC as well as how knowledge is shared and constructed to complete surgical procedures; the organization of training procedure and practice, that is, the team that participates, the knowledge shared, the knowledge needed, and the use of resources to solve the problem. Together, this will provide insight into team performance and the way in which, non-technical aspects or social processes of collaboration influence the way surgeons are mentored. To approach the collaboration during surgical telementoring, we employ video-recorded observations.

The rest of this paper is organized as follows. Section II describes the framework for the field and the need for knowledge about collaboration and teamwork in surgical training. Section III describes the empirical context for exploring collaboration among laparoscopic surgeons interacting via VC. Section IV addresses the qualitative design, including both the design for this explorative study, and more specifically, the video recordings. Section V provides the results and presents an approach to surgical practice when making video recordings. In Section VI, we discuss video-recorded observations for interaction analysis and show how they can contribute to the understanding of interactions between mentor and mentees, and we discuss the role of the researcher. Section VII is the conclusion.

II. FRAMEWORK

Research regarding the educational aspects of VC in surgery stresses the educational benefits [8] and refers to telementoring as effective for the development of surgical skills [9], allowing young surgeons to be educated through distance learning by an expert surgeon [10]. Past research has suggested that VC provides access to the best educational resources and experience without the limitations of distance and time; thus, VC facilitates learning [8]. For example, community surgeons with no formal advanced laparoscopic training benefit from expert advice during procedures [11]. Students reported that the experience utilizing VC was better than conventional procedures because of the enhanced learning, better visibility, and verbal accuracy in describing the procedures due to the fact that the instructor was not standing in the way [12]. These studies illustrate the outcomes possible with VC technology, but no studies have explored the social processes of collaboration and the knowledge necessary to complete surgeries (i.e., guidance, problem solving, and interaction). Neither did these studies explore how learning might be an outcome of this collaboration.

Knowledge of the effects of VC on surgical practice is limited [6]. A special focus is needed to gain a better understanding of the factors that influence surgical outcomes, that is, communication and team performance [13]. The CoaST project expands upon previous work by investigating knowledge sharing between surgeons and the way in which, their use of resources affects treatment outcomes. It aims to investigate the current organization of surgical training, the use of VC, collaboration in practice, and the problem-solving process. Here, video recordings are a well-suited tool.

When observing daily activity, we often take actions for granted. Surgeons accomplish daily activities through interactions with others. These activities are the product of a variety of resources, i.e., spoken, bodily, and technological resources. Video recordings of an activity enable us to capture the activity. They also make it possible for those participating in the operating theater to share and discuss information with others outside the operating theater. In this paper, we discuss how video-recorded studies may provide a contribution to understanding the interaction between mentors and mentees and present designs for approaching the practice.

III. EMPIRICAL CONTEXT

This study investigates collaboration among laparoscopic surgeons in northern Norway interacting via VC. The empirical context includes collaboration between the mentors and mentees during surgical training, where VC is utilized to overcome the distance between the mentor and mentees.

Laparoscopic surgery uses several small abdominal incisions. At each abdominal incision (i.e., port), an instrument is inserted. Telementoring happens by connecting the laparoscopic surgery, the surgeon (mentee), the expert (mentor), and the technological artifacts, that is, robots, monitors, and a mobile touch screen device. The

laparoscopic procedure, which is visual, is transmitted to a monitor in the operating theater. The expert can view the procedure on the monitor or at a touch screen device in the operating theater or at a distance. All procedures are transmitted to the monitor. In some cases, mobile touch screen devices may be used. Freehand markups are drawn over the video (telestration) so that the visuals can supplement the verbal instructions.

Telementoring over distance is possible using VC [14]. VC is defined as the sharing of sound and pictures through two- or multi-channel communication. By connecting the monitor or the mobile touch device to an external computer (PC) and using microphones locally to transmit audio to an external computer, the local mentee in the operating theater and the remote mentor are able to collaborate. The surgical operation is viewable on the monitor, which is transferred to the expert mentor's device. The mentor can be mobile, in the operating theater, or at distance while providing full attention and offering required training and instruction to the mentee. The visual representation on the monitor, the instructions being given, and the mentor's telestration drawings on the device supplement the collaborative work during surgical training.

The study follows the traditional education program to explore this practice. The observations will continue until there is a thematic saturation or until the use of VC for mentoring is phased out. The participants will be recruited according to their use of VC for mentoring. When VC is used, it will include the interactions that occur during the training until methodological saturation is achieved. The periods and the length of observation will be determined based on the total activity during the education program. A lower frequency of training using VC will require longer periods of data collection. Periods are defined in regard to the education program and are referred to as the periods of training.

For this paper, the empirical context comprises video observations of the first telementoring procedure held within the CoaST project period. At this stage, we needed to reveal challenges of using video for social research to inform further research. Approaching the practice, experiences from 8 real-time cases, and one simulation of collaboration using VC in the operating theatre illustrate how the design needs to be organized.

IV. VIDEO OBSERVATIONS OF SURGICAL PRACTICE

Exploring collaborative processes requires empirical data and analysis of the social processes and interactions of those who participate. These data and analyses make it possible to explore knowledge sharing among surgeons, mentors, and mentees who collaborate and use VC in surgical training and practice. However, the field lacks an in-depth understanding of the social processes of interaction under training. Thus, an expansion of traditional research methods (i.e., randomized control trials) in this field will enrich the knowledge base. Ethnomethodology analytics and talk-in-interaction, supported through qualitative video observations, offer great potential.

The way in which, telementoring is accomplished is a part of the social organization of surgical work—and a part of everyday clinical practice. Thus, the research on the collaboration in the operation theater with real patients is a workplace study. Workplace studies examine the detailed co-ordination of verbal, visual, and material conduct through which, technology is used [15] and seek to understand how such tools affect organizational practice.

Video-based studies of interactions amongst surgeons are in demand [13]. Heath, Luff, and Svensson [16] have been studying surgical teams and how video provides access to complex forms of interaction. Though, they have completed detailed workplace studies regarding the use of tools, telementoring has not been a part of their studies. As part of a work practice, image-guided surgery produces video recordings of procedures, which are transmitted to a lecture room to improve communication [17], but not for researching the communication itself. Focusing on telementoring, miscommunication between mentors and mentees has been videotaped as a trial [18], disconnected from real-time work practice.

Despite a growing amount of video-based studies, there are few guidelines on how to undertake video-based research [15]. Though we do not aim to provide a guideline, we will reflect on video recordings and provide a contribution to designs for approaching practice. The CoaST project will use qualitative methods. It is designed as an explorative study of the practices of interaction. The knowledge shared and constructed will be explored as surgeons with different types and levels of experience and expertise interact and perform surgeries over periods of time. In this paper, we prepared and explored the design through discussions with technicians and a surgeon, who also participated in the 8 real-time cases. Observations will constitute the main source of data. The second source of data will be qualitative interviews.

A. Observations

The observations are built on interaction analyses—the empirical investigation of talk and the use of resources [19]. The observations will be made as surgeons collaborate in surgical training and practice, guiding and discussing treatment using tools such as VC. Observations are well suited to exploring team interactions because reconstructing the medical language and using artifacts is not possible. To intercept the social aspects in the collaborative work between the mentors and mentees, the interaction will be video-recorded using three sources: (1) output from a laparoscopic camera/monitor, (2) connecting the mobile touch screen device to a recording unit, and (3) a camera recording an overview of the operating room.

The use of video recordings during the observation provides access to complex forms of interaction and to

collaboration in the visual and spoken data [20][16][22]. By following the language and the use of resources (i.e., talk, gestures, mobile touch screen, and surgical equipment such as knives, scissors and needles), it is possible to see how the mentor and mentees organize the instruction and practice, how problems and routine practices occur, and how the surgery (the medical problem) is solved.

B. *Interviews*

To complement the observations, the participating surgeons will be interviewed. The purpose of the interviews is to enrich the context by giving the participants the opportunity to express themselves in regard to the surgical training and the use of VC in training, instruction, and collaboration. It is also essential to discuss themes based on the observations. The interviews will be semi-structured [22][23]. They will involve dialogue resulting from a mixture of structured questions (from an interview guide) and the themes that emerge in the dialogue. Interviews will provide insight into mentor and mentee experiences. The interviews will be used to validate the interaction analysis.

C. *Ethical Considerations*

During surgery, the identification/visibility of the patient in the video recordings is not possible. The patient is covered by sheets, and only the part of the body undergoing the operation will be visible. The videotapes will be collected and handled according to the guidelines established by the Regional Committee for Medical and Health Research Ethics (REK). The interviews will be recorded, transcribed, and handled according to the REK's code of ethics.

V. RESULTS: CAPTURING SURGICAL PRACTICE

Here, we present results from the preparation and the first procedure within the CoaST project period. To prepare for the main collection of audio and visual data, we began with a simulation of a surgery in the operation theater. When the first mentoring case appeared, we used experiences from the simulation to prepare for the eight planned real-time mentoring cases.

A. *Simulation of a fixed design*

In order to decide where to place the camera and microphone for the best picture and sound, and to capture the most relevant activities, we simulated a fixed design. We have a special interest in the naturally occurring talk and tools that surgeons use when collaborating. Approaching the telementoring team includes giving attention to the mentor, mentees, and the tools they use (i.e., the monitors and the mobile touch device). The monitor shows the picture inside the abdomen, which is the same picture the surgeon sees. The mobile touch device displays the same picture as the monitor and can be drawn on. Both the monitor and the mobile touch device can record within the unit in addition to recording the technical aspects of the surgical performance. These recording units represent the traditional way of exploring surgical performance. To capture the social processes of collaboration, an external camera needed to be located in the room. When we simulated the design, we planned according to the team, the resources they use, and our single camera.

Figure 1 illustrates the fixed design of how the surgical team, monitors, mobile touch device, and camera were placed during the simulation. The arrows in Figure 1 show the three sources recording the surgical practice. The circles in Figure 1 point out the resources that will be focused on for gaining an in-depth understanding of the collaborative work. The green circle illustrates how the social processes of collaboration are an overall understanding of the whole process of surgical practice: the mentor(s), mentee(s), and their interactions with each other, the monitor, and the mobile touch device as they perform surgery. When connecting via VC, the PC is also included in this interaction. The surgical team can see the expert mentor in real time on the computer. Connecting with VC, the expert sees only what happens on the mobile touch device. Figure 1 illustrates the design, after the simulation, of the setup and the team. The external camera was placed in a position that could capture an overview of the collaboration. The external microphone was placed on top of the camera so as not to disturb the surgeons (e.g., by cables twining about their legs).

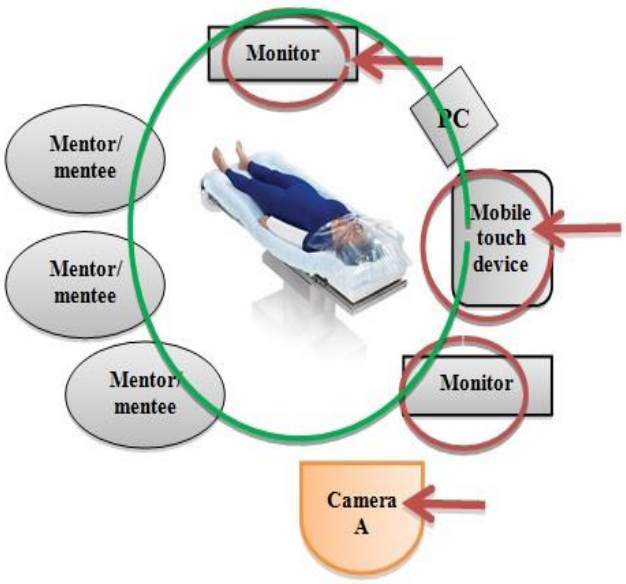

Figure 1. Simulation of the organization of the surgical team, their resources, and the recording units.

By focusing on what happens in the interaction between all elements during surgical training (the green circle), we

aimed to expand the traditional method focusing on technical aspects and capture the social processes of collaboration between mentors and mentees in surgical training.

B. *Real-time flexible design*

We planned to use the fixed design when starting to video-record. However, upon entering the operating theater we realized that the fixed design was not suitable in this workplace setting. Contrary to what we had assumed, the mentee preferred to stand at the opposite side of the patient, and the tools were adjusted to fit this team. The team and the tools they use are organized differently between procedures and mentors/mentees. Without foreknowledge of the team, the researcher needs to be flexible in the video recordings. We had to adjust the planned setup as we entered the operating theater.

In the first three cases, the expert surgeon mentored on-site. The mentor moved around in the operating theater (illustrated by a faded-out figure), depending on how actively he was mentoring. During difficult parts, the mentor stepped forward, and during more low-risk parts he stepped backward. The mentor has the opportunity to use the mobile touch device, both when he is located in the operating theater and when he is at a distance. His opportunity to use the mobile touch device is illustrated with a blue arrow in Figure 2. His activity is included in the green circle, illustrating that he is a part of the social processes of collaboration.

Figure 2 illustrates the activity among the surgical team when the mentor moved around the operation theater. It includes the monitor, which represents the picture of the patient and the surgery inside the abdomen. As the mentor was on-site, the VC was not connected. The PC did not have a function other than to record the same picture as on the monitor.

We started video-recording in camera position B. As the PC was not included as a working tool, we moved to camera position C to include the view of the mentor and the monitor showing the abdomen. Since the monitor located on the foot side of the patient shows the picture inside the abdomen, the surgeons orient their faces towards this monitor during the procedure. In position C, we were not able to see the mentees' faces or which, direction they were oriented to at each point during the procedure. Standing behind them also made it difficult to intercept their talk. Since the naturally occurring talk during the procedure is important for our study, we could not choose this position. As the talk was most often directed between the mentees and mentors on each side of the patient's bed and towards the monitor, we placed the external microphone on top of the monitor. This was the best position for capturing the voices.

Moving to the planned position A (Figures 1 and 2), we got a nice overview of the work with the patient: the mentees hands and the tools they used. The video recordings captured the patient's body and a close-up impression of the movement of the tools. However, some equipment on the monitor to the right made distracting sounds, making it difficult to hear the talk. The mentees had their faces oriented towards the monitor in front of them, which made both the physical and verbal communication between them hard to intercept. Camera position D did not fit into the physical organization of the team, standing in the middle of the mentor working space where the rest of the team (i.e., nurses) worked.

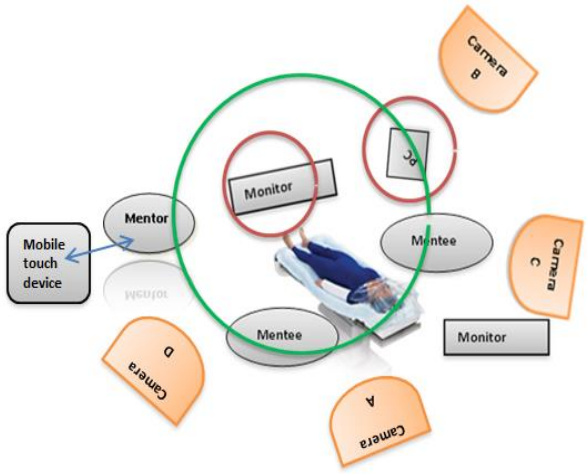

Figure 2. Real-time flexible design of the organization of the on-site surgical team, their resources, and the recording units.

As the mentees became more experienced with the procedure, the mentor started to use VC, providing the opportunity to instruct at distance. To allow the mentor who was not on-site to be seen, another monitor was included. The PC was used to connect the mentor, the mobile touch device, and his PC remotely. In this way, the mentees were mentored using VC, as illustrated in Figure 3.

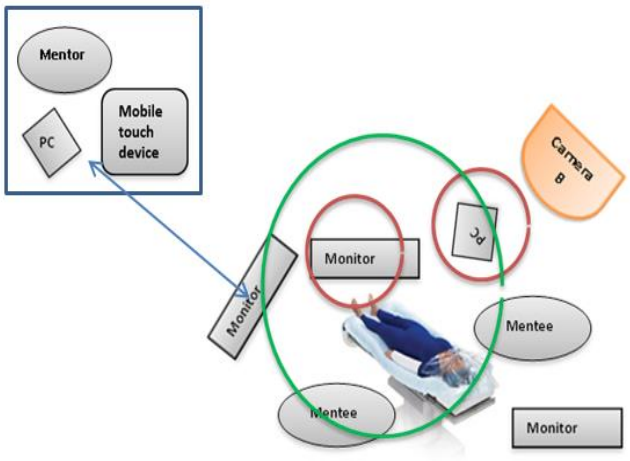

Figure 3. Real-time flexible design of the organization of the surgical team, their resources, and the telementoring.

When using VC, the PC showed the same picture that the surgical team saw on the monitor. This included the picture of the abdomen (which is the same picture the mentor sees and the important working tool when performing laparoscopic surgery), the picture of the mentor at a distance, and the use of the mobile touch device. The mobile touch device supplements verbal explanations with the opportunity to draw while explaining. Using the view of the PC as a way to gather all resources in one picture was an excellent way to video-record all activity. In camera position B, we captured both the communication tools that were important for the local team and the picture on which, the remote mentor was dependent. At the same time, we were able to record the local team, with their faces oriented towards the remote mentor on the monitor. The microphone, connected to the camera, was also nearby, so we did not have worries about long cables crossing the floor.

VI. VIDEO-RECORDED OBSERVATIONS FOR INTERACTION ANALYSIS

Experiences from eight real-time cases and one simulation of collaboration in the operating theater reflect video-recorded observations of surgical telementoring. The results explore both a fixed and a flexible design for video-observations when capturing collaboration between mentors and mentees.

As a work procedure, the technical performance of the surgery in the operating theater is analyzed by recordings from the monitor unit. This unit records a stationary picture of what happens inside the abdomen. These recordings are used to evaluate the mentees' technical skills after surgery. Hence, surgeons are used to produce video recordings of their actions but not of their interactions.

Exploring the interactions between mentors and mentees in the time leading to the surgery provides a broader picture. Using video recordings to analyze the interaction between the mentor and mentees is more complex. When professionals accomplish everyday work activities through interactions with others, they utilize a variety of resources (spoken, bodily, and material) as objects and tools. The individuals interact with each other, and are influenced by actions in the operating theater. During the simulation and eight mentored sessions, a number of resources were identified that are important both for the interaction during surgical (tele)mentoring and for determining the camera position.

Collecting video-recorded observations for approaching the practice presents several issues and queries. Establishing a fixed frame prepared us for entering the setting, even though we could not carry out the recordings in this way. The team is not stationary; that is, the mentee who has the central role decides whether to stand on the left or right side of the patient, and the assistant mentee moves accordingly. The tools the team uses are organized in the room according to the position of the team and the procedure to be accomplished. Hence, the position for telementoring is influenced on-site. For new procedures, on-site mentoring is a first part of the instruction process. When the mentee has obtained a certain skill level, VC can be used for mentoring. Telementoring adds tools to the activity and affects the situation—whether used in the operating theater or at a distance.

It is a methodological debate whether to follow the action with a camera or to maintain one perspective. Here, we have tried several camera positions to determine *one viewpoint* where we are able to follow the activity. The 'best design' is principally dependent on the focus of the study. The results of this study show that the best viewpoint for video-recorded observations of telementoring allows observation of the team as it orients itself towards the monitor showing the picture of the patient (inside the abdomen) and the mentor with the mobile touch device. At the same time, it is important to see the faces of the surgeons and meet the direction of their voices (as talk is a part of the focus in the study). In camera position B, it was possible to use the picture on the PC (showing the same picture as the monitor) while recording the team from a satisfactory angle.

According to the CoaST study, capturing the activity from a 'flexible position B' is not just a practical methodological issue for video recording; it is also characterized by the work practice. The 'flexible position B' is oriented towards the knowledge and tools that are important for the mentor and mentees to complete the laparoscopic procedure.

The flexible design requires the researchers to have dual roles as cameramen and observers. As qualitative researchers, we often observe from a corner in the room, taking field notes. As the activity happens centered towards 'the patient in the middle', we are standing half way behind what is happening. The sound is disrupted by noisy instruments, and the mentor and mentees are covered by gauze masks, making it harder to hear them talking. Around them, there is a sterile zone, which makes it impossible to be close. Thus, we want to maximize the quality of the recordings and capture the activity where it happens. At the same time, we must not disrupt the activity.

In addition to the movement of the team and the tools they use, the shape of the operating theater affects the researchers' role. In large operating theaters, a tripod can be used, and when the camera is placed in a satisfactory position on a tripod, the researcher can leave or change position within the operating theater. In small operating theaters, however, the camera must be handheld to get a satisfactory angle of the team. Handheld cameras make it possible to move closer to a corner than the tripod allows. In such a position, the researcher has to concentrate on being a cameraman and focus on the interaction when watching the recordings afterwards.

In this study, we present designs for video recordings of interactions with telementoring. Revealing the complexity

of making these recordings also explores the interactions of the mentor and the mentees. The spoken, bodily, and material objects and tools that are part of the surgical practice make the CoaST study intriguing. Here, the results show that performing a procedure requires more than successful technical performance. Social and organizational factors regarding clinical practice affect the outcome.

VII. CONCLUSION

This paper describes a work in progress, a project studying collaboration among laparoscopic surgeons who are instructed during education (CoaST). Currently, there is a limited understanding of VC in surgical practice and a lack of in-depth understanding of the non-technical aspects and social processes involved. The project strives to capture the interactions that occur within a surgical team and their use of resources when mentoring surgeons. Knowledge of the social processes could be used to improve surgical education and enhance surgical team performance in everyday practice.

This is not a traditionally study of VC setup in surgery, drawing on previous successes and failures with implementing VC. Here we explore the method of video-recorded observations studying interaction in surgical teams, which are in demand [13]. Capturing several sources of action is challenging. Interactions within the team happen between members, around the patient, on the monitors that depict the patient's body, and on the mobile touch device. We tried to meet this challenge by simulating a fixed design for video recordings. Afterwards, we tested the fixed design during eight real-time cases. We tried several camera positions, one of which was suitable for this specific laparoscopic procedure. At this point in the study, the design for video recordings needs to be flexible with an active researcher.

As researchers, we need to define our own role. Being in the operating theater to perform video observations has an impact on the activity, the setting, and the relationships of the participants. We made a decision to use a single camera source. This was necessary to minimize the workload as multiple cameras might lead to difficulties in analyzing the material [24]. The number of cameras, the strategy for recording sounds, and the way the action is followed (i.e., fixed or dynamic frame) impact the data that is collected and the analysis that is possible.

The experience gained from these cases has brought us one step closer to proposing a less resource-demanding design. When using VC, the monitor could have a built-in video recorder. If a camera and microphone are placed on top of the monitor and the team is video-recorded while directed towards the monitor, it is also possible to capture what they are focusing on. If this recorded picture also appears on the monitor, we are able to collect all the sources in the same video-recorded picture. Then, the challenge is to install this system in all potential operating theaters and give someone in the operating theater the responsibility to inform the team about the recordings and start and stop the recording. This might lead to methodological biases, however, which are not discussed in this work.

Collecting video-recorded observations for approaching surgical practice presents several issues and queries. There are challenges in several phases of this method, from planning, collecting, and analyzing the data. Here, we have focused on some challenges with data collection. This paper is not a guideline for approaching video-recorded observations of surgical telementoring. It is a complex interaction, and the importance of capturing the procedure as an outcome of collective actions is often taken for granted. The present research contributes to the field of interaction studies. The findings will give rich insight into the phenomena itself, which is communication and team performance in surgical education using videoconference. The detailed analysis of the interaction gives insight in specific aspects of how they communicate. Our analytic concepts will be used to create systematic analysis of communication and our analysis becomes a contribution to the field of knowledge that investigates surgical team performance. In ongoing research, these sources together with a review and a theory create the basis for our analytic claims, as we in the future will call analytic generalization. Analytic generalizations aims to develop concepts that make qualitative studies as strong as possible.

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Intelligent Insulin Pens

A promising technology toward smart diabetic management systems

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Abstract—**Ever since their introduction, insulin pens have been playing a critical role within the Multiple Daily Injections. Insulin pens were originally a solution created to offer a couple of enhancements in injection. They were appreciated for their simplicity and accuracy. Recently, intelligent insulin pen technology has been introduced to offer a new direction toward enhancing the management of Multiple Daily Injections therapy. In general, technologies have always been playing a major role in the enhancement of insulin delivery; it has been more notable within the pumps therapy practices. For Multiple Daily Injections in particular, the use of technology was relatively limited, but with the introduction of intelligent insulin pens, there is an expectation that the Multiple Daily Injections therapy would elevate into a higher level of standards. Because the technology is still barely known among the groups of diabetic patients, the paper first presents a couple of assessment studies to evaluate the necessity of the intelligent insulin pen technology among diabetic patients. Based on the outcomes, patients and practitioners saw great potentials within this technology. Nevertheless, the study concluded that the intelligent insulin pens technology itself would be essential for certain groups among the diabetic patients, but for the general use, this technology could be a good alternative to the regular insulin pens. The intelligent insulin pens technology still needs to implement more functions that can serve the general diabetic patients. One feasible suggestion to achieve this goal is to extend this technology through the utilization of smart devices and ubiquitous technology. In the second stage, in order to examine the possibility of the previous point, a series of pilot studies was conducted to oversee their influence on the regular management. Based on the assessment study outcomes, a smart reminder system was proposed to test the influence on medication adherence and daily routines. The system utilizes the technology of smart devices and intelligent insulin pens. The final outcomes showed that the system could be a good support to the regular routines, and it had the potential to promote a better compliance toward the insulin medication.**

Keywords-Electronic Medicine; Diabetes Mellitus; Multiple Daily Injections; Smart Systems; Ubiquitous Technology.

I. INTRODUCTION

A. Study Overview

This paper presents a continuation of a previous qualitative study [1], which was conducted for the intelligent insulin pens technology assessment. It also includes additional results from new usability studies, interviews and a series of pilot experiments. The previous study was aiming to survey the importance of using intelligent insulin pens technology as part of the MDI therapy. In this extended study, a new goal was added to the main objective in the previous study. The new extended study aimed to test the feasibility of extending the functionality of intelligent insulin pens through the utilization of ubiquitous technologies.

The previous study highlighted the potential existed within current models of intelligent insulin pens. It concluded that the intelligent insulin pens can be a good option as an alternative to the current available instruments, but the intelligent insulin pens technology itself is not necessarily essential for the majority of diabetic patients. In the previous study, the experience of intelligent insulin pens technology was mostly based on demonstration and visual aids materials. At the current stage of this study, we had results from patients, who had actual experience with this technology itself. The study included also some opinions from a number of specialized practitioners; these results were helping to give insights about the importance of the technology from the primary care side. Additionally, the previous study highlighted the role of ubiquitous technologies in expanding the functionality of the intelligent insulin pens. The current stage of this study showed some evidence—through a couple of pilot studies—that can support the previous claimed idea.

This paper is organized in the following manner: The second part of this section gives some historical background about the evolution of the insulin pens instrument. Section II gives some information about the technologies existed within diabetes mellitus. It presents some information about the devices that have widely been used for diabetic management, and then it highlights the role of smart devices within diabetes mellitus. Section III provides some assessment studies for the intelligent insulin pens technologies. Section IV presents some pilot studies for the connectivity between intelligent insulin pens and smart devices. Finally, Section V

concludes this paper by summarizing its contents and outcomes, and then it points to the limitation and future directions of this research.

B. The Evlution of Insulin Pens

Originally, the launch of insulin pens came in 1985 by the Danish company Novo Nordisk [2]. The main aim was to find a more practical instrument that can replace the traditional syringes and insulin vials. The introduced solution managed to ease the insulin dose administration, especially among elderly and young patients. It has always been noted for its accuracy and simplicity [3]. Currently, in most parts of the world, insulin pens have already surpassed traditional syringes, and they have become the main instrument for the MDI therapy [4]. Both types of instrument have some similarities between them, e.g., mechanical-driven motor for dosing; however, they differ in how to prepare and adjust the dose.

In the regular syringes case, patients need to insert the syringe inside the insulin vial, and then start pulling the end of the instrument to let the medication fill in. On the other hand, the vial—called cartridge here—for insulin pens is inserted inside the instrument itself. Patients just need to adjust the required amount using the dose knob at the end of the instrument, and then by pushing the button at end of the pen, the dose can easily be administered.

There are a couple of advantages of using insulin pens instead of using regular syringes. First, the pushing mechanism can prevent the air bubbles from coming inside the vial, i.e., air bubbles can reduce the accuracy of the administered dose. Second, the dose knob at the end of the pen is easier for dose adjustment and more visible to most patients. Finally, the insertion of vial inside the pen itself makes it more convenient for storage and carrying.

Nevertheless, there are still some disadvantages in using insulin pens. First, the overall cost of using insulin pens is higher when compared to regular syringes [5]. Second, the dosing mechanism in insulin pens is considered slower than regular syringes. During the dosing process, the patient needs to push through the whole insulin vial. As a result, this requires the patient to keep the instrument inside the skin few extra seconds [6]. This is to make sure that the dose has been fully and correctly drawn out of the vial. Finally, unlike regular syringes, patients cannot mix two different types of insulin in the same pen, e.g., Regular and NPH insulin; however, this is might not be a major issue since most of the new types of insulin are actually not mixable, e.g., Insulin Glargine and Insulin Glulisine.

As per the upgrading cycle of insulin pens, from the days of their introduction, insulin pens had very slow upgrading movements. Most of these upgrades were minor ones. For example, some of the upgrades were mainly related to the outer designs and weights. Others had some enhancements with the dosing process, yet the functions and mechanism concept have remained the same until just few years ago [7].

We started to see some significant upgrades in 2007 when Eli Lilly and company introduced their HumaPen® Memoir™ model [8]; it was the first model to introduce the memory function. Basically, this model can keep records of date, time and dose amount for a number of administered doses. The main purpose is to remind the patient about last taken doses in order to avoid the risks of double or missing doses. The dosing mechanism retains the same mechanism as regular insulin pens, i.e., mechanical-driven motor. The model has been discontinued due to some commercial issues [9].

In 2012, Novo Nordisk introduced the same memory function within two of their own models NovoPen® 5 [10] and NovoPen Echo® but in a totally different concept; basically, rather than keeping the records of date and time, it shows the total dosage taken within the last 12 hours. In addition to that, Novo Nordisk introduced a smaller scale dosing, i.e., scale of 0.5 unit, within their NovoPen Echo® model for young patients, who usually have higher insulin sensitivity than regular patients [11]. Once again, the dosing mechanism remains mechanical-driven like all the previous models.

A new intelligent model has recently been introduced exclusively within parts of Europe and South Korea [12]. The model was manufactured by the Korean company Diamesco Co.,Ltd, which specializes mainly in insulin pumps manufacturing. The introduced model borrowed a couple of features originally existed within pump devices. The most significant feature is replacing the dosing concept from mechanical-driven motor into digital-driven motor. The feature eliminates the need of human-force and it provides more precise dosing scale, i.e., 0.1 unit scale. Another remarkable feature is the ability to keep a large number of dosing records, i.e., more than 100 records, which can also be transferred to personal computers. This is additional to some other features such as alarming for battery and empty cartridge, pre-saving doses and countdown for dose administration. The model has been marketed in Europe as Pendiq Intelligent Insulin Pens and SmartPlus in South Korea.

This latest model of the intelligent insulin pens was used as the main subject within this stage of the study. This model was used within the usability studies to test the use of technological solutions within MDI therapy. It was used also within the pilot studies that test the integration between ubiquitous technologies and the intelligent insulin pens technology.

II. THE ROLE OF TECHNOLOGIES IN MANAGING DIABETES

This section gives a brief background about the role of technology in facilitating and enhancing the insulin delivery. It also highlights the differences between the Insulin pumps and MDI therapies from the technical side. Lastly, it gives some background about the current uses of smart devices under the diabetes mellitus.

A. Technologies and Insulin Deliveries

Among the distinctive types of insulin delivery for diabetes mellitus, insulin pumps rely heavily on technologies. The use of technologies in insulin pumps has made them distinguishable with multiple features for diabetic

management [13]. For example, pumps now can keep updating you about insulin and glucose levels running within the body; they can ease the calculation of bolus doses by providing a built-in list for food data associated with carbohydrates values; lastly, they can keep records of doses, which can also be synced to personal devices like PC and smart devices. Furthermore, the technological nature of insulin pumps has allowed easily creating new models with new functions.

One remarkable example, which can elaborate this point, is the insulin pump pad— known as Omnipod in the market [14]. Unlike the other insulin pumping models, pump pad comes tubeless packed in one single unit. Each unit of these pump pads is packed with all the necessary components for insulin pumping delivery, i.e., the insulin reservoir, cannula and infusion set. Each unit is also embedded with wireless connectivity module. The patient can set the infusion and doses through a dedicated wireless remote. The main advantage here is providing a solution that allows more flexible movements, and eliminates the exposure of skin to the outer environment. The last two points have always been major hindrances within pumping delivery, especially among patients, who are doing heavy activities like athletics [15].

The inclusion of wireless modules within pumps has opened the door to create more new solutions such as the semi closed-loop pumps [16]. The solution is integration between the pump devices and continuous glucose monitoring devices (CGM). Basically, the patient can view the CGM readings directly on pumps, and then the patient can adjust the delivery rate manually according to the readings. The CGM module can issue an automated suspension of insulin fusion in the case of Hypoglycemia detection. The method is still suffering from some technical issues due to the inaccuracy of CGM reading, but it is still under continuous enhancements. If developers managed to create a CGM with accurate reading, it will be possible to create what is called the closed-loop pumping solution [17]. This is the optimal automated solution, which can imitate the actual work of human pancreas.

Although the technological enhancement within pumps, such as the inclusion of wireless communication, opened the door to create more creative solutions, it invited some new challenges here as well. For example, the controlling through remote devices makes the pumps vulnerable to communication risks like hacking and malicious attacks. Some earlier articles reported that a couple of experiments could manage to hack and control pump pad remotely in the absence of patient's awareness [18]. A couple of solutions have been proposed to avoid such an issue but it is still getting a major attention from the researchers [19]. The point here is there is a need to give careful consideration to the challenges associated within any new proposed technical solutions.

On the other hand, as it was stated before, insulin pens have mostly remained simple without any sophisticated technologies for quite some time. Insulin pens, which have been used for MDI therapy mainly, rely heavily on the patient's cognitive skills and some other companion devices like glucometers. For MDI routines in particular, there are

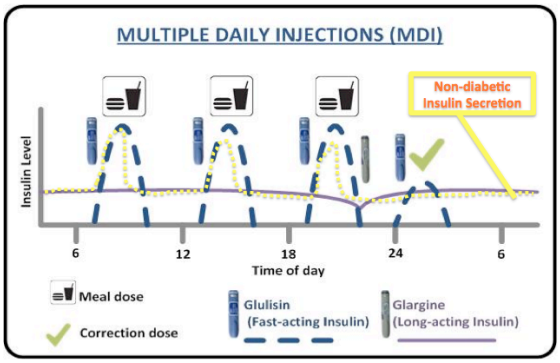

Figure 1. Multiple Daily Injections (MDI).

two types of doses (Figure 1). The first type is Basal, i.e., long acting dose, which lowers the glucose level out of the dining time, e.g., between meals or sleeping time. The dosage amount is usually determined by the primary care and should be taken within a fixed period of time, i.e., every 24 hours; for example, the Glargine type in Figure 1. The other type is called bolus, i.e., short (fast)-acting dose, which is usually taken before or after meals. The patient needs to know the value of the carbohydrates intake in order to adjust the dose according to that value; for example, check the Glulisin type in Figure 1. The patient needs also to measure the glucose level before taking any dose, especially in the morning, in order to check if the dose needs any adjustment or not. For example, if the glucose level is lower than the regular, the patient needs to decrease the usual dose, and if the glucose level is higher, then the dose has to be increased. This is to avoid the occurrence of any Hypo/Hyperglycemia episodes. The main purpose from having these two different types is to imitate the normal insulin secretion in non-diabetic individuals.

Therefore, glucometer devices are considered vital within MDI routines. Nevertheless, the technology within glucometer is mostly simple without any sophisticated features. Some recent models have started the implementation of simple smart features such as smart indicators and directions [20]; however, there are some other models that managed to include sophisticated features such as wireless connectivity for cloud computing utilization [21]. As per CGM, they were mainly developed for pump users only, but there were some researches that showed benefits of using CGM within MDI routines [22]. Aside from the glucometers, smart devices can also be used within the MDI therapy; however, their uses are currently limited. More details will be given in the next section about the uses of smart devices within the diabetes mellitus.

MDI and insulin pumps are still holding the top positions among other methods for external insulin delivery. Both methods have their own pros and cons within their uses. For example, insulin pumps have been remarkable for their glycemic control performance [23], but at the same time, they require extensive training to master, and require continuous on-body attachment. On the other hand, insulin pens within MDI, require almost no effort to master, and

TABLE I. COMPARISON BETWEEN INSULIN PENS AND INSULIN PUMPS

Comparison between insulin pens and insulin pumps		
Features	***Insulin Pens***	***Pumps***
Level of accuracy and precision	Lower	Higher
Flexibility and convenience	Higher	Lower
Costs	Lower	Higher
Performance and glycemic control	Lower	Higher
Level of risks	Lower	Higher
Ease of mastering	Higher	Lower
Level of complexity	Lower	Higher
Hight-tech and upgradability	Lower	Higher

they are greatly flexible to use, but at the same time, they require much dedication to doses management from the patient's side. Table I gives a brief summary for the differences between MDI and insulin pumps therapies [1].

Nevertheless, as it was implied within this section, there is a wide gap between them in terms of technological utilization. Insulin pumps have evolved greatly into better shapes than their early days, while insulin pens have almost remained unchanged. Technology has great potential to ease the complicated management of diabetes. MDI routines need to follow the same footsteps as insulin pumps. They need to start effectively utilizing some of the latest available technologies, such as cloud computing, wireless communication or smart devices. The intelligent insulin pens as mentioned before could be a good step toward this point. The solution kept some of the features originated within regular insulin pens, such as dosing flexibility, but at the same time, it implemented several new features never existed before, such as the digital-driven motor.

B. Smart Devices and Diabetes

Most smart devices available now in the market have powerful processing and multitasking capabilities. Beside the basic functions, i.e., making calls or messages, you can also browse the Internet, take pictures or even play video games on them. In addition to that, with the current generation of wireless network, the connectivity within these devices has become so high. The previous listed features of smart devices have made them more likable among their users. Moreover, because the user interfaces within these devices have become easier and manageable than previous generations of user interfaces, regular users, who lack deep technical knowledge, can now use these devices more skillfully than before [24]. Smart devices are now playing major roles within our daily routines: shopping, entrainment, education and of course healthcare as well.

For diabetes in particular, there is an enormous number of applications developed specifically for the diabetic users. Most of these applications circulate around four types of functions: patient's records, decision support, education and social communication [25].

Patient's records functions are mainly related to any diabetic data, such as the daily blood tests, daily doses, carbohydrate intake and burned calories. Most of these applications require the patients to enter the data manually, but few of them can be synchronized with glucometers or other sensors for direct data upload [26].

For decision support functions, they are mainly related to the management of daily activities, i.e., medication, meals and exercise. For example, the collected diabetic data can be used to create charts known as trends. These trends can be observed to detect any fluctuation within the patient's glucose values. Additional useful applications are functions like medication reminders and carbohydrates ratio calculators. The previous listed functions can help the patient to take the right decisions regarding the attempted routines, such as doing more exercises, consuming the proper amount of carbohydrates or taking the right amount of dosages.

For education functions, they generally give information related to the diabetes itself, such as guidelines, tips about medication and food or deep knowledge about symptoms and side effects. There are some applications—still under clinical trials—that aim to make these applications more personalized; these applications can give information based on the patient's profile [27].

As per the communication functions, they are mainly related to the communication between patients and practitioners or through social media, i.e., FACEBOOK, Blogs or Internet groups. Communication with practitioners can help smoothing the exchange of information between the two parties or setting up regular follow-ups. For social media, it is an alternative way to find some support outside the clinics. Through this communication, patients can be out of their diabetic isolation, and they can share some of their diabetic experience among other members.

With all the previous functions and features, using smart phones under the diabetes mellitus is still considered a non-standard practice and very limited [28]. Most of these applications are still not recognized by official organizations, such as US Food and Drug Administration (FDA) [29]. The absence of these types of recognition makes them barely known among practitioners and less trusted for recommendations.

Moreover, some functions could be useful, but it might be difficult for some patients to handle them without enough experience. For example, providing trend charts for analysis can be useful, but not all the patients can interpret them smoothly without experts' aid.

For communication functions in particular, security and reliability of information are critical issues here. For example, concerning the communication through social media, the major issues come from the authenticity of provided information; some of this information can actually be advertisement disguised as users' comments [30]. Providing false diagnoses or medication to the patients

without the practitioners' supervision can lead to multiple high risks. Similarly, advertisement can take advantage of social media to advertise products by giving false comments or recommendations. Keeping Internet groups or forums free from false information and advertisement is still a big challenge within social media for healthcare.

Finally, most of the standard diabetic gadgets are closed-sources, i.e., they do not share their data protocols with third parties. As a result, most of these applications lack the capability to sync data with standard diabetic devices. The diabetic management by itself is a difficult mission; adding extra tasks like the manual data entry to the key mission would not be appealing to some patients. Few diabetic gadgets in the market have started to utilize the powerful environment of smart devices, but it is still very limited and needs more support from specialized organizations and practitioners [31].

In general, most of the efforts focus on how to digitize the long-established diabetic practices. For example, rather than noting the daily blood test results in the patient's diabetic physical diary, the patients can instead write them digitally on their smartphones. Nevertheless, in reality, both methods are requiring the same amount of efforts and time; furthermore, the data on the phone is not being utilized smartly to enhance the patient's daily management. The main point here is that rather than focusing on creating solutions that would only digitize usual practices related to diabetes, it would be more ideal to create smart solutions, which can ease the diabetic tasks or encourage a better compliance. For example, a more practical solution is to provide a way to upload all the data to the phone effortlessly, and then utilize them to provide smart functions or directions, e.g., tagging them with some other diabetic data automatically. There are few diabetic gadgets applied the previous example. An American-based company Telcare Inc developed a new type of cloud-based glucometer [32]. The glucometer utilizes the cellular communication to upload patient's daily blood test automatically to any personal devices through a cloud server. Some other developers created glucometer kits that can be attached to the smartphone itself, and then the phone itself can do all the glucometer functions like any standard devices [33].

III. ASSESSMENT OF INTELLIGENT INSULIN PENS TECHNOLOGY AMONG DIABETIC PATIENTS

This section gives details about the assessment study conducted for the intelligent insulin pens. It highlights the research method first, and then it states all the collected results. Lastly, the section concludes with a brief discussion about the observed results.

A. Assessment Study and Research Method

Qualitative surveys and interviews were conducted through two stages among individuals related to the diabetes mellitus. The first stage was conducted through online communities. This was either by sending them direct emails or by recruiting them through online groups [1]. The second stage was conducted physically through specialized clinics. 25 individuals were recruited through the Ministry of Health Training, Postgraduate Studies and Research Center in Jeddah, Saudi Arabia.

In addition to that, during this stage, oral interviews were conducted as well among practitioners related to diabetes mellitus. The total number of participants in both stages was 101 diabetic individuals, and the number of interviewed practitioners was 5 individuals.

The study was focusing on patients who were using insulin medication as part of their treatment. All the cases that reported using oral medication only have been excluded from this study. The questions were directed toward patients or their caregivers. The questions focused on the following information: patients' general information (i.e., age, gender, use of smart devices, etc.); patients' diabetic information (i.e., period of diagnoses, diabetes types, types of insulin therapy, data management, etc.); patients' Hypo/Hyperglycemia encounter (i.e., number of episodes, possible reasons, etc.).

During the second stage, additional experiments have been conducted: first observing the administration of doses using regular insulin pens, and then observing the patients while using intelligent insulin pens.

In the last two parts of the survey, the questions were focusing on intelligent insulin pens in particular; for example, best features, expected improvement or overall impression. The last part focused on the future direction of intelligent insulin pens; in particular, it concerns the potential in the connectivity between smart devices and intelligent insulin pens. Lastly, interviews with practitioners were concerning the following information: the use of smart devices under diabetes mellitus; the preferred format for patients' records; the overall impression for the intelligent insulin pens; and the overall impression for the connectivity with smart devices. The summary of results and experiments are enlisted below in the next section.

B. Summary of the Assessment Study Results

1) Patients' General Information: As per the groups of age, 32% of the participants were from the young and teenage groups. Participants, who were between the age of 20s and 40s, were about 39%. The remaining participants

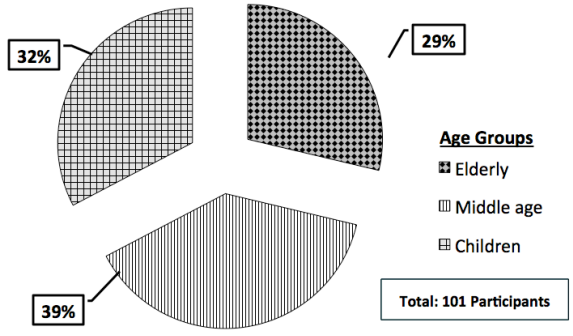

Figure 2. Total number of participants & age groups.

29% were in the age of 50s or above (Figure 2). Female and male participants were about 56% and 44%, respectively. We inquired about the usage of smart devices within daily routines, we found that 81% of the participants were using smart devices regularly, the remaining 19% indicated either non-use of smart devices or use of simple devices only, i.e., landlines and regular cell phones.

2) Patients' Diabetic Information: The majority of participants were from the Type 1 group 66%, while the remaining 34% were from the Type 2 group. Participants, who were diagnosed recently with diabetes, i.e., less than 5 years, were about 25% of the whole group. Participants, who had more than 15 years of diabetic experience, were about 43%. The remaining 32% were having between 5 to 15 years of diabetic experience.

For insulin therapy, participants who indicated using two types of insulin at the same time were about 62% of the whole group. The remaining 38% indicated using one type of insulin only, i.e., long acting in the case of type 2 and fast acting in the case of pump users. Most of the participants 72% reported that they were using insulin pens (and occasionally syringes as well), while syringes only users were about 17%. Participants, who were under insulin pumping, were about 11%.

We inquired the participants about the mistakes during insulin administration, i.e., missing doses, double doses or inaccurate dosage. 24% of participants reported that they were frequently running into some mistakes with their insulin administration, while 39% were sometimes running into some mistakes. The remaining 37% reported that they were rarely running into any mistakes.

For keeping records of diabetic data, 57% of participants were keeping tracks of daily blood tests; 21% of participants were keeping tracks of carbohydrates intake; 44% of participants were keeping tracks of daily insulin doses. 41% of participants indicated that they preferred physical format, i.e., physical dairies, while 37% of them preferred the digital ones. Only 20% of participants reported that they preferred both ways—digital and paper—at the same time. The remaining 2% of participants indicated another preferences other than the two methods, such as the usage of voice memo or self-memory.

We inquired the participants, who were using smart devices regularly, about the usage of smart devices under diabetic management. Only few participants 30% indicated using their smart devices for their diabetic management (Figure 3).

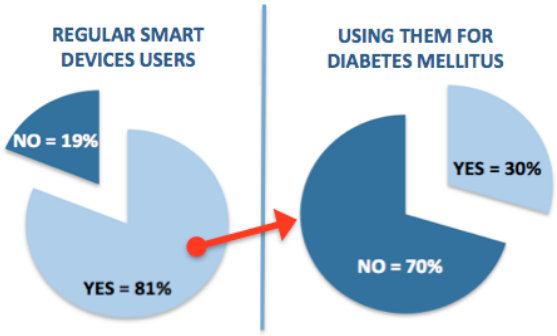

Figure 3. Smart devices users.

3) Patients' Hypo/Hyperglycemia Encounter: 35% of participants reported that they were frequently running into Hypoglycemia episodes every month, while 31% were sometimes running into Hypoglycemia episodes every month. The remaining 34% reported that they were rarely running into any Hypoglycemia episodes every month. 45% of participants reported that they were frequently running into Hyperglycemia episodes every month, while 35% were sometimes running into Hyperglycemia episodes every month. The remaining 20% reported that they were rarely running into Hyperglycemia episodes every month. The likely main reasons for encountering Hypoglycemia were due to: 51% insufficient amount of carbohydrates in meal, 27% excessive activities, 21% over medication or mistakes and only 1% for other reasons, i.e., not from the specified list, such as illness, high insulin sensitivity or oversleeping. On the other hand, the likely main reasons for Hyperglycemia were due to: 62% extra amount of carbohydrates in meal, 16% lack of activities, 12% insufficient amount of insulin or mistakes and 10% indicated other personal reasons, i.e., not from the specified list, such as stress, illness or poor control.

4) Patients' Views about Intelligent Insulin Pens Technology: Latest technologies of intelligent insulin pens were presented to the participants. The presentation was done through two stages. The first stage was done through demonstration and visual aids embedded within the survey materials. The second stage was done through interviews and a couple of usability studies. It was found out that the majority of the participants 80% never heard of or used intelligent insulin pens before this study.

After that, remarkable features available within current models were highlighted within a list, and then the participants were asked to pick the most preferable features, i.e., the ones considered essential for the diabetic management. The highlighted features were (ranked by the highest collected scores from patients' sides):

1. Memory feature
   (i.e., keeping records of doses, date and time).
2. Alarming system
   (e.g., blockage, dosing countdown and low battery).
3. Syncing data to PC.
4. Precise scale
   (i.e., 0.1 unit scale).
5. Pre-saving time period and dosage amount
   (i.e., automatic dosing adjustment).

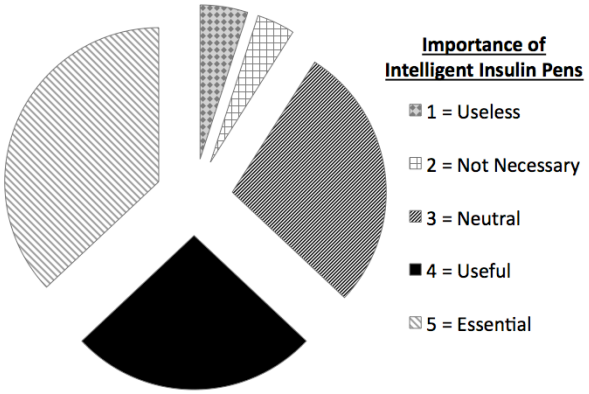

Figure 4. Importance of intelligent insulin pens.

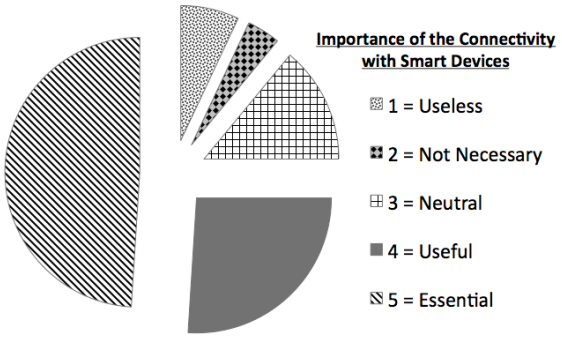

Figure 6. Importance of the connectivity with smart devices.

6. Switching between manual and digital modes (i.e., in case of battery outage).

Following that, the participants were inquired about the expected improvements after using this type of technology. The majority of the participants were expecting to encounter fewer Hypoglycemia and Hyperglycemia episodes. Easier management and data collection came in the second place. Precise dosing capability for each meal and then encountering fewer mistakes came as the last two in the rank.

The participants were asked about hindrances that would prevent them from obtaining this type of technology. The top hindrance went to the availability within the local market. High cost came as the second one. Complexity and then compatibility with insulin brands came as the least two reasons.

Finally, the participants were asked to rate the importance of intelligent pens for diabetic management. In the scale of 5 = essential to 1 = useless, 37% of participants thought that intelligent insulin pens would be 5 = essential for them, while 26% could be 4 = useful. On the other hand, 4% of the participants thought it could be 2 = unnecessary, and 5% thought it could be 1 = useless for diabetic management. The remaining groups 28% were 3 = neutral about them (Figure 4).

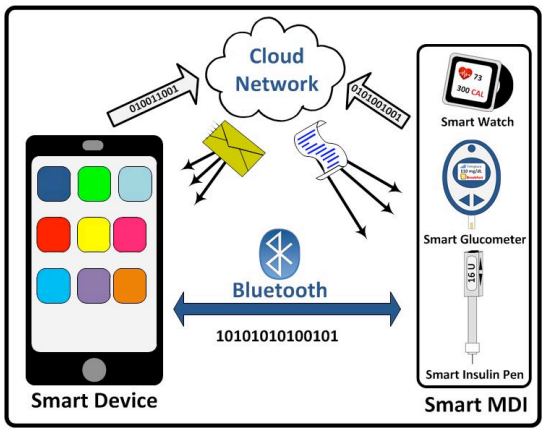

Figure 5. Connectivity with smart devices.

5) Patients' Views about the Connectivity between Intelligent Pens and Smart Devices: In the last section, assuming that intelligent insulin pens and other diabetic devices could have the capability to communicate with smart devices (Figure 5), and at the same time, they could manage to provide the following functions:

1) Automated reminder and confirmation for doses
2) Automated data collection and sync with software managers
3) Warning and error detectors while dosing
4) Remote controlling through smart devices

The participants were asked once again how they would evaluate the importance of using smart devices under this vision. Similarly, in the scale of 5 = essential to 1 = useless, 49% of the participants rated this type of communication as 5 = essential, while 26% rated as 4 = useful. One the other hand, 4% the participants considered this as 2 = unnecessary and 7% as 1 = useless. The remaining 14% were 3 = neutral to the idea (Figure 6).

The participants were asked which feature from the above list could be considered essential for their management. The automated reminder and data collection features were ranked as the first and second, respectively, while the warning and remote controlling features were ranked the third and fourth, respectively.

6) Results from the Usability Study: Within the second stage of the interviews and usability study, we added a two

extra experimental sessions. The first session was to evaluate the compliance while administering the doses, while the second session was to evaluate the intelligent insulin pens usability. Among the 25 participants 22 of them reported using insulin pens to take their doses. The patients were observed while administering their own doses with insulin pens. The recommended instructions state that the patient should wait few seconds before removing the pen from the body [6]. Among the 22 cases, only 4 cases did not follow the appointed instructions. As for the other patients, they were following the recommended instructions but the waiting time to take out the pen varied from patient to patient.

After that, we gave instructions to all the 25 participants explaining the use of intelligent insulin pens. The model used in this experiment was the intelligent insulin pen manufactured by Diamesco Co., Ltd [12]. Most of the participants managed to use the intelligent pen on their own after repeating the instruction at least once after the first set of instructions. Some of the positive comments that we got from the participants were: the large screen makes the dosing more visible and easier for adjustment; the digital-motor eliminates the need for finger-force; the pen gives countdown before removing the pen from the body.

For the other functions, such as viewing memory data or replacing cartridges, there were some difficulties in mastering them among the participants. The participants needed to follow the instructions multiple times in order to manage these functions on their own. Some of the negative comments that we got regarding the intelligent pens were: the intelligent pen was considered heavier and bulky compared to regular insulin pens. Also, some patients considered the intelligent pen slower in dosing compared to regular ones. This is because the used model forces you to prim the pen before dosing. Some patients believed that the priming step should be optional here rather than being compulsory.

7) Results of the Oral Interview with Diabetic Practitioners: Table II provides the list of participants along with some brief information. Regarding the recommendation of using smart devices under diabetes mellitus, the 1st P.C., 2nd P.C. and 4th P.C. pointed out that they were using smart devices regularly, but they were lacking the experience in finding any application under the local language for their recommendation. The 3rd P.C. pointed out that she was using smart devices regularly and at the same time she was recommending using them for diabetic management; i.e., mainly for dose reminders and monitoring calories through wearable sensors. The 5th P.C. pointed out that he was also using smart devices regularly and was recommending his patients to use smart devices as well. Most of the recommendations were for communication with the primary care, blood test applications and diabetic education as well. Both of them did not point to any specific applications.

TABLE II. PARTICIPANTS OF ORAL INTERVIEWS

Primary Care (P.C.)	Age	Gender	Intelligent pen technology rate	Connectivity with smart devices rate
1st P.C.	30-49	Female	4	5
2nd P.C.	30-49	Female	3	4
3rd P.C.	30-49	Female	5	5
4th P.C.	30-49	Female	5	5
5th P.C.	30-49	Male	3	4
Rating scale of 5 = essential to 1 = useless				

As per the preferred format for patients' records, the 1st P.C. and 2nd P.C. pointed out that they preferred both types of format, i.e., digital and paper, since there were some patients that have limited technical skills. They wanted to keep it flexible for all patients. The 3rd P.C. preferred paper format; she thought that generating digital record was still too difficult for the majority of patients. The 4th P.C. preferred using digital format to avoid any misreading of patient's data due to bad handwriting or any similar issues. The 5th P.C. preferred digital format in order to keep them within his PC as references.

As per the intelligent insulin pens technology, after conducting a couple of experiments, the 1st P.C. chose dosage auditing system and the alarming functions as her best features available within current models. She pointed out that the auditing system would give more background regarding the patient's daily routines, while the alarming system would keep the patient alerted and assure a proper dose administration. The 2nd P.C. thought that the intelligent pen with the current features had limited uses, which might not be useful for all types of patients. The 3rd and 4th P.C. appraised the auditing system and PC data syncing functions. They thought that both features would help them to understand the patient better and keep more references about them. Additionally, they believed that both features would help the patients effectively as they would able to associate the data with their daily routines. In this way, it would reduce the number of encountered Hypo/Hyperglycemia episodes. Moreover, it would prevent missing or duplicating doses. The 5th P.C. thought that the audit system and digital-motor were good features, but he still believed that not all patients would able to use the intelligent pens smoothly without any difficulties. The overall rate of the intelligent insulin pens technology for each P.C. was summarized in Table II.

For the main hindrances that might prevent the patients from obtaining this technology, the 1st P.C. and 2nd P.C. thought that the availability within the local market would be a major concern here; in addition to that, the 1st P.C. thought that the auditing system itself might actually be a possible hindrance for using such a technology. Some patients have the habit of concealing part of their daily information while reporting to their primary care. So using such a device would stop them from keeping up with these habits. The 3rd P.C.

and 5th P.C. listed high prices and complexity—especially among elderly—as the main hindrances for using this technology. The 4th P.C. thought that both high cost and local availability would be the main hindrances for obtaining this instrument.

For the connectivity with the smart devices, the overall rate regarding this capability was summarized in Table II. The 1st P.C. thought that the automated reminder function would be the first choice for her. The 2nd and 5th P.C. thought that the automated data collection feature would be extremely important, as it would ease the mission of collecting patients' data. The 3rd and 4th P.C. thought that providing an interactive interface would allow different types of features, such as easy control, flexible dose adjustment or carbohydrates ratio calculation.

C. Discussion and Analysis of the Assessment Study

Overall, the data showed that most of the participants had no experience with the intelligent insulin pens before this study, but the overall ratings of intelligent insulin pens were mostly positive among the participants. Few cases had negative views toward the technology. Most of these cases were patients, who have been under insulin pumps therapy. There were still quite a number of participants, around 28%, who do not mind this technology, but at the same time they cannot see great advantages in its usage. It is still difficult to have an absolute conclusion about the importance of the intelligent pens—as compared to other methods—from this study only.

As per the evaluation of the intelligent pens features, Memory feature was ranked the first in the scoring rank. There were about 63% of participants who reported liability of dosing errors, either frequently or occasionally. So apparently, the memory feature would get the major attention among these participants.

In the second place came the alarming feature. The feature was probably appreciated as it helps to keep the patients alert about battery and insulin cartridge level, and at the same time, it also helps to assure a better dose administration, i.e., because of the automated alarm countdown while administering the dose. It would save the effort of doing the counting manually.

For the precise scale and data transfer both features got a lower rank than the previous two. This was because only certain groups would appreciate these features. Precise scale is certainly critical for those who might have high insulin sensitivity. The case is common among children and athletics. In our data, young participants were about 32% of the group, while people, who picked the excessive exercises as the main reason for Hypoglycemia, were about 27%. Both groups were not dominant in the sample, so certainly precise scale would not get a higher rank than the previous two features.

Similarly, for transferring data to PC, the feature got lower ranks than the other features. The feature itself has the potential to ease the collection of doses records. Nevertheless, the group who reported keeping tracks of daily doses was less than half, about 44%. Many participants among the other groups did not appreciate the importance of doses records collection; so, as a result, the feature of transferring data to PC was less appreciated among these individuals. On the other hand, the feature itself was greatly appreciated by primary cares; it would ease monitoring the adherence of insulin medication among patients.

Pre-saving doses got a lower rank within the list; although the majority of the participants 62% were using two types of insulin, the feature was assumed to get a higher rank and gain more appreciation from the patients. Nevertheless, because some patients make regular adjustment in daily bases for each meal to match the carbohydrates intake, it could be possible that this feature would be meaningless to them. Pre-saved dose function will limit the flexibility of adjustment. Basically, patients will keep re-adjusting all the pre-save doses similar to the regular manners. The feature could be more appreciated if they were for example implemented with some smart features; for example, like including an alarm or warning for not taking the dose during the usual time. Such a feature could be useful for those who would frequently forget to take their meal doses either before or after their meal.

Finally, as per the ability to switch from digital mode to manual mode, this feature would be useful in the case of battery outage; however, with the availability of the alarm feature, it became less meaningful; because it can notify when the battery would reach low level. Moreover, in such a case, the patient can switch to regular insulin pens without the need to switch to the manual mode itself.

The question here now is how important this technology would be for diabetic patients. Most patients saw some promising potentials within this technology, but we need to look deeper into the actual characteristics of the technology itself. The two unique features within the current technologies are the data memory and precise scale. For the use of data memory in particular, if the patient is among the individuals, who regularly encounter dosing mistakes—like one of the 24% of our participants, then this kind of solution can be essential in order to avoid any risks of serious Hypo/Hyperglycemia. Similarly, if the patient is one of the individuals, who have high sensitivity to insulin, this kind of solution will provide a high flexibility of dose scaling. Other than this, both features will be great options for general groups; the patient might not need to use them in regular bases, but in some occasions, they would be handy, i.e., during busy schedules or heavy exercise routines. The large data memory itself might be useful as reference for individuals like primary cares, but for the patients, it would be more useful if they can be associated with other diabetic data to enhance the self-management.

In general, most of the patients were hoping for a fewer number of Hypo/hyperglycemia episodes after using this technology, but at the same time, in the data, participants indicated that the most likable reason for these episodes was due to inaccurate carbohydrates intake. Encountering these episodes because of mistakes came as the least reason among the other ones. Unfortunately, there is no feature available within current models, which can give precise carbohydrate intake values, i.e., like the one available within pumps. From the hindrance side, participants and primary cares indicated

that the availability within local market and high prices would be the two likely reasons for passing on this technology. Unluckily, current models are still suffering from one of these two issues or both. For high cost in particular, high cost can be a hindrance, but if the solution could justify its effectiveness, patient might pass on costs for the favor of ideal performance. This case can actually be observed among the users of insulin pumps. Although pumps are well known for their high costs, they are still a popular solution among Type1 patients, especially in United States. This is because pumps have been known for their remarkable performance and convenient management [34].

During our usability study, complexity as well got some attention also among some participants and primary cares. Intelligent pens were noted for being a little complicated than regular insulin pens, however, mastering them is still not hard as the insulin pumps. The complexity in our data could not get a higher value because most of the participants were from the middle-aged groups. If most of the participants were from the elderly groups, we might see a higher value for complexity as a hindrance.

We can conclude here that current solutions of intelligent pens can be essential for certain groups of patients, but for the general, it is a good option if the patient could justify their needs over the existing hindrances.

IV. CONNECTIVITY OF SMART DEVICES AND INTELLIGENT INSULIN PENS

In our last section of our survey questions, which was related to the connectivity with smart devices, we saw some changes within the evaluation of intelligent insulin pens under the proposed vision. We could see some evident movement from the neutral group side to the positive group side. There were some other movements from the neutral sides to the negative sides but they were only few, especially among users who do not use smart devices regularly. We inquired the patients to pick the most desirable feature among the proposed list in order to locate the start point of our pilot studies. Since the patients were more concerned about creating solution that would remind them automatically about their own doses, we decided to conduct a series of experiments under this vision. The main objective is to test their usability and effectiveness on the regular management.

This section gives some details regarding a series of pilot studies, which were conducted to test the feasibility and usability of connecting intelligent insulin pens technology with smart devices. The section first gives some background about the current smart technology and their capabilities, and then it states some details about the proposed system used for this study. After that, the section highlights the experiment details, and then it lists all the observed results. Lastly, the section concludes with a brief discussion and analysis about the obtained results.

A. The Role of Ubiquitous Technologies in Enhancing the Intelligent Insulin Pens

The intelligent insulin pens showed some potential in providing a couple of helpful features for insulin delivery; however, the technology still needs more improvement to make them highly effective for the majority of diabetic patients. The issue is that this improvement could lead to some major concerns, such as additional manufacturing cost or complicated user interface. Intelligent insulin pens have already a huge difference in their prices compared to regular insulin pens. Moreover, mastering its use is not straightforward as regular insulin pens; it requires some time to fully adopt the user interface and handle all the functions. This means adding more features within the unit in the future, such as carbohydrates calculators or smart reminders functions, would raise the cost of each unit, and it could complicate the interface even further.

Alternatively, rather than adding extra processing modules within the unit itself, we can focus on the connectivity with ubiquitous technologies, such as smart devices and cloud computing. As it was stated before, smart devices are remarkable for their powerful processing capability and simple user interface. They can act as an extension unit for intelligent insulin pens to do some sophisticated tasks such as automated reminder function or automated dose adjustment.

In addition to that, technologies such as cloud computing can play a major role in this type of extension. Exchange of data and commands could effortlessly be managed between the two technologies through the cloud communication. Multiple sectors, e.g., communication, gaming, e-commerce, etc., are already utilizing the cloud computing technology within their practices; yet, the healthcare sector is still a little bit slow in following the same example [35]. The reasons could go back to the differences between regulations in handling healthcare data [36], or the risks associated with the multiple threats surrounding the cloud technology [37]. Nevertheless, we cannot ignore how helpful the cloud computing have become in handling our daily data. Luckily, experts are aware of this potential and they are trying multiple ways to overcome the risks associated with the healthcare data [38].

B. The Proposed Reminder System

General recommendations state that the patient should associate medication time with daily routines, e.g., bedtime or mealtime; however, additional recommendations suggest using reminder systems to back up daily routines; the reason is that daily routines are liable to changes or alteration. Studies found out that smart devices are the most common way among patients to remind themselves about their own medication [39], and several other studies proved that the use of smart devices managed to improve the adherence among patients [40][41].

Nevertheless, most of the results from these studies were relying on patients' self-reporting. Unfortunately, it was found that self-reporting were liable to alteration and human-errors [42]. For this reason, it would be better to create smart

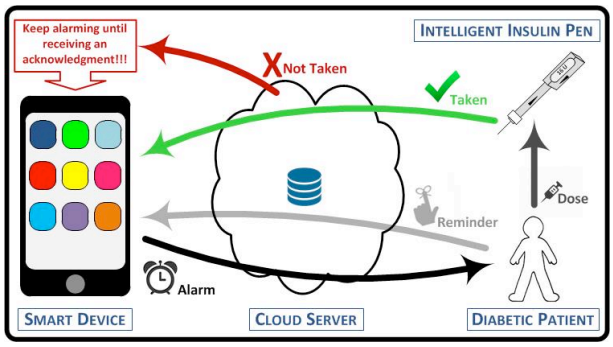

Figure 7. Cloud-based reminder system.

solutions that can automatically keep tracks of dose administration.

There are some examples from several conducted studies concerning the previous point. One study applied the gamification concept to keep tracks of the medication and adherence level [43]. In this study, the patients competed with each other through social media to maintain the highest rank of adherence level among the group members. Other studies used wearable computing to keep tracks of medication routines [44].

Following the same directions, we proposed a smart cloud-based reminder system using smart devices and intelligent insulin pens. With the proposed system, we conducted a couple of pilot studies to test the usability of the system and its potential among diabetic patients.

The suggested system (Figure 7) is similar to some cloud-based reminders system available within current generation of smart devices, i.e., Apple®'s iPhone or Android based devices. In these devices, as soon as the user would set a reminder, it would be activated automatically in all the devices associated with the user's account through the cloud services; similarly, the user can deactivate, i.e., check the reminder, from any device available in hands at that moment.

We would like to apply the same concept for doses reminder; however, rather than allowing the patients to deactivate the reminder alarm manually, the device should automatically check the collected records within the intelligent pens and verify if the patient has taken the required dose or not. If the device could not find the required record, it would keep snoozing the patient until it would make sure that the patient has taken the required dose.

This system would be specifically useful for the daily basal type of doses, i.e., background insulin doses such Glargine or Detemir.

This type of doses requires to be taken within a fixed period of time, i.e., 12 or 24 hours, in order to assure a better glycemic control [45]. Applying this type of systems can encourage the patient to adopt a better compliance to the diabetic management and, consequently, the patient would keep maintaining a high level of adherence to the medication.

C. The Pilot Studies and Research Method

Three usability studies were conducted with 13 participants in total; each one of this study lasted 3 weeks. The first two experiments were part of another study [46]. Additional study was conducted and analyzed for this research. Table III summarizes the information concerning the participants.

All the patients were using Insulin Glargine as part of their medication. Three individuals withdrew in the middle of the study due to a couple of reasons, i.e., busy schedule or technical difficulties, while the remaining ten participants continued till the end of the studies. The experiments in the studies were split into two phases.

The first phase of the experiment lasted 10 days. It focused on the interaction of patients with the intelligent insulin pens and measuring the patients' adherence level.

The second phase of the experiment also lasted 10 days; however, this time the focus was on the interaction between the patients and the proposed cloud-based reminder system. The adherence level was measured here as well to oversee the influence of the system on this data.

For the first phase, the patient was asked to follow the same usual routines for taking the basal dose using the intelligent pens. For the second phase, the patient had to use the proposed reminder installed within the personal smart device. The patient was directed to take the medication every day on the same determined time. The patient was allowed to take the medication within 30 minutes earlier or 30 minutes later from the appointed time. Basically, the system will check the data within the intelligent insulin pen. If the required dose was taken, the reminder would automatically be deactivated, and then a confirmation message would be sent to the patient. If the administration of the dose could not be confirmed, snooze would be activated for every 10 minutes. The snooze would be kept activated until either the

TABLE III. LIST OF PARTICIPANTS

ID	Gender	Usage of Smart Devices	Age	Study Completion
P1	Male	High	21-39	YES
P2	Male	Low	60-75	YES
P3	Male	High	40-59	YES
P4	Female	Average	40-59	YES
P5	Female	High	40-59	YES
P6	Male	Low	60-75	YES
P7	Female	Average	40-59	YES
P8	Male	Low	60-75	YES
P9	Female	Low	60-75	YES
P10	Male	High	40-59	YES
P11	Female	Average	21-39	NO
P12	Female	Low	40-59	NO
P13	Male	Low	40-59	NO

confirmation or until a period of 30 minutes from the first alarm. After that, a message would be sent to the patients stating that "the dose was not administered within the appointed time and it should be administered as soon as seeing this message".

The system was partially based on the Wizard of Oz prototyping concept [47], but from the patients' side the system actions were fully automated. The main tools used for this experiment were:

1. 4 x intelligent insulin pens.
2. 4x portable laptops with pre-installed diabetic management software.
3. Smart reminders with cloud feature installed in the patient's personal devices.

The level of adherence was measured based on SANOFI's directions for their insulin Glargine [48], i.e., "once a day" and "within 24-hour". If the patient managed to take the dose within the assigned period, a full score would be given. If the patient administered the dose outside the assigned time, a half score would be given. If the patient did administer the dose during that day, no score would be given.

We conducted another measurement to evaluate the speed of response to the issued alarms. Table IV summarizes the scoring method for the response speed. After that, one day was dedicated to collect participants' feedback for both phases.

TABLE IV. RESPONSE SPEED SCORES

Scores	Period of time	Patient's Awareness
5	Before the time	Mostly responded before the 1st alarm
4	On time	Mostly responded to the 1st alarm
3	10 minutes passed	Mostly responded to the 2nd alarm
2	20 minutes passed	Mostly responded to the 3rd alarm
1	30 minutes passed Or more than 30 minutes earlier	Mostly responded to the last alarm or miscalculated the assigned time
0	Dose not taken	

D. Summary of the Pilot Studies Results

1) Scoring Data: Figure 8 summarizes the results of the adherence level before and after applying the cloud-based reminder system, while Figure 9 summarizes the scores for the response speed to the alarm system. For the level of adherence, most of the patients had either the same level of adherence or slightly better after applying the system, while four cases showed notable differences within the measured level, especially for the second and third participants.

For the response speed level, the results of the cases showed that most of the participants were likely respond the second alarm. This means that this group might require a medium level of alarming, i.e., at least two to three snoozing alarms. Three cases showed an immediate response to the alarming system, which means this group might require a low level of alarming, i.e., maximum two snoozing alarms. Two cases only showed a low level of response speed to the alarming system, which means they might need more than three alarms in order to administer their medication on time.

2) Patients' Feedback: Most of the participants had positive views toward the systems. The participants' opinions have been grouped according to their reminding behavior before using the system.

For those who used to have a regular reminder system, like remainder apps or devices, they considered the system as an upgrade to the usual reminders. This was because the

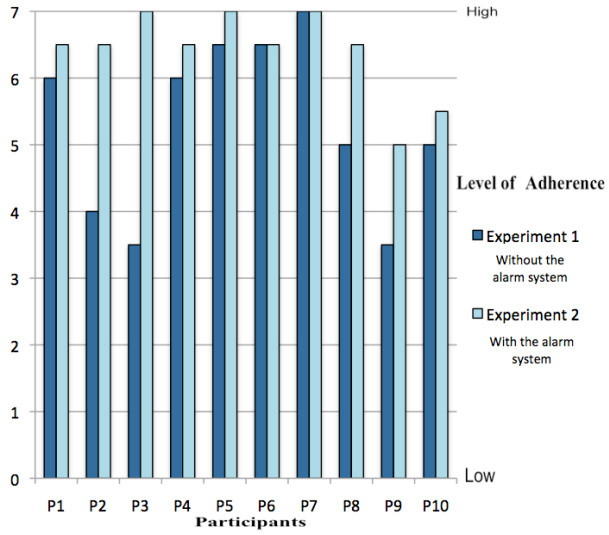

Figure 8. Level of adherence results.

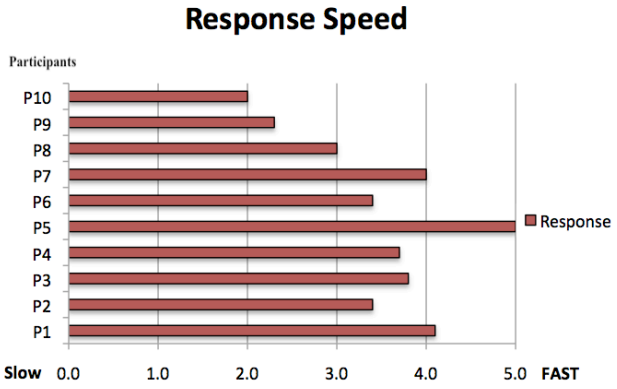

Figure 9. Response speed results.

system could automate the snoozing function and post-acknowledgment for the doses.

For those who were associating their dose time with daily habits, they reported that the system was as good backup for the daily habits. They felt that the system is more reliable because daily habits were liable to changes or alteration.

For those who were not following any of the previous two methods, they felt that the system helped a lot to maintain the dose time, especially under busy schedule routines.

The ability to run the system on multiple devices was apprised a lot. When one device would be down for any reason, the second one will act as a backup.

Few cases showed less appreciation to the system. The main reason could be that their use of smart devices was limited to basic functions only, i.e., calling or messaging only. The most notable negative feedback was the inability to customize the alarming system. The sound level and type of tunes were limited in the systems, this sometimes caused some inconvenient for the participants; it caused missing at least the first alarm in a couple of cases.

The other negative view was the Internet communication dependency. Since the system relies heavily on the cloud servers, it requires keeping the devices connected to the Internet all the time. Sometimes it is hard to maintain this condition due to communication lost or weak signals.

The patients were inquired about the main reasons for not administering the dose on time while using the system. Some cases reported that they were receiving the alarms but they could not take the dose on time because they left their digital pens at home or office. Another cases were due to heavy sleeping; some participants missed the alarm while sleeping because the sound was not loud enough to wake them up. Another reason was due to the engagement of certain activities that prevented them from being excused to take their own doses on the appointed time, i.e., being in a meeting or giving some lectures.

E. Discussion and Analysis for the Pilot Studies

The pilot studies were divided into two phases of pilot studies. The first phase was focusing on observing patients' regular routines, while in the second phase, patients were asked to rely on the proposed reminder system for managing the doses time; the proposed reminder system here acted as an extension feature for the intelligent insulin pens. The purpose was to see the influence of the applied reminder system on the patients' compliance.

After evaluating the obtained results for adherence, we found that participants, who were using regular reminder systems or daily routines to remind themselves about the doses, had some advantage from the system. First, the participants managed to maintain the same high adherence level in the second experiment without any extra effort, i.e., no need to adjust the reminder manually. Second, the system was more reliable because all the confirmation and snoozing processes were done automatically without any external alteration. This system among these types of patients could act as a good support for the regular daily routines.

For the participants, who were not following any methods to remind themselves about their own doses, benefited more from the proposed reminder system. Even under busy schedule, participants achieved to maintain a better management for their own doses. This kind of system could help this type of patients to sustain a better compliance toward the medication directions.

As per the second measurement related to the alarm response. The response speed results showed that this kind of system should offer some customization level personalized for each user. For example, people, who have limited uses of smart devises, might need to be reminded more frequently than regular cases; similarly, heavy sleeper might need a louder or more noticeable notification to wake them up.

As per the patients' feedback in using the system, the use of intelligent insulin pens along with this kind of reminder system was greatly appreciated among most of the participants. Also, since this system is utilizing cloud services, it can be available within multiple numbers of personal devices. This would make the system more portable and convenient for use.

Some cases, especially among participants with limited technical knowledge, had less appreciation to the whole system, which combines intelligent insulin pens and the proposed reminder system. The reasons could go back to the limited uses of smart devices or to the hindrances available within intelligent insulin pens technology itself.

For a final word about future development within this types of researches, For systems that are similar to the proposed reminder system within this research, these kinds of systems rely heavily on using an advanced type of devices, which can record and exchange data among other devises. The exchange of data should be done in an intuitive way, which do not require the user's involvement, such the communication through cloud computing. In our proposed system, unfortunately, current model of intelligent insulin pens do not have the capability to achieve the previous function, which allows exchanging the doses data with other devices automatically. The study relied on other methods, such as the Wizard of Oz, in order to the give intuition of automated data exchange to the participants within this study. Future development of intelligent insulin pens might need to focus on how to make the data exchange smoother and intuitive for the users, such as the utilization of cloud communication.

On the other hand, among the feedback in this study, some of the participants showed some concerns toward the use of intelligent pens technology itself, such as large size or complicated user interface. Such hindrances would directly affect the overall convenience of the whole system. In this study, the system relies heavily on using intelligent insulin pens for data collection. Nevertheless, if the intelligent insulin pens are not user friendly enough, then the user will not able to utilize useful functions such as the reminder system. In the future, when creating new solutions, developers should try to retain some of the convenience originated within former solutions, for example, in our particular case, regular insulin pens are being noted for their lightweight design, which ease carrying them around, while

on the other hand, the design of intelligent insulin pens is considered bulky compared to regular insulin pens. It could be difficult to find a good balance between enhancement and convenience, but the main objective is how to make a new introduced solution more appealing among the users. At the end, the ability to use the technology without difficulties will contribute in simplifying the diabetic management itself.

V. CONCLUSION AND FUTURE WORK

In general, technology has had a significant role in enhancing the insulin therapy. This was noted evidently within the evolution of insulin pump therapy. For MDI, before the arrival of intelligent insulin pens technology, the use of technology was limited to a couple of diabetic gadgets such glucometer and smartphones. The advent of intelligent insulin pens technology could be a promising evolution toward a smart MDI management system. Nevertheless, in order to examine the intelligent insulin pens necessity among diabetic patients, a couple of assessment studies were conducted among insulin dependent individuals.

The assessment studies included a couple of question related to the diabetic management and evaluation of the intelligent insulin pens technology. The study required a group of diabetic patients, who were mainly relying on insulin as part of their diabetic treatment. . The recruitment for participants was done initially through online communities, and then physically through diabetic clinics at alter stage.. The outcome of the study found that the patients in general had positive opinions toward the technology itself. The memory function was the most favorable feature among the other ones. The patients were still longing for more features and upgrades from these kinds of technology of intelligent insulin pens.

Judging on the outcomes, we found that the technology in its current shape could be essential for certain diabetic groups, but for the general insulin dependent patients, the technology could be a better alternative if the patient could justify the needs and overlook its current hindrances. In order to make the technology more functional for general diabetic group, more functions should be made to enhance the diabetic management itself.

Nevertheless, approaching such a goal might have a negative impact on the cost and complexity of the technology itself. Alternatively, we suggest focusing on the connectivity between this technology and ubiquitous technologies, such as smart devices and cloud computing. To demonstrate this point, a couple of pilot studies were conducted based on the outcomes of the assessment study.

The pilot studies included a Wizard of Oz prototype system tested among insulin dependent patients. The suggested system was a smart reminder system, which utilizes a couple of technologies like intelligent insulin pens, smart devices and cloud communication. The outcomes of the study were mostly positive among the patients. It is believed that the proposed system could be a good support for the daily diabetic management, and it would help to promote a better compliance toward the insulin medication. A couple of negative outcomes were observed, which were likely related to the limited uses of technologies. The main goal is to simplify the management of diabetes mellitus itself. For this reason, future developments should focus in how to keep new technologies user-friendly as much as possible. Failing to maintain this might affect negatively on the usage of these introduced technologies, and it would complicate the diabetic management even further.

Finally, there were a couple of limitations within this study. First, the sample size of the participated patients was relatively small. Results from this study cannot be representative. If we need to have an absolute conclusion about the intelligent insulin pens technology evaluation, we need to collect a large sample size that would be enough for statistical type of studies. Moreover, the conducted usability testes were short period studies, which were enough to observe the overall impression and collect limited information. Longer period studies can inspect more on the positive and negative outcomes of using the technology, and it can oversee the influence on the glycemic control. Similarly, for the smart reminder system pilot studies, the system was based on the Wizard of Oz prototyping, which was enough to collect some impression about the function itself and observe the interaction with the system.

Future studies should implement a full working prototype for a longer period of study. The goal is to find more about the positive and negative impacts while using the system, and once again, to observe the influence on glycemic control. These kinds of long-term studies require at least three months of continuous experiments and direct supervision from diabetic practitioners. We hope by investing in these studies, we would able to provide a contribution toward simplifying the complexity of diabetic management.

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Integrated Framework of Knowledge Management and Knowledge Discovery to Support E-health for Saudi Diabetic Patients

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Abstract--**In the last decade, the government of Saudi Arabia has given high priority to developing and implementing e-healthcare services and technologies. However, it has met a number of barriers in implementing its healthcare initiatives. This paper describes these barriers and proposes an e-health knowledge management framework to overcome these barriers by integrating developments from knowledge management with knowledge discovery techniques. This framework should assist in the delivery of competitive e-healthcare services and improve intellectual capital to provide smart health services in the country. The proposed framework will be applied to the domain of diabetes mellitus address the difficulties that diabetic patients encounter.**

Keywords - knowledge management; knowledge discovery; Saudi Arabia; diabetes mellitus; self-management; diabetes education.

I. BACKGROUND

The integration of knowledge management and knowledge discovery can play an important role in supporting e-health [1]. Eysenbach defines e-health as 'an emerging field in the intersection of medical informatics, public health and business, referring to health services and information delivered or enhanced through the internet and related technologies' [2]. According to the World Health Organization (WHO) e-health refers to'...the use, in the health sector, of digital data - transmitted, stored and retrieved electronically- in support of healthcare, both at the local site and at a distance'.

In the last few decades, the Saudi Arabian government has given a high priority to improve its e-health services. A number of new initiatives have emerged focusing on many aspects of healthcare, ranging from creating electronic files for patients, statistical monitoring of infectious diseases, connecting all hospital systems using technologies of cloud computing and monitoring the arrival of pilgrims and vaccines given to each pilgrim in their home country [3]. However, the implementation of these initiatives has been impaired by many problems outlined as illustrated in Figure 1:

- ***Non-connectivity of information systems***. Though some regional directorates and central hospitals are using information systems [4], there is no effort to connect these information systems in order to build up a national healthcare system [5].
- ***Lack of technical expertise and computer skills***. Computer skills of healthcare staff and professionals are deficient due to their lack of experience in using computer applications [6]. No guidelines are provided to handle electronic medical records (EMRs), and the staffs complain about poor maintenance of computers, networks, slow computers and old terminals.
- ***Failure of adoption Health Information Services (HIS).*** There are critical issues associated with planning and adopting HIS, and its implementation in Saudi Arabia; some of these are caused by the poor technical support and over running with respect to time and budget [6][7].
- ***Human barriers.*** This problem has been considered as the major reason for failing to adopt health information systems in Saudi hospitals [8]. Human barriers include negative beliefs of healthcare professionals towards technologies and lack of trust by medical staff towards computer based medical solutions. Therefore, many medical staff resists the change from traditional to computer based healthcare services.
- ***Cultural barriers.*** Cultural factors contribute to the failure in adopting e-health because of limited human interaction [7]. Aldraehim and Edwards [9] explain that Saudi Arabian people are extremely influenced by their culture and, therefore, they prefer physical interaction to virtual contact.
- ***Medication safety***. According to Aljadhey et al. [10], medication safety raises two major e-health issues. The first issue refers to communication gaps among healthcare institutions, which contribute to medical mishaps and patients' medical historical issues. The second issue is limited use of technology whose consequences occur in illegible handwriting. Computerised Provider Order Entry (CPOE) can solve this problem; however, this is being adopted slowly.
- ***Financial barriers***. Transmitting traditional paper medical records to electronic system can be very costly [11]. Such high expenditure, which needs to be spent on the adoption of IT in health, may lead to the slow uptake of e-health applications.
- ***Security and privacy***. This focuses on the easiness in accessing EMRs of patients due to the fact that some medical records of patients can be disseminated to others without permission of the patient or the doctor [6].

Figure 1. E-health Barriers in Saudi Arabia

This paper is structured as follows. Section I presents the background regarding e-health barriers in Saudi Arabia. Section II explains the role of knowledge management and knowledge discovery in healthcare. Section III provides insights regarding barriers that can hinder the SECI model utilization in the Saudi Arabian context. Section IV introduces the proposed framework to overcome e-health barriers in Saudi Arabia. Section V introduces the domain of application. Section VI describes the difficulties faced by diabetic patients. Section VII discusses the self-management and education approach to overcome these difficulties. Section VIII describes the feasibility of the internet in diabetes self-management and education. Section IX explains how an integrated framework can be used to help patients of diabetes and their health careers in managing those difficulties. Finally, Section X summarises the main directions adopted by this project.

II. KNOWLEDGE MANAGEMENT AND KNOWLEDGE DISCOVERY

Nowadays, patients and health practitioners are connected to hospitals, clinics and pharmacies; they share knowledge in order to reduce administrative costs and improve the quality of care. Although the focus tends to be on managing health records and interoperability of IT healthcare systems, knowledge management plays an important role in providing high quality and effective healthcare system. It also allows the capture, representation and dissemination of knowledge of healthcare professionals such as their strategies, practices and insights. This knowledge is the power that enables organisations and individuals to select the best actions and strategies [12]. Utilisation of best practices provides significant advantage for organisations in term of competition and efficiency. Individuals keep their knowledge in their brain and those individuals have the brainpower or intellectual capital that every organisation desires [13]. Furthermore, their knowledge helps identify current problems as well as achieve desired results [14]. Consequently, many top managers have recognised the importance of capturing and managing knowledge of its healthcare professionals and developing systems to improve their services.

Knowledge management is a useful mechanism to capture the intellectual capital of organisations, and healthcare establishments, in particular, so that they can deliver the best quality of care. It can help healthcare professionals cope with the fragmented and distributed nature of medical knowledge, the challenges caused by information overload and the importance to access local knowledge in making clinical decisions [15]. Additionally, it can provide healthcare practitioners with educational and training initiatives in terms of professional development and changing environment preparation [20][21][22]. Finally, dissemination of medical knowledge and best practices enable social learning initiatives where evidences can be disseminated to clinicians, nurses, and other healthcare workers [23][24][25] at national and international levels as well as to rural areas.

Knowledge management can provide a dynamic process of capturing, storing, sharing and creating both types of knowledge, explicit and tacit [22]. Explicit knowledge is communicable in systematic language whereas tacit knowledge is obtained through experience and cannot be articulated [23]. Nonaka and Takeuchi [23] suggested that knowledge changes from explicit to tacit and vice versa in two dimensional learning environments through four processes, namely Socialisation, Internalisation, Externalisation, and Combination, known as SECI (as illustrated in Figure 2), and represented in the form of a spiral. Socialisation enables the conversion of tacit knowledge via interaction among individuals, and can be achieved through shared experience. Internalisation enables converting explicit knowledge to tacit knowledge, while externalisation enables tacit knowledge to be converted to explicit knowledge. It makes tacit knowledge understandable and can be recorded or saved by visualising it in an explicit form. Combination is the process of 'systematizing concepts into a knowledge system' [23]; for example, people synthesise different sources of explicit knowledge through meetings, conversations and exchange of documents [16][27]. Nonaka concluded that knowledge is continuously created a third dimension, which account for restructuring the existing knowledge through the synergy of these four processes. However, a number of issues have been raised regarding Nonaka's premises; consequently, other models have been developed and/or extended Nonaka's basic ideas. For example, Nissen [24] developed the knowledge flows model to capture the organisational knowledge dynamics and added two further dimensions to Nonaka: life cycle and flow time. Harsh [25] proposed a third dimension, which accounts for knowledge reusability and where technology and human interaction can play a significant role in management of data, information and knowledge. Yao et al. [26] argued that SECI assumes that the only source of corporate knowledge originates from the staff within the organisation.

Figure 2. SECI Model [23]

In the healthcare sector, patients as well as healthcare workers significantly contribute to knowledge creation and knowledge sharing. However, tacit and explicit knowledge, which are embedded in people, are constantly updated and new knowledge is acquired from external sources through the analysis and knowledge discovery of patients data and databases, and scientific documents Knowledge discovery is another emerging discipline aimed at identifying valid, novel, understandable and useful patterns in data, texts, images, and other media [27]. It uses statistical and artificial intelligence techniques to analyse and process large amount of data [28] without or/at least less human intervention [29]. Data mining is a subfield of knowledge discovery, which discovers novel and valid trends/associations using machine learning techniques [30]. Typical applications of data mining in healthcare include monitoring high risk of diabetic individuals, so that appropriate messages can be communicated to them [31], predicting length of stay of patients with spinal cord injuries [32], and predicting hypertension from patient medical records with eight other diseases [33]. According to Berger and Berger [34] data mining is a useful approach for dealing with the rapid expansion of medical knowledge and healthcare data.

Whilst knowledge discovery can support the discovery of new knowledge from patients' healthcare data, knowledge management provides a forum to share and disseminate this new acquired knowledge and to combine it with the explicit and tacit knowledge acquired from healthcare practitioners. Such integration can address some of the problems discussed above and improve the quality and performance of healthcare services. Furthermore, it can assist healthcare organisations in making strategic effective decisions [35]. Hwang et al. [36] demonstrated how association rules can be applied to extract knowledge from patients' medical records along with medical rules of tumor associated diseases, and to develop guidelines for clinicians. Then, these guidelines can be shared among healthcare practitioners through a knowledge management system and deliver a better quality healthcare to patients.

III. SECI MODEL ISSUES

Even though the SECI model has always proved to be powerful tool to manage and share knowledge, it has been widly criticised and has been suggested that the model is not universally valid. Nonaka and Takeuchi [23] and other scholars suggested that each mode can take place by specific tools and conditions need to be there to make the knowledge conversion processes happen. For example, socialisation can take place via observation and experience when individuals are willing to share knowledge. According to Tyagi et al. [37], trust, respect and mutual understanding among resources during communication are important requisites for socialisation. Moreover, M. Glisby and N. Holden [38] mentionned other factors that must be provided in order to perform socialisation. Those factors are strong affiliation to the organisation, cooperative working environment instead of competitive, developing relationships with those who share the same fate, external sharing of knowledge facilitated by networks of partnerships between organisations and close interrelationships. To externalise knowledge, on the other hand, group commitment must occur among individuals in their workplace. In addition, participation of internal competent members and external experts in the training programs and seminars with little external control (i.e., minimal pressure from shareholders) are required for successful completion of externalisation [37] [38]. For the combination mode, Nonaka and Takeuchi stressed the importance of lack of interdepartmental rivalry, polychromic task orientation, high personal commitment and permanent occupancy. Internalisation mode can take place where there is minimal risk of mistakes occurring among individuals. This stage of knowledge conversion can be performed via job rotation, which encourages movement of members of staff in the organisation and thereby innovates knowledge transfer and increases motivation [39].

The overwhelming success for the SECI model in Japanese organisations is well-documented. However, the SECI model when applied to other countries does not necessarily indicate success as there are different cultural factors, which can influence the outcome of the knowledge conversion of the model; According to Schein [40], Nonaka and Takeuchi insist that the knowledge creation process needs social interaction, which is influenced by cultural norms. Factors of organisational culture, such as trust and the style of the organisation structure, are important to ensure knowledge sharing [39]. When considering factors suggested by Nonaka and Takeuchi for SECI model implementation it is important to appreciate how much these factors are influenced specifically by Japanese culture. Close interrelationships between organisations, which is significant factor for socialisation, is a specific characteristic of the Japanese culture only [38]. Low external control and group commitment, which are necessary requirements for externalisation, are features of the Japanese culture [76][79]. High personal commitment, permanent

occupation and other conditions essential for combination are typical Japanese practices and, therefore, combination may have difficulties when implemented in other cultures [42]. The same concept also applies to internalisation. Intensive job rotation is a typical Japanese practice because Japan focuses on developing generalists rather than specialists in particular domains. So, the experimental learning or 'learning by doing' is widely accepted in the Japanese organisations, which constitute the context of internalisation [38].

Several studies have examined the validity of SECI model in different cultures. T. Andreeva and I. Ikhilchik [42] analysed the implementation of this model in the Russian context. Dialogues with senior management were seen to be problematic in Russian companies because of the authoritarian leadership style and the prevalence of top-down communication, where employees do not directly communicate with senior managers or they are inhibited for fear of reprisal. These issues constitute a barrier for utilising the externalisation mode successfully in the Russian context. Furthermore, more effort is needed to perform combination in Russian organisations because of the presence of the concentrated authority and decision-making. In another study published by Weir and Hutchings [43], combination and internalisation do not work in the Chinese culture, in the way suggested by Nonaka and Takeuchi, due to the presence of interdepartmental rivalry and the risk of making mistakes.

In the Kingdom of Saudi Arabia (KSA), the culture is formed by three factors: religion, tribal or family systems and the Arab culture [7]. Islam influences the Saudi Arabian culture by setting moral principles among people in the country. Family is extremely valued in the Saudi Arabian culture as it provides security to its members. Members of the KSA family are expected to have good relationships with their relatives and this collectivism style ensures assistance, such as job opportunities, to be given to family members through the family leaders. Their belief is also influenced by the Arabic culture, which implies that all members in the family perform their roles in order for the family to continue its standing in society. Furthermore, the father in this culture is responsible for the family and always has the authority [44]. It is also a high power distance culture and has high level of uncertainty avoidance, collectivism and feminism [45]. In another study, cultural dimensions such as extreme power distance, masculinity, low uncertainty avoidance, and extreme individualism hinder the process of knowledge sharing [46]. Therefore, the process of externalisation and internalisation may be hindered in the Saudi Arabian culture. Weir and Hutchings [43] reviewed the utilisation of the SECI segments and concluded that socialisation and combination can be achieved in the Saudi Arabian world although there is tendency to keep knowledge among themselves unless there is a need for communication and if they trust their colleagues. This can impact the sharing of tacit knowledge and its externalisation. Internalisation does not work effectively because of the lack of confidence and trust from the information outlined from the knowledge holder because work life is still influenced by Saudi family culture and is not completely separated from the work environment. Although, job rotation is adopted in KSA, it is not widely practiced and tends to focus on developing deeper experience in the same field rather than widening an employee's competence in different domains.

Solutions have been suggested to adapt the SECI model to the Arabic culture at the organisational and national levels [39]. These suggestions can be used to improve successful utilisation of Nonaka's' model in KSA.

- ***Socialisation***. KSA citizens are seen to be pre-socialised [43]. Accomplishing strong relationships between top managers and employee will emphasise socialisation in Saudi Arabian organisations. Trust is important in this stage of the SECI model. Therefore, religious and social events, such as Ramadan festivities, graduations and weddings, can reinforce trust among colleagues. Establishing a reward system has also an impact on the socialisation mode. It reinforces knowledge sharing when considering the employees' different needs and objectives [47]. Rewards for knowledge sharing can be tangible or in incorporeal forms. Self-worth is an example of an incorporeal reward which means the individual who shares knowledge has the feeling of being valued and it includes personal acknowledgement and recognition in applying shared knowledge [47].
- ***Externalisation***. Improving office design in the organisations in the Saudi Arabian context will allow higher interaction and communication between staff. This will give the opportunity for discourse in the work environment. Motivation can play its significant role to encourage knowledge discourse among colleagues in organisations. Rewards such as incentives should consider knowledge sharing behaviour among individuals. As group commitment is prerequisite for externalisation, workshops and seminars can be used to improve loyalty to work place among members. This will help to separate private life from work life. Likewise in socialisation, organisations can take advantage of the religious and social events to enhance trust and accomplish good relationships among members in order to strengthen externalisation.
- ***Combination***. As an Arabic community, KSA culture is seen to have concentrated authority and decision-making. A useful solution to overcome this barrier would be to expand the level of participation in decision-making. This action will enable information flow vertically among all

members regardless of their importance or position in the organisation.

- ***Internalisation***. The literature review has suggested that job rotation has been adopted slowly in the Saudi Arabian culture. Increasing the adoption of such a solution by moving individuals in the organisation, can improve knowledge transfer, expertise, and increases motivation. Saudi Arabian organisations normally give their members opportunities to engage in training courses, which is distributed equally among members in the organisation to ensure internalisation is being implemented.

IV. E-HEALTH KNOWLEDGE MANAGEMENT FRAMEWORK

It is important here to recognise that despite significant advantages in applying knowledge management in the healthcare sector, there are a number of barriers primarily caused by the absence of clear knowledge management strategy related to deficiency of effective team working, cultural barriers, poor IT infrastructure, degree of sectorial professionalisation, and political conflicts [41][42][43]. Finn and Waring [51] illustrated the importance of effective team working and stated that 'architectural knowledge' is fundamental for efficient team practice to ensure the delivery of safe and effective care to patients. As mentioned earlier, cultural barriers play also a negative role as some cultures do not encourage knowledge sharing; this constitutes an obstacle to knowledge management processes [52]. The healthcare sector tends to be mono-disciplinary and relationships of professionals within this sector are highly standardised, hence there is a resistance among doctors to share their findings and initiatives [49]. Strong governmental regulations and political and management conflicts can also hinder knowledge sharing among healthcare practitioners [53]. Guven-Uslu [50] described the clinician-managerial conflict as one of the important obstacles; the priority of managers is to minimise cost whereas the first priority of clinicians is to provide best care for patients.

To address the above issues, we propose a holistic framework approach to the healthcare knowledge management; this approach is still inspired by the SECI model of Nonaka, although we are aware of the critical issues associated with the two dimensional approach to knowledge management. One of those issues relates to the fact that the SECI model is embedded within the Japanese context and culture. Similarly, our framework must take into consideration the Saudi Arabian context, which is strongly influenced by the Arabic culture when applying the SECI model of Nonaka and Takeuchi [24][43]. Some of these issues are discussed later in this paper.

This framework is primarily designed to address the barriers highlighted above from the four perspectives: Business, Human, Financial and Technology. By integrating knowledge discovery into knowledge management we aim at identifying, extracting and organising tacit and explicit knowledge related to problems and solutions from multiple sources and at providing a forum for generating and sharing current and new knowledge by linking tacit and explicit knowledge to a specific medical domain. The proposed framework, referred herewith as e-health knowledge management system, is initially tailored to address the healthcare issues in Saudi Arabia and is dedicated to the diabetes mellitus domain, described in Section IV; this will allow us to evaluate the viability and performance of the proposed e-health knowledge management system.

This section describes the four components of our framework (as illustrated in Figure 3). The *Business* component focuses on organisational issues and aims at extracting and managing the barriers associated with the failure of adopting health information services and medical safety, such as poor technical support and unrestricted access to medications.

The *Human* component deals with the human barriers in relation to the use of technology from the healthcare workers and the cultural barriers from the patient perspectives; this will address the negative beliefs of healthcare professionals and patients towards the use of virtual contact and interaction with technological devices. The role of patients in the process of knowledge production and the computing skills of both, the healthcare professionals and patients, are critical to the success of our framework. To this end, the *Technology* component manages the non-connectivity issues and focuses on the technical expertise and computer skills, security and privacy issues. This component includes training aspects to address the limited/lack of computer skills among healthcare staff and professionals and their patients. Finally, the *Financial* component attempts to elicit the constraints and policies associated with the implementation, maintenance and monitoring of healthcare information services, namely the high cost of transmitting from traditional patients' paper records to electronic records. The proposed framework will elicit some of these problems and propose solutions and made available to the community via a dedicated knowledge management system (as illustrated in Figure 4).

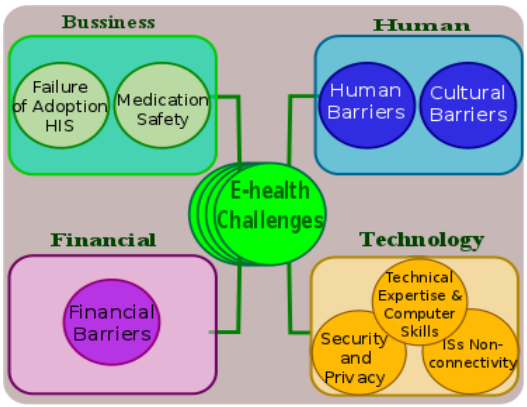

Figure 3. Components of e-Health Knowledge Management System

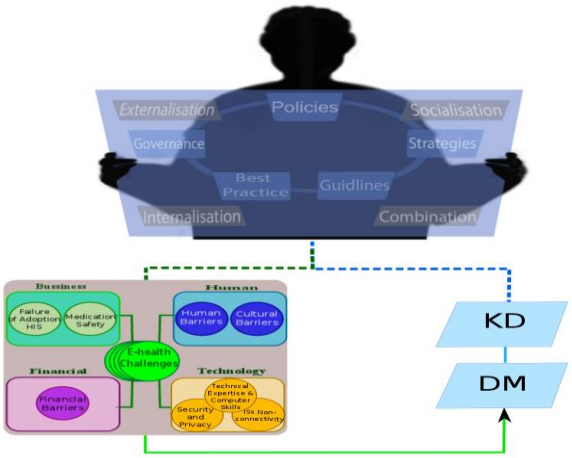

Figure 4. E-health Knowledge Management System

This approach is to be applied to support the diabetes community, which is increasing at an alarming rate in Saudi Arabia. Elicitation of their problems and issues faced is to be accomplished through interviews and protocol analysis, and via statistical data mining analyses extracted from the World Health Organisation (WHO) dataset. Using machine-learning techniques such as association rules and decision tree we can elicit typical issues and problems faced by the diabetes community and relate them to the four components presented in Figure 3. The new discovered knowledge can then be expressed in terms of recommendations and best practices to support both, healthcare professionals and the diabetes community.

The aim of the knowledge management system is to provide relevant knowledge not only to healthcare professionals who may be seeking or sharing best practices, strategies, guidelines and policies, but also to patients who need to contact specific healthcare services or professionals for advice or help. The proposed system will also provide access to academic papers related to specific problems to keep healthcare professionals up-to-date with new findings.

V. DOMAIN OF APPLICATION

Diabetes mellitus, which is one of the highest chronic diseases that affect patients from different genders, ages and weights, is to be used to validate our proposed framework. It can have severe complications such as stroke [47][48], heart attack [55], heart failure [56], kidney failures [55], Alzheimer disease [57] and mortality [58].

It is estimated that 382 million people have diabetes in the world, and by 2035, this will rise to 671 million. The number of patients who are suffering from diabetes mellitus is increasing in the Kingdom of Saudi Arabia (KSA). According to Shaw, Sicree, and Zimmet [59], KSA is in the third place among the top 10 countries for diabetes prevalence. In 2010, the prevalence percentage for diabetes mellitus in Saudi Arabia was 16.8% among adults in the ages of 20-79 years old. This percentage is expected to rise in 2030 to reach 18.9% [59]. In another statistics, there were 3.8 million cases of diabetes in Saudi Arabia in 2014, this number represents 20.5% of the prevalence of this disease among adults in the country [60].

There are twenty health regions distributed among all regions in KSA, providing services to more than 3 million diabetic patients, belonging to different ages, gender, and weight. The number of diabetic outpatients visiting the healthcare centers (HCC) is 1,891,765. This number of diabetic patients represents 6.4% of the overall number of visits to all HCC in KSA and put diabetic patients in third place in the scale of all outpatients visits in the kingdom [61].

Over 96% of all Saudi medical healthcare budgets are attributed to diabetes by Saudi citizens and 4% incurred by non-Saudi nationals. The national healthcare financial burden has reached $0.87 billion, excluding (i) indirect costs such as absenteeism, lost productivity, unemployment from disease-related disability, lost productivity due to early mortality by disease, and (ii) healthcare system administrative costs, cost of medications, clinician training programs, and research and infrastructure development [62]. The proposed framework will include the financial costs and its impact on human and barriers components into the framework. It will also attempt to overcome the barriers by utilising technology components.

A number of data mining applications have focused on diabetes. For example, Meng et al. [63] produced a model to detect diabetes using 12 risk factors and Chang, Wang, and Jiang [64] used risk factors to identify hypertension and hyperlipidemia. Suh et al. [65] developed the WANDA system to remotely help monitor blood glucose, weight, and blood pressure. HealthOrg is an application to monitor high risk diabetic individuals so that appropriate message can be communicated to patients [31]. Roch et al. [66] recognise the need and the challenges that healthcare professionals and researchers face in developing a much needed comprehensive knowledge management support system for diabetes care. To the best of our knowledge, no integration of data mining and knowledge management for diabetes has been attempted.

VI. DIFFICULTIES FACED BY KSA DIABETIC PATIENTS

Beside the many health related complications associated with this disease, diabetic patients also face difficulties and challenges related to the control and the management of diabetes, and adherence to appropriate dosage of their medication. As Péres et al. [67] report, some of these challenges include difficulties in controlling their eating habits, doubts in time schedules and correct usage and dosage of their medications, leading sometimes to their refusal to take insulin [68]. For example, most patients are not able to remember their blood glucose and blood pressure target. They also face problems in identifying medications and understanding prescriptions, especially when patients asked to change medication [69]. In addition, indicated patient deficiency in adherence to lifestyle measures and pharmacologic therapies as one of

the most common reasons cited for failure to achieve glycaemic goals. According to Onwudiwe et al. [69], inadequate health literacy can lead to an inefficient use of health services.

VII. DIABETES SELF-MANAGEMENT AND EDUCATION

Diabetes education and self-management are two research studies which have been highly studied to understand the difficulties and issues that diabetic patients may encounter every day. Funnell et al. [70] defined diabetes self-management education as the constant procedures for facilitating the needed knowledge, skills and ability for diabetes self-care for the overall purpose of supporting self-care behaviour. Diabetes education aims at increasing the knowledge of diabetic patients about their disease and health condition and at empowering them to have control over their condition [71]. In addition, diabetes self-management education have other objectives including supporting informed decision-making, problem-solving and active cooperation with the healthcare team, and to improving clinical outcomes, health condition, and quality of life [70]. Blonde [68] stresses the importance of ongoing medical nutrition therapy and self-management education which must be made available to all patients with diabetes. Furthermore, Onwudiwe et al. [69] claimed diabetes education, knowledge and self-management as the key to successful diabetes management. Funnell and Anderson [72] stated that patients are to be responsible for 95% of diabetes management, which should be carried out at patients' home through self-care. Therefore, patients of diabetes are to be given sufficient knowledge about their disease and guidelines to control it.

Self-management of diabetes includes guidelines and activities related to diet control, exercise, blood glucose testing, foot care and reduction of smoking [73]. Such knowledge can assist patients in dietary habits, enable self-monitoring of accurate glucose and weight [74]. In other words, self-management of diabetes and diabetes education can not only reduce the risks of diabetes complications and enhance patients' health and life but also it can bring financial benefits such as reducing patients' visits to hospitals and minimising healthcare professionals' consultations.

Successful utilisation of diabetes self-management and education has been implemented in some developed countries. In the United Kingdom, for instance, the National Institute of Clinical Excellence (NICE) guidelines recommend diabetes education programs to be offered to diabetics and their healthcare providers, to assist them in best managing the condition [75]. For example, DESMOND [76] offers short courses through presentations and workshops and provides diabetics patients with the skills and knowledge needed to enable them to control their conditions. The Canadian Diabetes Association (CDA) offered diabetes self-management program for people with diabetes in Canada. This program offers many services to diabetic patients to help them self-manage their condition and live healthier with diabetes. Examples of the services CDA provides are virtual health coaching, educational events about diabetes such as exhibitions and keynote speakers, learning series about diabetes risk factors and symptoms, and food skills to guide different ethnic groups in Canada in how to prepare healthy food [77].

Such programs are required to be introduced to healthcare centres and support diabetic patients in KSA. We believe that our knowledge management system can play a significant role in eliciting the best practices from various healthcare organisations and disseminating them through appropriate means to patients and healthcare providers.

VIII. E-HEALTH SELF-MANAGEMENT EDUCATION SUPPORT

Internet is used increasingly by people who suffer from chronic diseases in order to self-manage their illnesses and learn from other patients' experiences [78]. The literature review conducted by Ziebland and Wyke [79] revealed seven domains for accessing health experiences of others on the internet; (1) searching for information, (2) feeling supported, (3) maintaining contacts with others, (4) undergoing health services, (5) learning to communicate the story, (6) visualising disease, and (7) affecting behaviour. In terms of diabetes mellitus, Ramadas et al. [80] discuss the intervention of web-based technology for managing type 2 diabetes. They review 13 web-based results on positive impact of such intervention on the management of the disease. Another study showed how web-based diabetes management system helped its users reduce their glycated haemoglobin (HbA1c) [81]. It offered educational programs related to diabetes management, exercise, nutrition and recommendations for the patients with type 2 diabetes based on the information they enter such as their medications and glucose levels.

Official report shows promising indication for using internet services for health related issues in KSA. Internet penetration in KSA has risen from 13% in 2005 to 63.7% in 2014 and the number of internet users has reached over 19 million [82], showing common use of the internet in search for health associated information [83]. However, the literature review does not provide evidence of internet usage by Saudi diabetic patients. This confirms the critical need to provide self-management education not only to support diabetic patients to cope with their daily difficulties but also help healthcare professionals provide quality and consistency of care to their diabetic KSA patients.

IX. KNOWLEDGE MANAGEMENT FRAMEWORK FOR DIABETES

The above difficulties and challenges is the motivation behind the development of the proposed e-health framework, which can help address the gaps of diabetes self-management and education in KSA. This framework is to be implemented in a web-based (portal) system to provide a tailored knowledge management approach to

(i) help diabetic patients self-manage and monitor their health conditions and (ii) support healthcare providers to share best practices.

To this end, a survey is carried out to analyse and understand the current difficulties and issues of KSA faced by both, diabetic patients and healthcare providers at the healthcare centres. The results of the survey are ~~to be~~ data mined to elicit useful trends and discover crucial issues and needs that need to be addressed through the knowledge management framework. The proposed framework is based on the SECI model aimed at converting and disseminating both types of knowledge: tacit through the data mining approach and explicit through the elicitation of problems via the survey and face-to-face interviews with both stakeholders: patients and healthcare professionals. The framework is designed to provide a web-based assistance to patients in monitoring and providing tailored guidelines and support related to diet, medication usage and schedule, and recommend appropriate exercises. Patients, through the internalisation model, are "learning by doing" and through externalisation healthcare providers are disseminating their best practices. Socialisation and combination modes aim at facilitating the exchange of knowledge, practices and concerns among diabetic patients and healthcare professionals through a dedicated web-based forum to help diabetic patients meet with others sufferers, discuss various issues and learn from each other.

The framework that integrates data mining and knowledge management can become the vehicle for social media for diabetics and their health carers; it can also reduce isolation and depression, which are often faced by diabetic patients. The feasibility of social media and its contribution to knowledge management is identified by Ray [46]. Twitter, Facebook, Blogs and other means of communication, which have become extremely popular in among citizens in KSA, can be easily integrated into the proposed framework.

X. CONCLUSION

Knowledge management and knowledge discovery are two well-developed disciplines. However, to the best of our knowledge, there has been no methodical attempt at integrating them within the SECI model to address critical healthcare issues in KSA. The aim of this research project is to bridge this gap and consequently improve the healthcare services and provide a forum for both, healthcare professionals to deliver the best healthcare to their patient, and diabetic patients to overcome their problems and difficulties in managing their medical condition. The first stage of this research has focused on eliciting the barriers associated with the KSA diabetic patients and their healthcare providers. The development of the proposed integrated framework requires the need to understand any issues and challenges faced by IT specialists in KSA in developing the system across the healthcare centres. The specific domain of diabetes mellitus is used to validate the ambitious proposed e-health knowledge management framework. The paper has outlined the difficulties of applying Nonaka's SECI model to other countries as the model is based on Japanese organisations. It has suggested practical solutions for use in KSA for knowledge transfer within the segments of the SECI model. The proposed framework is designed to meet the recent government initiatives of the Saudi Ministry of Health in improving the national healthcare of its citizens.

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Design and Assessment for Hybrid Courses: Insights and Overviews

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Abstract - **Technology is influencing education, providing new delivery and assessment models. A combination between online and traditional course, the hybrid (blended) course, may present a solution with many benefits as it provides a gradual transition towards technology enabled education. This research work provides a set of definitions for several course delivery approaches, and evaluates five years of data from a course that has been converted from traditional face-to-face delivery, to hybrid delivery. The collected experimental data proves that the revised course, in the hybrid delivery mode, is at least as good, if not better, than it previously was and it provides some benefits in terms of student retention.**

Keywords – Hybrid Courses; e-Learning; Distance Education; Course Evaluation; Course Assessment.

I. INTRODUCTION

The abundance of computing power and the widespread availability of the Internet had a tremendous impact on society for the past decades. Education as a fundamental branch of social activity has been rapidly reshaping itself adapting to the informational era. The online teaching technology, like any novel approach, presents both advantages and disadvantages, appropriate use and misuse. This article presents the recent evolution of teaching styles vis-a-vis technology focusing on defining and assessing hybrid delivery methods. The research builds on previous work [1], adds additional related work studies, as well as an additional year of experimental data and discussions.

Studies in the United States (i.e., The Gartner Group Research Institute) anticipated that the world's e-Learning sales would grow 14.5% annually from 2006 to 2011 [2]. Over a similar timescale, government policies in the United Kingdom also indicated that the effective use of technology-assisted student-focused learning is essential for the future of higher education [3-6]. In a review of higher education and the future role of the university, Ernst & Young [7] have suggested that "… campuses will remain, but digital technologies will transform the way education is delivered and accessed, and the way 'value' is created by higher education providers, public and private alike."

Large scale as well as smarter use of technology in teaching is widely seen as a promising way of controlling costs [8]. When compared to other service industries, higher education stands out as being particularly affected by what has been described as the "cost disease" [9]. Universities have large costs for infrastructure and labor, with reliance on expensive face-to-face provision. The urgent need to boost university productivity has been noted by many [10-12]. Moreover, cost reductions are demanded by students (as they want to spend less time and lower the costs of traveling to the main campus) and improved time flexibility, specifically for full-time or part-time working students.

Face-to-face lectures are accepted as being a very inexpensive way of presenting new ideas and concepts to students. Additionally, lecturing has been described as an ineffective tool for promoting theoretical understanding [13], as it rarely stimulates student thinking beyond the short-term memory [14][15]. The passive role assumed by students in lectures is too focused on the subject being delivered, rather than the learners and their individual needs [16]. But, teaching the same content can be made more interesting, and students can become active, independent learners, if different delivery methods (including multimedia) are used [17].

Implemented proficiently, the online and the hybrid (blended) provision has the capacity to lower costs and at least sustain, if not boost student outcomes [18-20]. Hybrid/blended learning can ease some of the economic strain on students, as it reduces commuting expenses and allows for a flexible timetable that may better accommodate the students' personal circumstances [21]. Cost simulations, although speculative, have indicated that adopting hybrid models of instruction in large introductory courses has the potential to reduce costs quite substantially [8].

This article presents in Section II a set of definitions for the terms in common use in educational delivery, and provides clarifications on the use and meaning of these terms. The choice for hybrid/blended learning is described in Section III, followed by the "Fundamentals of the Internet and the World Wide Web" (CSCI 1150) course description in Section IV. The methodology for data collection is detailed in Section V, with Section VI exploring the evaluation of said data in terms of student outcomes and attrition rates. The relationship between assessment weighting and online student interactions in discussion forums is also measured and analyzed. Section VII identifies the limitations of this study and concludes that the CSCI 1150 course, in hybrid delivery mode, continues to provide as good, if not a better provision, than the previous traditional face-to-face delivery method.

II. UNDERSTANDING HYBRID (BLENDED) LEARNING

The growth of e-Learning has blurred the boundaries of educational modes [22]. Higher education institutions and academics use a wide range of terms to describe ways in which students may engage with their studies, including on-campus, face-to-face, off-campus, open education, distance education, external study, online education, e-Learning, flexible learning, blended learning and hybrid. Both Lund and Volet [23] and Schlosser and Simonson [24] have suggested that there is limited consensus on the meanings of these terms, and a degree of confusion for academics, administrators and students exists within the university sector. For each learning environment listed above, there are distinct attributes that help locate and define them in a typological structure. For example, an on-campus mode relates to "courses that deliver material face-to-face and students interact with instructors face-to-face" [25], whilst distance learning (or education) is the various forms of study at all levels which are not under the continuous, immediate supervision of instructors collocated with their students. These forms of study, nevertheless, benefit from the planning and guidance of a supporting educational organization (Holmberg, cited in [24]). Still considering the location of delivery, Howland and Moore [26] suggest that an online course is "one in which no more than one face-to-face meeting is required". Offering a slightly contrasting view, Bollinger and Wasilik [27] consider a course to be online "if 80% or more of the content is delivered via the Internet". With the advent of technology in education, the boundaries of what learning environment fits within a mode of enrolment fades and misunderstandings arise.

While initial observations of computer-based learning have noted that "e-Learning is a confused and confusing field, fragmented into multiple disciplines and emphases" [23], a general definition is provided by Pollard and Hillage [28] who suggest e-Learning represents "the delivery and administration of learning opportunities and support via computer, networked and web-based technology to help individual performance and development". Kruse defines it as the use of technology to deliver learning programs and training programs through CD-ROMs, the Internet, local area networks (LANs), and wireless (WiFi) networks to promote active learning [29]. E-Learning and Computer-based Learning can be seen as broader than Online Learning as they do not always require web-based connectivity [30] since learning activities can occur on stand-alone devices.

The term Blended Learning is being used with increasing frequency in academic writing but there is no consensus on its meaning [31]. An alternative term, Hybrid, is defined as being of "mixed character; composed of different elements" [32], and Blended is defined as "an unobtrusive or harmonious part of a greater whole" [33]. Blended Learning has been described as a hybrid instructional approach combining aspects of e-Learning and a traditional classroom environment [30] and defined as "courses that deliver material both face-to-face and online" and where "students interact with instructors both online and face-to-face" [25]. Many colleges offer hybrid courses, which combine traditional face-to-face with online instruction. Previous research proves that this combination may promote learner-centered and active learning [34].

To understand the position and better define Hybrid (or Blended) learning we are looking at the possible categorizations of instructor-student interactions on different dimensions, e.g., space and time. Hence, instructor-student interaction can be categorized based on the geographical location/space as:

- Local (face-to-face): the instructor and the students share the same physical location, usually the classroom on the university campus grounds.
- Remote (distance): the instructor and the students do not share the same physical location. Students in this case can conveniently attend courses from home - the "living room" vs. the "classroom" paradigm.

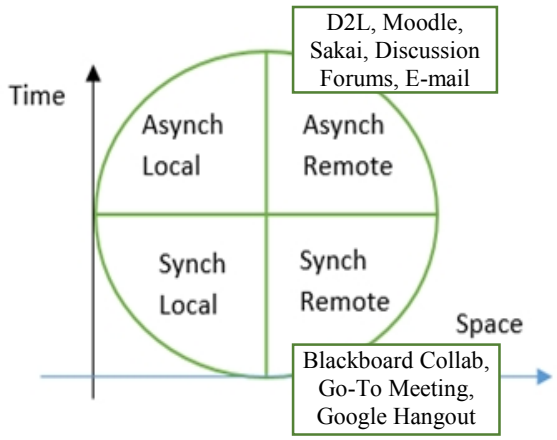

Figure 1. Time-distance diagram: local vs remote, synchronous vs asynchronous and applications used for the remote case.

The second dimension and an important categorization used for learning methods is based on the interaction time (or interaction style) among the course participants: students and instructor, as illustrated in Figure 1.

For synchronous interaction, the students and instructor are present and interact at the same time. Such interaction can occur in the traditional face-to-face setup or in a remote setup. Anohina [35] describes synchronous online learning as a method to bring a learning community together at the same time without distance being a barrier to interactions. Time flexibility can be an issue here. Web conferencing applications such as Blackboard Collaborate, Citrix Go-To Meeting, Adobe Connect, Google Hangout, and Videoconferencing are used in such synchronous interactions.

In case of asynchronous interaction, the students and instructor are not present at the same time. This type of interaction is not common in a traditional face-to-face setup but it is more common in a remote (distance) setup. It brings together the learning community without distance or time being a barrier to interaction. Learning management systems such as Desire-to-Learn (D2L), Blackboard, Moodle, Sakai,

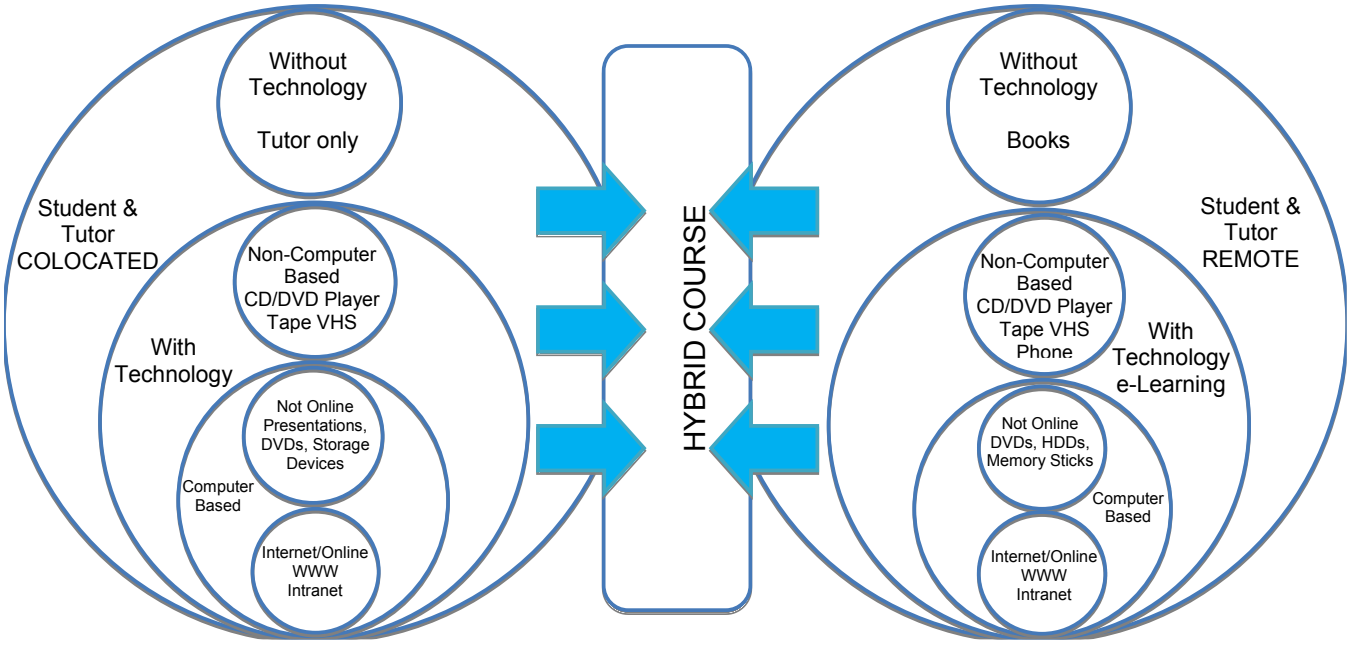

Figure 2. Hybrid courses in relation to traditional and online delivery

and others are used to deliver asynchronous online learning using a variety of tools (e.g., discussion forums).

A third dimension is possible based on the use of a computing system: computer-based learning (CBL) uses software running from DVDs, remote servers (the "cloud") or downloaded to student computer for instruction. Many textbooks now come with CBL modules, which can stand alone or be incorporated into online course delivery. Non-computer based learning involves any device that is not a computer (e.g., DVD/video player, other devices).

From the above categorizations, a hybrid course (as illustrated in Figure 2) is defined as a course in which the instructor and student is partially remote and partially in the same physical location. A hybrid course does not necessarily use a computer and the Internet but, with the wide spread of these technologies, we find that it is very common for the hybrid course to be computer and Internet based.

Research shows that the hybrid mixture of on-campus and off-campus activities is difficult to explain to prospective students [36]. A potential solution to the confusion is to define courses specifically by their construction. The public University System of Georgia (USG) [37] defines the following course types:

- Fully online: All or nearly all the class sessions are delivered via technology (96% to 100% online).
- Partially online: Technology is used to deliver more than 50% of class sessions (51% to 95% online).
- Hybrid: Technology is used to deliver at least one class session and up to 50% of class sessions.
- Campus (or on-site): No class sessions are replaced by online technology.

The relationship between traditional, online, and hybrid courses, is displayed in Figure 2. Armstrong State University part of USG, defines three types of programs based on the level of online interaction [38]:

- Online program: includes only fully online courses. Does not included partially online or hybrid courses. Fully online programs are meant for those who live far from campus or may have jobs that prevent them from attending campus classes.
- Blended program: includes partially online and fully online courses. Blended programs are ideal for students who live on or near campus but work part-time.
- Campus/On-site program: this program is ideal for students living on or near campus who attend class part-time or full-time. These programs can be ideal for full-time students who benefit from the structure of face-to-face instruction. There are three types of campus/on-site courses: hybrid courses, technology-enhanced courses and "no technology" courses.

III. THE CHOICE FOR HYBRID LEARNING

During lectures students usually assume passive roles as listeners while the instructor distributes information. Educating in this way is too focused on what is being delivered, rather than the learners and their needs.

White et al. [39] demonstrated that traditionally delivered, subject-intense courses can be converted to a 'blended/hybrid' delivery approach with "as good, if not better, outcomes", if they are well-designed with high quality content and regular interaction.

As observed in the e-Learning Ladder [16], a constructivist theory, the student, rather than the instructor, should be the focus, and he must 'construct' new knowledge through analysis, experience and understanding. The Ladder further identifies that opportunities for learners to be active in creating their own knowledge and understanding can be offered through Web 2.0, and more recently Web 3.0 technologies, such as: discussion boards or forums and various types of social media applications. These applications allow students to retrieve information, as well as provide a platform to create and own the data within them. These tools can be used as an alternative or in addition to traditional lectures resulting in a learner-centered environment [40].

There are also indirect benefits in using technology-enhanced learning, such as the development of students' computer skills. However, this is directly relevant to one problem commonly associated with e-Learning, because just as with any genre of course, learners need to have the appropriate resources in order to be successful. These resources in an e-Learning context can be classified as 'External' to the learner, such as slow Internet connections or older computers, and 'Internal' to the learner, which may be a lack of the necessary computer skills. Without these resources, accessing the course materials can be difficult and the learners' performance can be significantly hindered [41]. Anxiety can set in leading to lack of motivation [42], which may ultimately result in students becoming frustrated and giving up on that particular learning environment [43]. However, it has also been identified that an initial lack of confidence can be quickly replaced by positive excitement once the initial experience of e-Learning has taken place and the technology involved mastered [44].

The goal of a blended learning experience is "to provide a mix of both on-line and face-to-face experiences which support each other in achieving desired learning outcomes" [45]. Many universities experiment with a blended learning model as part of their teaching strategy, but "the term is still relatively new, therefore, leaving many to question how the mixing of online and mobile learning with face-to-face interaction will actually improve student experience now and in the long term" [46]. This hybrid mixture of on-campus and off-campus activities [36] is difficult to explain to prospective students.

Combined with the need to be self-motivated and more independent, hybrid learning is most definitely no easier than the face-to-face course. Nor is it for all students. For this reason, among others, it is imperative that hybrid learning be carefully crafted from a pedagogical standpoint. That begins with the effective definition of the course goals and objectives. Goals are broad, generalized statements about what is to be learned, and they can be taught of as targets to be reached. The objectives are the base upon which one can build lessons and assessments that meet the overall course goals. From this solid foundation, the course content and student assessment has to be designed and implemented in a completely different fashion than for the traditional face-to-face course.

Bowen et al. [8] aimed to estimate the costs associated with course delivery under different circumstances. Whilst acknowledging that the simulations are admittedly speculative in nature and subject to considerable variation depending on how a particular campus organizes its teaching, they suggest that significant cost savings are possible. In particular, they estimate savings in compensation costs for the hybrid model ranging from 36% to 57% compared to the traditional model. These simulations confirm that hybrid learning offers opportunities for significant savings, but the degree of cost reduction depends on exactly how hybrid learning is implemented, especially the rate at which instructors are compensated and section size. A large share of cost savings is derived from shifting away from time spent by expensive professors toward computer-guided instruction. Their simulations substantially underestimated the savings from moving toward a hybrid model in many settings, because they did not account for space costs. It is difficult to put a dollar figure on space costs because capital costs are difficult to apportion accurately to specific courses, but the difference in face-to-face meeting time implies that the hybrid course requires 67% to 75% less classroom use than the traditional course. In the short run, institutions cannot lay off tenured faculty or sell or demolish their buildings. In the long run, however, using hybrid models for some large introductory courses would allow institutions to expand enrolment without a commensurate increase in space costs, a major savings relative to what institutions would have to spend to serve the same number of students with a traditional model of instruction. In other words, the hybrid model need not just "save money"; it can also support an increase in access to higher education. It serves the access goal, both by making it more affordable for the institution to enroll more students, and by accommodating more students because of greater time and space scheduling flexibility.

IV. HYBRID COURSE DESIGN

The course that we evaluate, CSCI 1150, had traditionally been taught face-to-face, in both the spring and fall semesters of 2010. In 2011, a Desire-to-Learn (D2L) online version of the course was developed. D2L is a web-based course management system that students were already familiar with. The content was made available online, within PDF slides that closely followed the associated textbook. The main reason of the slides approach was to provide structural guidance for the content in the textbook. Students were also provided with access to various interaction tools, both synchronous and asynchronous (e.g., e-mail, chat, discussion forums) as well as a set of assessment tools (e.g., online quizzes, online assignments and online exams).

The course content has been refined in subsequent years from 2012 to 2015, to include additional required reading material, as well as a better-defined set of discussion forums (one discussion forum per textbook chapter), where students were encouraged to interact during the semester. This refinement aimed to provide fresh stimuli to the course, in order to promote students' learning through questioning, investigating, challenging, seeking feedback, and learning through interactions with peers and tutors [47]. Technologies such as discussion forums can provide the opportunity for learners to be active in creating their own knowledge and

understanding by allowing them to create, own, retrieve and exchange information within them [48] in a time flexible manner. The face-to-face sessions were then used to explore the course content, and the online interactions, in order to further develop the students' understanding. This overall course design may be seen as consistent with the "flipped classroom" approach [49], and is presented in a 50:50 ratio, causing it to be described as Hybrid delivery under the University System of Georgia definition [37].

From spring 2012, the course assessment has also been completed online, with each element assigned a proportion of the overall grade: Assignments were weighted at 40%, Quizzes weighted at 10%, the Midterm exam at 25% and the Final exam at 25%. The grading scheme was further supplemented from fall 2013, with the online forum interactions being rewarded 2% of the weight, reducing the Midterm and Final exams to a weight of 24% each. The online interaction (based on discussion forums) weight has subsequently been increased to 10% of the final grade for the spring semester of 2014, causing the Midterm and Final exams weights to be reduced to 20% each. For the spring 2015 semester, the online interaction weight was further increased to 15% of the final grade by reducing the quizzes weight from 10% to 5%. These adjustments were driven by the need to increase student-to-student interaction, and to measure how increasing reward affects that interaction as well as student learning in a hybrid setup.

A. Automatic vs. Manual Grading

A course management system like D2L provides advantages to both the faculty and the student. It is possible to automate the process of quiz and exam delivery as well as grading, subsequently freeing significant faculty time and providing timely feedback to students. Freeing faculty time is of upmost importance in a current complex higher education system that requires teaching, service as well as research activities from the faculty.

The online quizzes for the hybrid course were designed to be administered quickly (on average they are timed to 30 minutes each) and contained about ten questions each. The questions were automatically and randomly selected from a database of 3000+ questions, all of the same difficulty level. The quizzes were automatically graded, immediately after the deadline, providing students with instant access to both the grade and the correct solutions. Then, students can use this information to identify where they went wrong and what concepts they misunderstood in each chapter. The results of the quizzes was then discussed both online and in the face-to-face session, both with the instructor and student peers.

The drawback in automating the process of delivery and grading comes from the fact that some type of problems, such as those requiring essay-type answers, are difficult to automate, as they require manual grading for optimum accuracy, as well as to provide constructive personalized feedback. For this reason, the manually graded assessment components have a greater weighting in the overall final grade and includes personalized detailed feedback from the instructor for each student.

B. Deadlines and Penalties

Each assessment component has strict completion deadlines. Assignments have to be completed in three weeks, with a deadline enforced through the D2L submission system. Late submission was not accepted, and failure to submit an assignment would almost certainly result in dropping a grade point, as the assignment weight was 10% of the final grade.

For the quizzes, each weighted at only 1% (respectively 0.5% for the spring of 2015) of the final grade, there is a two to three weeks' timeframe during which each quiz can be taken, providing the students with time flexibility in their learning schedule, but keeping them on track with the rest of the course pace. Therefore, quizzes are designed to keep the students on track with their learning of the course content, providing them with early and progressive feedback concerning their course progress.

As previously identified, the Midterm and Final exams were also given online, with a strict 12-hours window where they are 'live' and can be taken. Each exam consists of 10 problems, with 80% of the responses being essay type, therefore, requiring manual grading. Each exam is weighted at 20%, with no late submissions allowed. Specific D2L technologies like the Respondus LockDown Browser™ mode as well as the tight time-frame is used to hinder student cheating. A LockDown Browser prevents users from being able to cheat by printing, copying or browsing other websites while taking the tests. Once the test has started, the computer remains locked until the test is completed and submitted for grading, hindering cheating attempts.

The final element of assessment, is based on the interactions among students in a set of discussion forums. Students are allowed to post information and ask questions for one month in each forum. After the expiration date (which is set and announced for each forum) the students can still read the posts, however, they cannot post new content. The ability to read the forums content is important since it provides students with a continuous source of information. Particularly for slower (or problem) students it is important to provide means to catch up with the rest of the class without disturbing the pace of the course for the entire class.

The discussion forums contributions were weighted at 10% of the final grade, with the posts content evaluated subjectively by the instructor; being measured both quantitatively and qualitatively. As mentioned for spring 2015, the online interaction weight through the forums was further increased to 15% of the final grade and the outcomes measured. Further increase in the discussions forums weight may be beneficial to student-student interaction and may positively affect student learning as some students are sometimes eager to explain the concepts they understood to their peers.

C. Interaction

Besides the face-to-face interactions in class, two types of written discussions are frequently used in a hybrid course: synchronous and asynchronous. Whereas synchronous discussion requires participants to log in at a predetermined

time and simultaneously join the discussion, asynchronous activities allows users to organize, read, and post messages at their own pace, as dictated by their preferred schedule.

Where online/hybrid course designers have opted for the use of discussion forums, they play an important role, often making up the major part of the students' activities and providing evidence of attendance, class participation, and sometimes assessment [50-53]. The delayed element to asynchronous communication, can allow participants more time to consider their responses, promoting deeper consideration and reflection of the subject [54][55]. In spite of this, it has also been argued that scholarly thinking regarding assessment of online discussion has not kept pace with the growing popularity of such practices [56].

The asynchronous interactions in the CSCI 1150 hybrid course employ the e-Mail system, a News system, and the Discussion Forums, the latter consisting of one primary thread per textbook chapter. The News system is an efficient tool for the instructor to provide students with updates about the course, however, it is a unidirectional communication tool - from instructor to students.

Online synchronous interaction was implemented in CSCI 1150 through a Chat channel. It has been observed that the chat channel is mainly used immediately prior to the Midterm and Final exam period, serving as an emergency notification tool for the students if or when something goes wrong with the online exam session.

The other synchronous interaction occurred in the traditional in-class face-to-face meetings. As part of the Hybrid course, students meet with their instructor once a week, for a 75-minute session, where they can discuss and ask/answer questions. Attendance is not mandatory and it has been observed that by the middle of the semester only an average of 60% of the students attend these sessions mainly due to their part-time, full-time work schedule or other family commitments.

Online interaction through the spring and fall of 2014 was stimulated through the relationship between this activity and the assessment. Ten percent (10%) of the final grade was awarded for the discussion forum posts, with each student being expected to provide at least three posts per discussion thread, each being a paragraph of 200 words or more, as well as responding to classmates' questions providing original answers and/or alternate solutions. At the end of the semester, the student with the highest number of quality posts receives a further 10% towards his/her final grade; the other students receive lower additional percentages, representative of their contributions. A further increase to 15% of the final grade was implemented for spring 2015, as previously mentioned, and the effects of this assessment policy were measured and analyzed.

V. METHODOLOGY

The CSCI 1150 course, "Fundamentals of the Internet and the World Wide Web", is a service course at Armstrong State University, Georgia, US. The course was observed over a period of four and a half years, through seven semesters (spring and fall, 2011 to spring 2015). Each semester consisted of two or three sections of the course hence 50 to 75 students were observed each semester (as further illustrated in Section VI). The course was delivered by traditional face-to-face methods in 2011, and was then converted to the Hybrid delivery mode for the 2012-2015 time frame. There is no entry, prerequisite requirement for the course.

The average class size was 25, and the students included in the data collection ranged from 19 to 42 years of age, with a female to male ratio of 1.7 to 1. The analysis of the experimental data is straightforward. The outcomes for students previously undertaking the course in the traditional face-to-face format are compared to the outcomes for students undertaking the hybrid format.

The data collected consists of the students' final grades, failure rates and withdrawal rates. To further evaluate the hybrid delivery method, the students' asynchronous interactions are also investigated. The rate and volume of posts in the online discussion forums are analyzed in consideration of the changes in the course structure and assessment strategy. The number of read post in the forums as well as the number of written contributions in the discussions forums are collected and analyzed in the light of the various grading weights imposed.

VI. COURSE EVALUATION

The final outcomes for the students assessment are displayed in Figure 3, and these show no significant difference between the traditional face-to-face course that was delivered in 2011, and the subsequent hybrid delivery mode, with the course mean grade fluctuating between a B grade and a C grade (except for the anomalous D mean for the spring semester of 2011, course section 1).

TABLE I. MEAN AND MEDIAN GRADES FOR SECTIONS

	Mean Grade	Median Grade
Spring 2011 Section 1	D	D
Spring 2011 Section 2	C	C
Fall 2011 Section 1	C	C
Fall 2011 Section 2	B	B
Spring 2012 Section 1	B	B
Spring 2012 Section 2	C	C
Spring 2012 Section 3	C	C
Fall 2012 Section 1	C	B
Fall 2012 Section 2	C	B
Spring 2013 Section 1	C	C
Spring 2013 Section 2	C	B
Spring 2013 Section 3	B	B
Fall 2013 Section 1	B	B
Fall 2013 Section 2	C	C
Spring 2014 Section 1	C	B
Spring 2014 Section 2	B	B
Fall 2014 Section 1	C	B
Fall 2014 Section 2	C	B
Spring 2015 Section 1	C	B
Spring 2015 Section 2	C	B

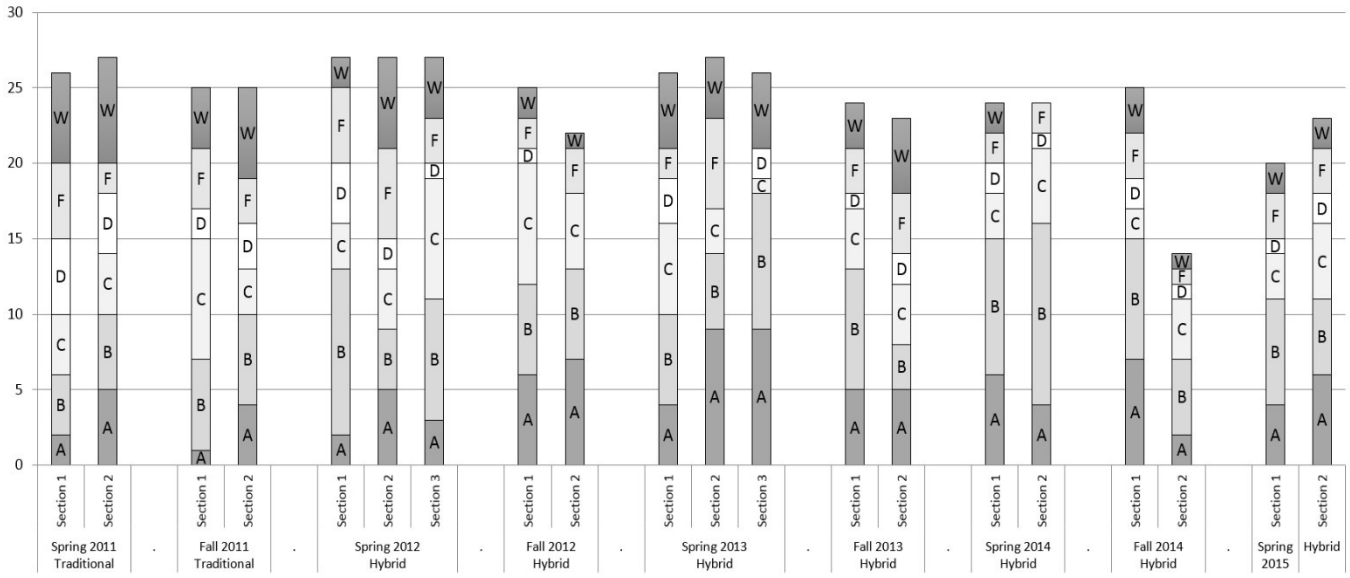

Figure 3. Total Number of Students, Number of Each Final Grade and Number of Withdrawals, per Section. (Grades A-D, F=Fail, W=Withdrawn)

There is, though, some suggestion, that the course outcomes may be improving, with a median of grade B appearing more regularly in the recent hybrid courses as illustrated in Table I; but whether this is due to the delivery method, or some external factor, cannot be determined precisely.

As mentioned earlier, the goal of a blended/hybrid learning experience is "to provide a mix of both on-line and face-to-face experiences which balance and support each other in achieving desired learning outcomes" [45]. Our results show that students taking the hybrid course format pay no "price" for this mode of instruction in terms of exam scores, and overall performance, proving that it is possible to hybridize certain courses without negative impact on learning. On the contrary, positive outcomes are possible for both the student and the instructor, resulting in time flexibility and cost savings on both sides.

In other sectors of the economy, the use of technology has increased productivity, measured as outputs divided by inputs, and has even often increased output. Bowen et al. [8] showed that a hybrid-learning system did not increase outputs (student learning) but could potentially increase productivity by using fewer inputs. When considering the course attrition rates, it is important to note that students are allowed to withdraw without penalty before an identified deadline – usually just

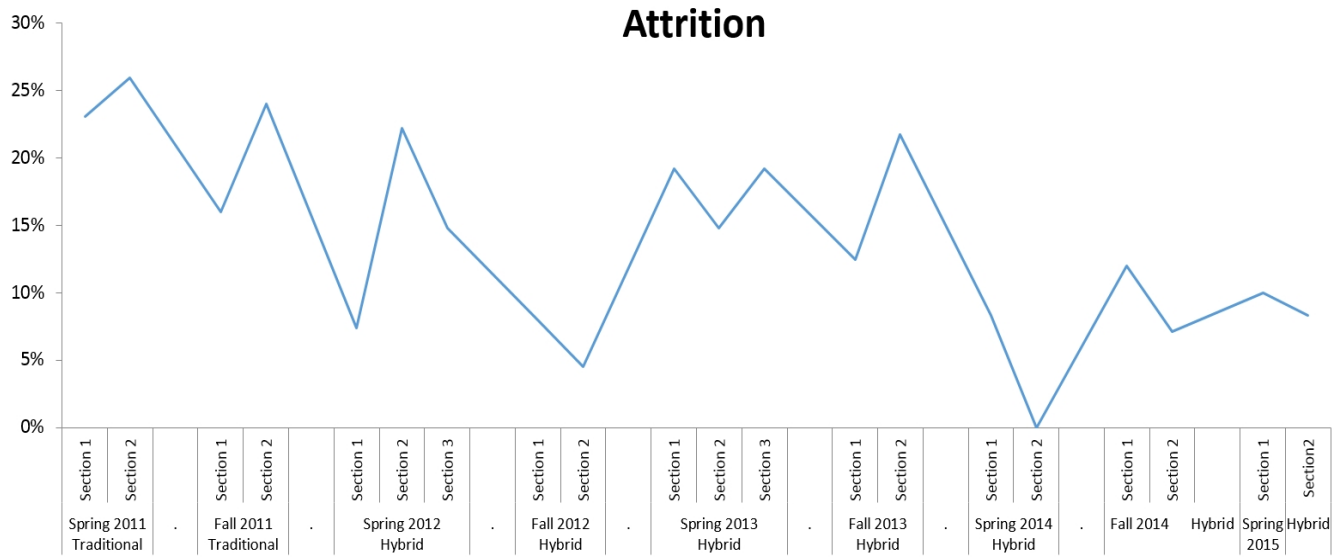

Figure 4. Course Attrition by Percentage of Total Enrolled Students (showing declining attrition)

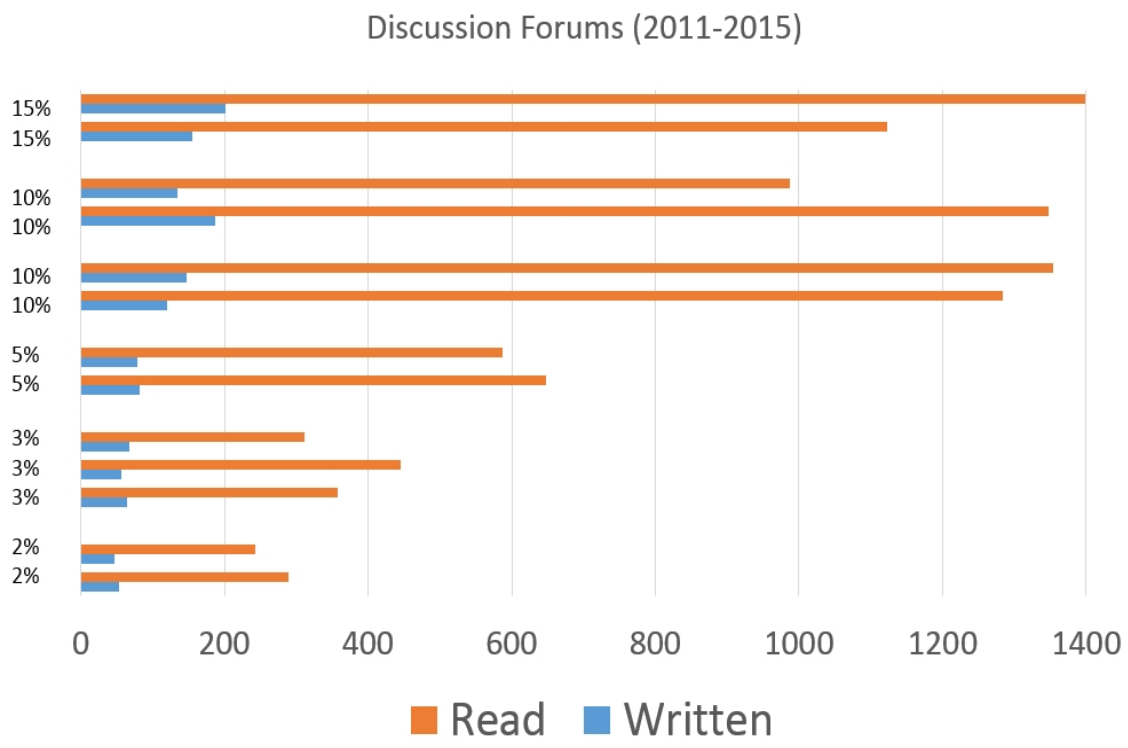

Figure 5. Relationship between the Forums Weight (2% to 15% of the Final Grade) and the Number of Read and Written Posts for each Semester, for each Course Section.

after the Midterm exam. This allows failing students to leave with a "clean record", meaning they can retake the course in the future, should they wish to. Despite this, there is positive indication that attrition rates are reducing, as illustrated in Figure 4. However, this is unlikely to improve significantly under the current withdrawal policy.

As previously identified, asynchronous interactions through the e-mail system are primarily exchanged around (one or two days, before and after) a major deadline for an assignment or exam. For example 76.5% of the e-mails received for sections 1 and 2 during the spring semester of 2014, were specifically targeted on questions around major assessment components. Students also tend to interact little amongst themselves using the e-mail system, with only 36% of the e-mails on average being sent for student-to-student communications for the same semester. For the spring semester of 2015 similar data was obtained: 74.4% of the e-mails received were specifically targeted on questions around assignments and exams. Student to student communication using the e-mail system amounted to approximately 34% of the total e-mails exchanged, showing that students prefer to communicate through other means (e.g., face-to-face, discussion forums etc.).

For the online interactions measured only through the discussion forums (from fall 2012 to spring 2015), a quantitative analysis of the forum contributions in terms of the number of written (authored) posts as well as the number of read posts reveals, somewhat unsurprisingly, that there is a direct dependency between the grading weight of the online interaction and the number of posts in the forum. Evidence shows that the higher the forum contribution weight is in the final grade, the higher the volume (and quality, in the instructor's opinion) of forum posts made by the students, as clearly illustrated in Figure 5. Specifically, one can observe a significant jump in the interest of "reading" the colleagues contributions, as well as a more moderate jump in the number of written contributions. This behavior could be explained by the fact that once the students use the forums, pushed by the grade constraint, they actually only then discover its contents value in solving assignment problems. This factor stimulates them to continue reading their colleagues posts and collaborate for problem solving. Stimulating such behavior, where student-student interaction is promoted, generates a superior learning environment where students become active learners. Active learning engages students in doing things and thinking about the things they are doing, becoming in this way problem solvers. A subjective, qualitative analysis of the forum posts advocates that students engage through these forums in higher-order thinking tasks such as analysis, synthesis, and evaluation.

VII. Conclusion and Future Work

In this paper, Hybrid/Blended learning is discussed in the context of the existing terminology. The design, as well as the main components of a course that was transformed from a traditional face-to-face format to a hybrid one, is described.

The course analysis and evaluation focuses on the outcomes for students that undertook the course in the traditional format, and the outcomes for students undertaking the revised hybrid formats. We show that students in the hybrid format pay no "price" for this mode of instruction in terms of pass rates, exam scores, or performance. Moreover, they can be motivated to interact online with slight adjustments in the grading policy, which promotes participation, interaction and improves students' computer skills while, at the same time, engages them in active learning.

The evidence supports the hypothesis that well-designed interactive hybrid systems in higher education, have the potential to achieve at least equivalent if not better educational outcomes as traditional courses, while opening up the possibility of freeing up significant resources on both sides: student and instructor. These resources (e.g., time, classroom space and financial) could be redeployed more productively. This alone is cause for the hybrid style of course delivery to be recommended.

In spite of all these benefits caution must be taken when choosing courses to be hybridized. Not all the courses are fit for hybridization, moreover significant man-hours and resources may be required to develop the proper hybrid version for a course. Such cost considerations have not been investigated in this research and depend not only on the course content but also on the institution policy for course development.

An assumption, from the administrative point of view, is that the hybrid course sections can be larger and accommodate more students. In general this is a wrong assumption and also a dangerous one, since it creates the false illusion of immediate Full Time-Equivalent (FTE) improvement for faculty. Special care must be taken, as some studies [57] suggest that having 15 students per section is a good starting number for courses that have online exposure while their face-to-face equivalent would accommodate twice as much, around 25 to 30 students. Therefore, one should not rush into conclusions that hybrid mode delivery would automatically accommodate more students per class section.

As future work, the course structure will continue to be reviewed, in consideration of student outcomes, to promote higher final outcomes.

We would like to mention that this is a relatively limited-scale study and the data was drawn from a specific course, with a medium number of participants oscillating from 50 to 75 participants per semester, depending on the number of sections taught. The study may have been influenced by factors specific to the student groups, which are not immediately evident from the findings. Also, experiences external to the course content and delivery may have contributed to student outcomes and opinions. In the near future we will provide additional data as this hybrid course continues to be taught at our university.

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Remote Rehabilitation System for Cerebrovascular Patients Combined with Video Call Center

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***Abstract*— Japan's low birthrate and rapidly aging population are causing medical expenses to take up ever more of the national budget and leading to a shortage of young medical professionals. As a result, rehabilitation therapy is being shifted from hospital-care to home-care. Thus, we propose a remote rehabilitation system combined with a video call center to make up for the shortage of rehabilitation therapy done by visiting physiotherapists. In this paper, we focus on cerebrovascular patients and adopt MS-KINECT to measure strain of the upper body and the Balance Wii Board to measure weight and center of weight for home usage. A remote rehabilitation system is also introduced that includes standing-up and sitting-down therapy content.**

Keywords- rehabilitation; remote rehabilitation; motion capture; KINECT; Balance Wii Board; standing-up and sitting-down therapy; video call center

I. INTRODUCTION

Japan's low birthrate and rapidly aging population are causing medical expenses to take up ever more of the national budget and leading to a shortage of young medical professionals. To suppress this increase in medical expenses, medical treatments, including rehabilitation, are being shifted from hospital-care to home-care. The amount of rehabilitation therapy in a home done by a visiting physiotherapist is limited by law and is insufficient for patients to recover completely. Thus, we proposed a concept of remote rehabilitation system combined with a video call center to make up for the shortage of rehabilitation done by visiting physiotherapists [1].

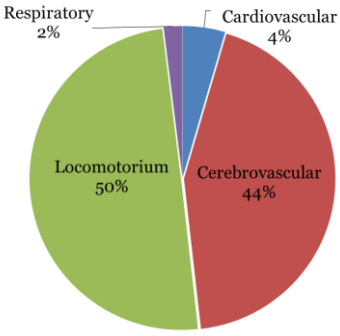


Figure 1. Ratio of disease for rehabilitation

Forty-four percent of rehabilitation patients suffer from cerebrovascular diseases as shown in Figure 1 [2]. These diseases also have the longest rehabilitation term as shown in Figure 2 [2].

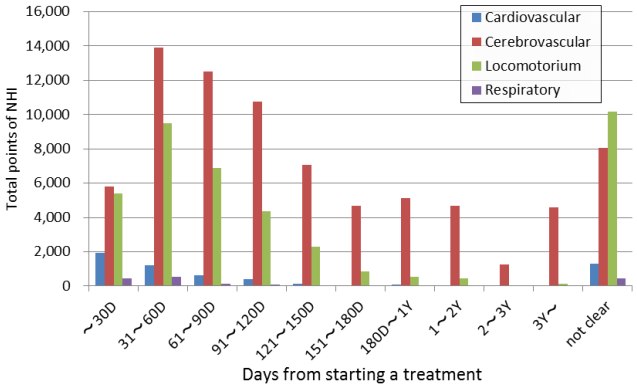


Figure 2. Total points of the national healthcare insurance (NHI) according to the duration of feeding period from treatment start date in Japan

Therefore, we focus on cerebrovascular patients in the first part of our research.

In case of cerebrovascular disease, most patients have paralysis on one side of the body, and their bodies lean and twist to the paralysis side. Also, because of unusual muscle strain, their hands and feet become stiff. In some cases, muscles of the upper body go into convulsions. Because of these strain of upper body, it is difficult for them to keep the body balance.

In case of a hand or foot, a joint angle is easy to measure with a protractor. However, a joint angle of a body is very difficult to measure with a protractor, because the joint angle combines the lead and the twist. A motion monitoring system, Vicon [3], which uses multiple video cameras, has been introduced to big hospitals and rehabilitation centers. Unfortunately, it is too expensive for a small facility to introduce. As a matter of course, it is impossible to adopt for a remote rehabilitation system, because the remote rehabilitation system is used personally.

One of the most important types of training for cerebrovascular patients is standing-up and sitting-down training (hereinafter called standing-up training). If patients cannot get up from a bed, they have to continue to stay on

the bed and sometimes have bedsores. Therefore, the standing-up training is usually put into practice as the first stage. We develop a standing-up and sitting-down therapy content that utilizes the Nintendo Balance Wii Board. This training content also improves imbalance of the body. Changes of weight and center of weight under the feet and buttocks are necessary to advice patients how to stand up from and sit down on a chair in the standing-up training. Since most pressure-sensitive mats are too expensive for home use, we adopt the Nintendo Balance Wii Board.

It is very difficult for patients to continue the self-rehabilitation at home, so our system has two features to help them continuously:

- A patient can check data to see the effect of rehabilitation.
- A call center operator guides patients through the therapy and encourages them with images and conversation through the Internet.

We believe that patients should see practical data showing them getting better and hear a person's voice to improve their morale and to motivate them to continue rehabilitation.

In our proposed remote rehabilitation system, a call center operator guides patients instead of a physiotherapist. Hence, our system has supervising functions for a physiotherapist to coach a call center operator like supervising functions in existing voice call center.

In this paper, we introduce not only concepts of the proposed remote rehabilitation system RRS but also how to design it.

After introducing related works in Section II, we describe the concepts and features of the remote rehabilitation system in Section III. Expression formats of strain of the upper body and change of weight and center of weight are explained in Section IV. Measuring schemes for the ante-flection, lean, and twist of the body are described in Section V. The standing-up training is detailed in Section VI. System designs to realize the above concept and functions are explained in Section VII. The key points are summarized in Section VIII.

II. RELATED WORK

In this section, we introduce existing remote rehabilitaion systems, tools for measuring the strain of upper body, MS-KINECT usage applications adopted in rehabilitation, and therapies for standing-up and sitting-down.

A. Remote rehabilitaion

Traditionally, remote rehabilitation has been administered between a therapist and a patient through a video conference system or video phones, without using measuring and monitoring tools [4]. In accordance with evolution of remote monitoring tools, robotics and virtual reality technologies, they are combined with video conference system. Holden et al. applied virtual reality technologies to their tele-rehabilitation system [5]. Carignan reported rehabilitation system for which robotics was applied including remote rehabilitation [6]. Bradley et al. reported investigations of the design, control and implementation of a form of the intelligent exoskeleton, web-based strategies and robotics for remote rehabilitation [7]. In these researches, therapists directly guide or coach patients through their systems. Therefore, existing remote rehabilitation systems can shorten convey time for a visiting therapist. However, these systems are insufficient to make up for the shortage of therapists.

B. Measurement tools for the strain of upper body

Vicon is one of the most famous companies in the motion capture industry. They can measure complex motions of joints in a body [3]. Vicon's system needs plural specialized video cameras, and know-how is needed to measure motions of joints. Thus, this system is too expensive for a small rehabilitation center or an individual to purchase and operate. Akimoto et al. developed a measurement tool for scoliosis [8]. It uses MS-KINECT to measure undulations on a body. This tool can express measurement data with an image, a graph, and numerical data and store them. Jing Tong et al. developed new scanning technology that can fully scan the body and show VR images of it [9]. It uses three MS-KINECTs. However, they did not account for measuring the lean and twist of a body. Burba et al. applied MS-KINECT to measure breathing rates derived from motions of the chest, and the number of shakes of tapping the knee derived from motions of the knee [10].

C. Therapy contents adopted MS-KINET and Ballance Wii Board to rehabilitation

Garrido et al. applied MS-KINECT rehabilitations for patients who have trouble with their sense of balance with cerebrovascular disease [11]. They express the lean of the body by an image of the balance scale and show arrows to correct a patient's posture.

There are also many video games for rehabilitation that use MS-KINECT [12][13][14].

Fraser Anderson et al. developed a therapy content that combined the Balance Wii Board and a virtual game to improve the sense of balance [15]. This content can measure and record performance of a virtual game and show it to a patient to motivate him or her to continue rehabilitation.

D. Therapy for standing up by the physiotherapist

We heard about physiotherapists trained in standing-up and sitting-down therapy, and searched for it on the Internet [16]. The standing-up and sitting-down therapy consists of the following four steps:

Step 1: A patient bends her or his upper body down to shift her or his center of weight to her or his toes and raises her or his buttocks from a chair.

Step 2: The patient streches her or his knees and simultaneously bends her or his upper body up.
Step 3: The patient slightly bends her or his upper body down to shift her or his center of weight to her or his toes from the upright position.
Step 4: The patient sits down on a chair.

This training emphasizes bending her or his upper body up and down to shift her or his center of weight. However, most cerebrovascular patients have paralysis on one side of the body, and their bodies lean and twist to the paralysis side. Imbalance of the upper body will need to be corrected for rehabilitation.

III. CONCEPT OF THE RRS WITH VIDEO CALL CENTER

Our RRS is based on the following ideas:

- Practical data that shows the patients getting better will effectively encourage them to continue rehabilitation, more than simply giving them vague information such as "you are a little better than yesterday".
- Hearing a person's voice is likely to cheer patients up.

Additionally, we plan to employee non-professionals as operators instead of physiotherapists to hold down operation costs and compensate for a shortage of physiotherapists.

We introduce roles of a physiotherapist and operator, and necessary functions to realize above concepts.

A. *Roles of a physiotherapist and operator*

Roles of a physiotherapist are as follows:

- Teaching operators how to guide patients through rehabilitation and supervising the operators.
- Deciding and changing therapy programs on the basis of diagnostics data and measured data.

Roles of an operator are as follows:

- Monitoring motions of a patient and measuring joint angles by the measuring tools.
- Coaching a patient in how to move his or her body using the administration tools and therapy contents on the basis of therapy programs.

B. *Necessary tools*

As shown in Figure 3, this system comprises following components:

- Administration tools: An operator uses these tools to guide patients.
- Measuring tools: An operator uses these tools to measure conditions of a patient including joint angles. Kinds of measuring tool that are kind of sensors are easily added to the RSS as necessary.
- Supervising tools: A physiotherapist uses these tools to coach operators. A physiotherapist can monitor how an operator is coaching patients and instruct him or her in therapy with these tools.
- Communication exchange application: This application connects a patient with an operator. This application works on a video conference server.
- Therapy contents: Presentation contents to explain how to train, or training content such as video games for rehabilitation.
- Patient database: Patient data that include profile data, measured data, therapy programs, and coaching video are stored and managed by this database. The access permission policy for this database has to be decided by the management organization of this system.

The supervising tools and communication exchange application are newly added to introduce operators to the remote monitoring system. However, existing remote rehabilitation systems have also same roles for the other components. As a matter of course, practical tools of these components are different in each system.

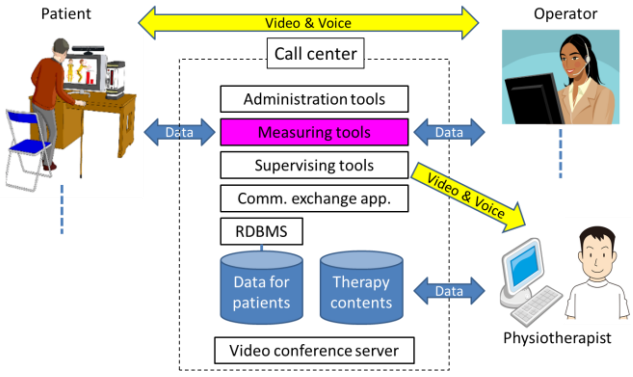


Figure 3. System concept of the remote rehabilitation

IV. EXPRESSION FORMATS OF SENSOR DATA

We design the proposed RRS to be able to easily add as many kinds of sensors as necessary as described in Section III. At present, we think that at least the motion monitoring sensor to measure strain of the upper body and the pressure distribution mat to sense changes of weight and center of weight are needed for rehabilitation of cerebrovascular patients. We choose MS-KINECT as the motion monitoring sensor and Balance Wii Board as the pressure distribution

mat for the home use. Both sensors are reasonably enough priced for home use.

In this section, we describe expression formats of strain of the upper body, and changes of load and the center of weight to show operators and physiotherapist in Figure 3.

A. *Strain of the upper body*

In this paper, strain of the upper body is shown from the ante-flexion, lean, and twists. We describe how to express the ante-flexion, lean, and twist in this section.

1) *Ante-flexion*

In the case of a skeleton model of the pre-packaged program in MS-KINECT v1, measuring points on the spine are the neck and the nave. However, these points are not sufficient to express the ante-flexion. Therefore, we add measuring points between the neck and the navel as shown in Figure 4 and measure the depth of each point. We decided to express the ante-flexion as shown in Figure 5.

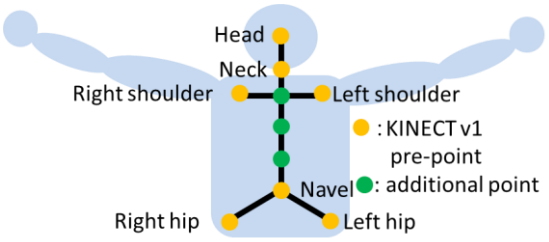


Figure 4. Skeleton model used in this research

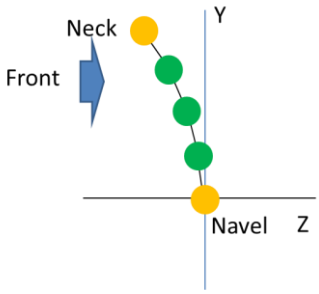
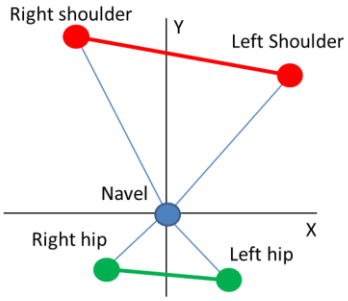


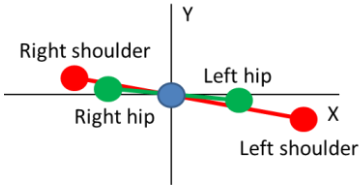
Figure 5. Expression format of the ante-flexion

2) *Lean*

We express the lean of the upper body with both a line connecting the right shoulder and the left shoulder and a line connecting the right hip and the left hip from the front view. Two types of front view formats are considered to express the lean of the upper body. One is making a triangle between the right shoulder, left shoulder, and navel, and a triangle between the right hip, left hip, and navel as shown in Figure 6 (a). The other is that both a line connecting both shoulders and a line connecting both hips are plotted on the X-Y plane on which middle points of both lines are plotted on the origin as shown in Figure 6 (b).



(a) Triangle expression format



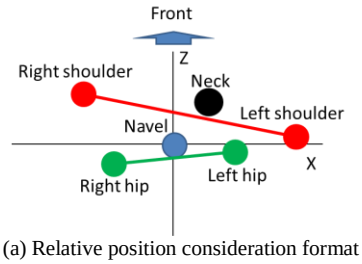
(b) No triangle expression format

Figure 6. Expression format for the lean of upper body

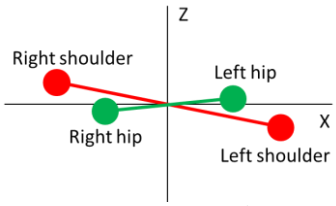
We asked 30 people which expression more easily explained the lean of the upper body. Results of answers to this question are shown in Table I. Most respondents chose the triangle expression format (a).

3) *Twist of upper body*

We express the twist of the upper body with both a line connecting both shoulders and a line connecting both hips from the top view. Two types of top view formats are considered to express the twist of upper body. One is plotting positions of the head and navel in addition to the above mentioned two lines as shown in Figure 7 (a). The other is plotting just the above mentioned two lines on the X-Z plane in which middle points of both lines are plotted on the origin as shown in Figure 7 (b). We asked 30 people which expression more easily explained the twist of the upper body. Results of answers to this question are shown in Table I. Most students chose the lines-only plotting format. On the other hand, 9 of 14 workers who responded chose the relative position consideration format. Every healthcare worker (3 people) said that positions of lines of the shoulders and the hips relative to the head were important to understand the twist. They all chose Figure 7 (a).



(a) Relative position consideration format



(b) Lines-only plotting format

Figure 7. Expression format for the twist of upper body

TABLE I. RESULTS OF QUESTIONNAIRE ABOUT WHICH EXPRESSION FORMATS ARE EASIER TO UNDERSTAND

		(a)	(b)
Lean	Students	15	1
	Workers	13	1
Twist	Students	0	16
	Workers	9	5

B. Changes of weight and the center of weight

As a result of hearing about the standing-up training content described in Section VII to physiotherapists who work in Yokohama Central Hospital, they requested us to express not illustrations of the body, but visually changes of load and the center of weight such as graph or something.

Since physiotherapists who give us suggestions want to know timings at when they say guides to patients, we express a change of weight as a line graph in accordance with the change of time like Figure 8, and the change of center of weight as not a real-time position or a trace with a solid-line, but the trace with a arrow-line like Figure 9. Lines of feet and buttocks are plotted on a same graph easy to know timing at when they say guides.

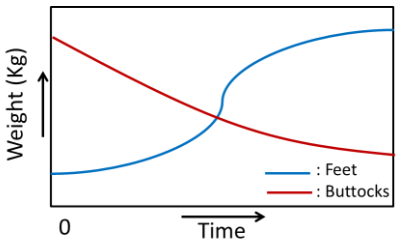


Figure 8. Expression format for change of the weight

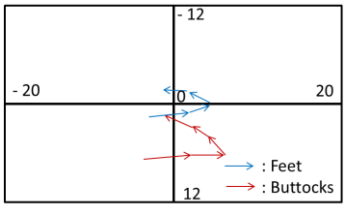


Figure 9. Expression format for change of the center of weight

V. MEASURING FUNCTIONS FOR STRAIN OF UPPER BODY

We developed a tool for measuring the strain of the upper body that will be a component of our remote rehabilitation system.

A. Measuring application

1) Ante-flexion measuring application

Depth of the neck, the navel, and three points that divide the neck and the navel into four equal parts are measured in this application. The number of measuring points can be increased. An example picture of the display is shown in Figure 10. A video image is shown for a call center operator to easily guide a patient on the upper-right portion of a display. Measured data include error caused by the curve of body and clothes. Therefore, we recommend measuring not the front view but the back view as shown in Figure 11.

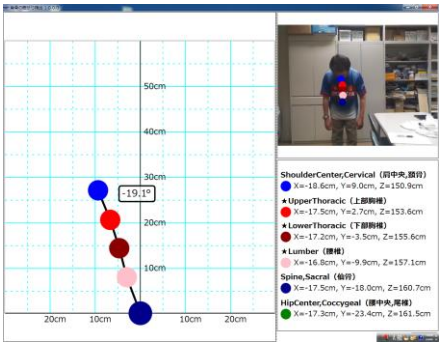


Figure 10. Example of front view measuring the ante-flection

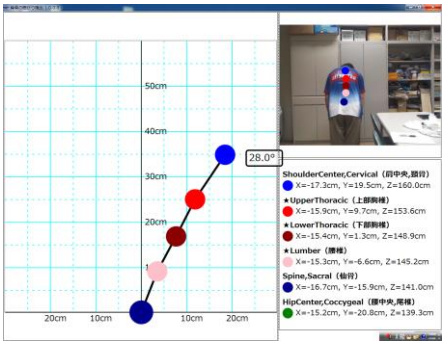


Figure 11. Example of back view measuring the ante-flection

2) Lean measuring application

Since most respondents chose the triangle expression format as shown in Table I, we adopted it. We showed numerical angles between the X axis and the line connecting both shoulders and between the X axis and the line connecting both hips to make practical data easy to understand as shown in Figure 12.

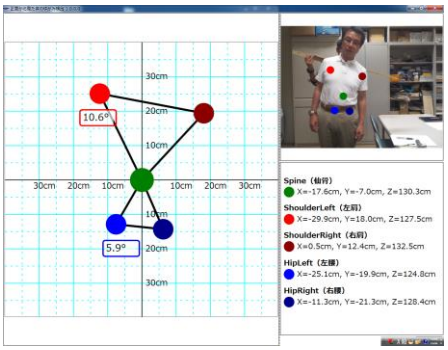
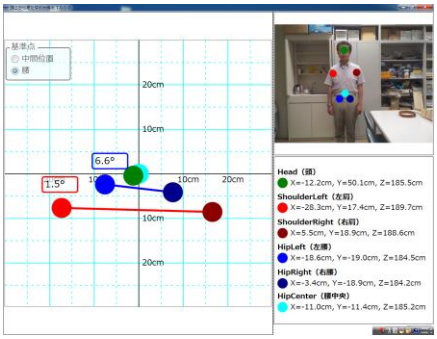


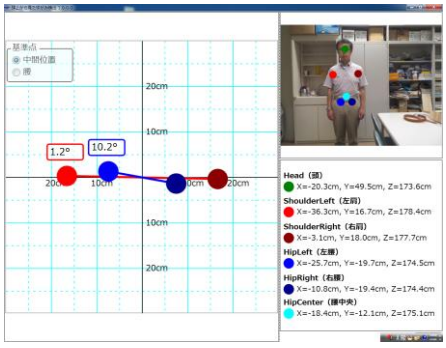
Figure 12. Example of measuring the lean

3) Twist measuring application

Since 30% of respondents (including every healthcare worker) chose the relative position consideration format and 70% of them chose the lines-only plotting format in Table I, we designed both of them. We showed numerical angles between the X axis and the line connecting both shoulders and between the X axis and the line connecting both hips to make practical data easy to understand, the same as the lean. Example screenshots are shown in Figure 13.



(a) Example of the relative position consideration format



(b) Example of the lines-only plotting format

Figure 13. Example of measuring the twist

B. Evaluation of measured data

Since the depth value in MS-KINCT is the shortest distance between the X-Y plane on the depth measuring camera and a measuring point, a tape measure or an acoustic measure is not useful. Hence, we evaluated the angle of the ante-flection, lean, and twist by comparing between values measured by MS-KINECT and by a big protractor (see Figure 14). We fixed a string to a protractor that had a weight at one side for indicating it was the perpendicular to the earth.

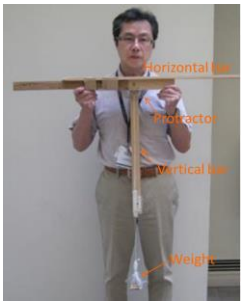


Figure 14. Protractor used in this research

1) Ante-flexion

The horizontal bar of the protractor is set on the floor. A rectangular board is fastened to the vertical bar; and an upper body is placed along with the rectangular board to remove influence derived from the curve of the body, as shown in Figure 15.

We varied the angle between the horizontal bar and the vertical bar from 0 to 15 degrees. Data measured by the ante-flexion measuring application corresponding to an angle of a protractor is shown in Figure 16. We measured 20 samples. Average and standard deviation data are plotted on the graph. Errors are a few degrees, which would be small enough for practical use.

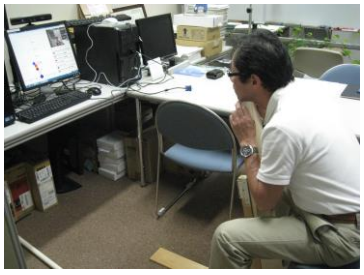


Figure 15. Measuring image of the ante-flection

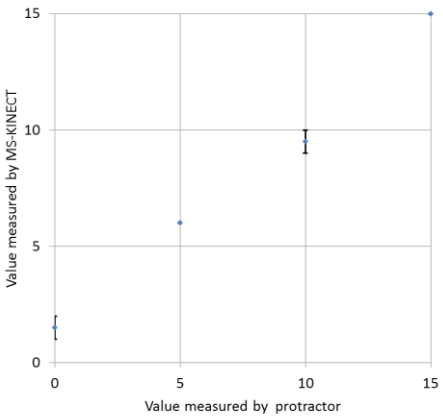


Figure 16. Measured data of the ante-flection

2) Lean

The angle between the X-axis and the line connecting both shoulders was varied from -20, -10, 0, +10, +20 degrees instead of the lean angle. These values were measured by the protractor fitted on both shoulders from the back. We measured the lean of the body by the lean measuring application, and measured data is shown in Figure 17. There are no errors.

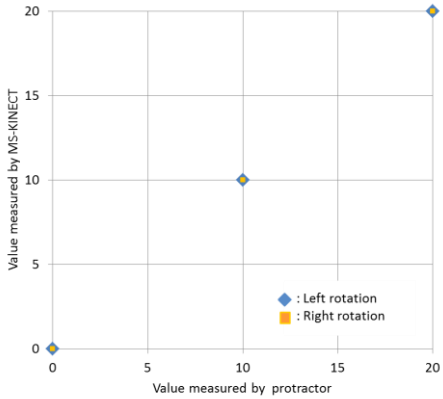


Figure 17. Measured data of an angle between X-axis and a line connecting both shoulders

3) Twist

We measured the angle between the X-axis and a line connecting both shoulders from the top view. The horizontal bar of the protractor is fastened to both shoulders, and the vertical bar points to the MS-KINECT to remove the influence derived from the curve of the body as shown in Figure 18. We also measured the line of hips the same as the line of shoulders. Measured data is shown in Figure 19. Errors for the right rotation in both the shoulders and the hips are very small. However, errors for the left rotation are a few degrees. We are not sure of the reason for this difference.

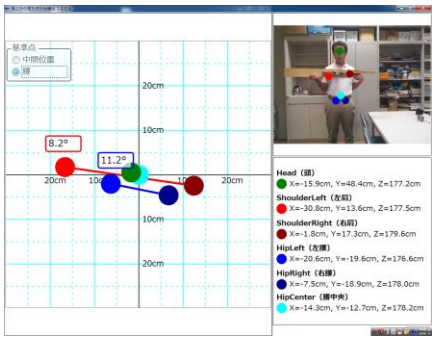
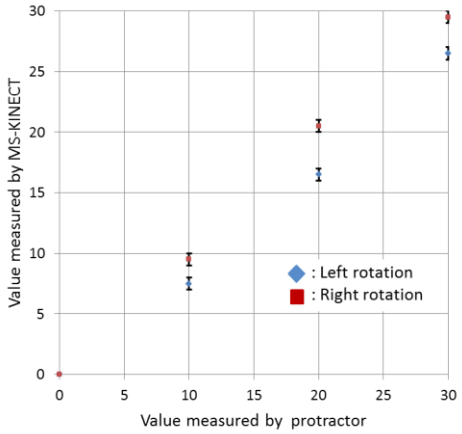
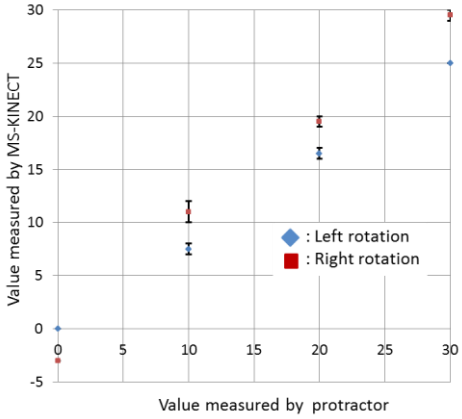


Figure 18. Measuring image of the twist



(a) Measured data for the shoulders



(b) Measured data for the hips

Figure 19. Measured data of the twist

VI. STANDING-UP TRAINING CONTENT

We develop training content for cerebrovascular patients to learn how to stand up from a bed and sit down on it. A chair is used instead of a bed. We designed this content for patients to learn not only with an operator's guidance but also by themselves.

A. System configuration

We use two Balance Wii Boards: the patient puts his or her feet on one and sits on the other as show in Figure 20. Both of them are connected to the patient's PC via Bluetooth. A Balance Wii Board has four load sensors at its four corners and puts out loads at each sensor: total load and the center of load. The scale of the center of load approximately corresponds to its surface size as shown in Figure 21. MS-KINECT is also connected to the patient's PC to monitor a motion of patient.

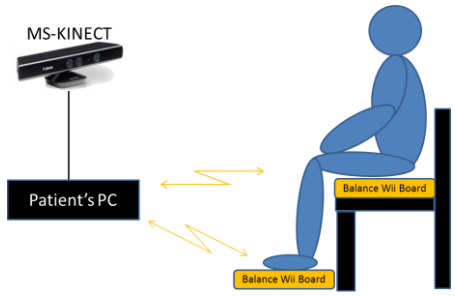


Figure 20. System configuration of the standing-up training content

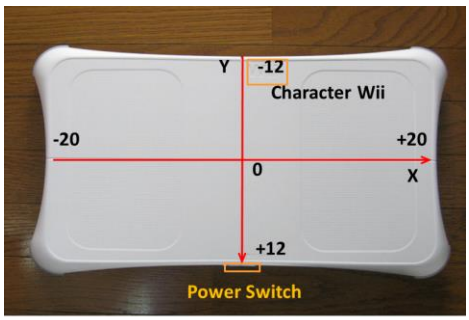


Figure 21. Scale of the balance in the balance Wii Board

B. Training steps

Therapy by a physiotherapist puts emphasis on bending the upper body down and up and shifting center of weight. However, we add correcting strain of the body to learning how to stand up and sit down. Guiding illustrations for each step are shown in Figure 22.

This training content is comprised of the following eight steps;

Step 1: A patient corrects imbalance of her or his upper body. An illustration on a screen leads the patient to correct imbalance of her of his upper body. While the patient leans to the right or left, the training content continues to show a left or right arrow and says "To the left" or "To the right" repeatedly until the center of load under the buttocks is between the decision levels ±TH1 (all TH values are described in the next sub-section.). When the patient maintains balance for 3 seconds, the next training step starts.

The above guidance and decision functions are used for self-learning. In case of guidance by an operator, the operator verbally instructs a patient with not illustrations or written instructions, but a graph of change of the center of weight like Figure 9. This scheme is the same as in the following steps.

Step 2: The patient moves her or his knees forward while continuing sitting on a chair. This step is not in therapy by a physiotherapist. Since it is impossible to stand up while the ankles are further forward than the knees, we add this step. The training content continues to show a forward arrow and say "Go forward" repeatedly until the center of load under the buttocks is shifted over the decision level TH2. When the patient maintains her or his balance for 3 seconds, the next training step starts.

Spep 3: The patient bends her or his upper body down to shift her or his center of weight to her or his toe and raise her or his buttocks from a chair. The training content continues to show a forward arrow and say "bend your body down and raise your buttocks up from the chair" repeatedly until the load under the buttocks is less than the decision level TH3. When the patient maintains this condition for 3 seconds, the next training step starts.

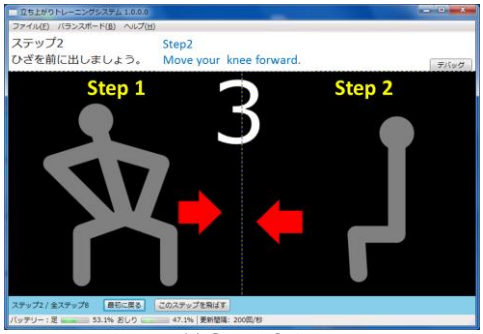
Step 4: The patient stretches her or his knee and simultaneously bends her or his upper body up. The training content says "Please stand up." Since this step does not include a conscious action to learn, it has no illustration.

Step 5: The patient corrects imbalance of the body while standing up. While the patient leans to the right or left, the training content continues to show a left or right arrow and says "To the left" or "To the right" repeatedly until the center of weight under the feet is between the decision levels ±TH4. Vice versa, while the patient leans to left, the training content continues to show a right arrow and say "To the right" repeatedly. When the patient stays upright for 3 seconds, the next training step starts.

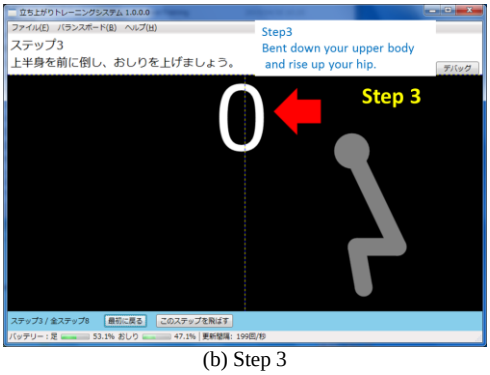
Step 6: The patient slightly bends her or his upper body down to shift the center of weight to her or his toes from the upright position. The training content continues to show a forward arrow and say "Bend your upper body down slightly" repeatedly until a load under the center of weight under the feet shifting over the decision level TH5. The next training step starts as soon as the patient has maintained this condition.

Step 7: The patient sits down on a chair. The training content says "Please sit down." Since this step does not include a conscious action to learn, it has no illustration.

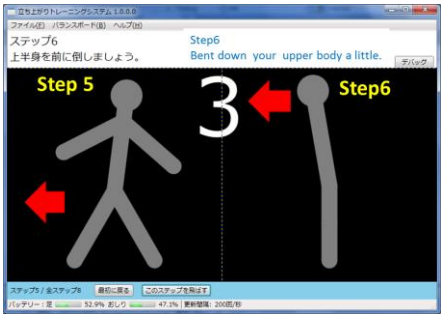
Step 8: The patient bends her or his upper body up and returns to Step 1.



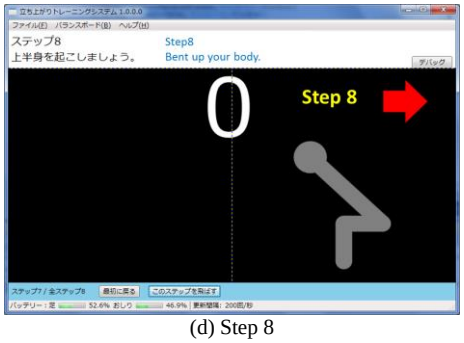
(a) Steps1 & 2



(b) Step 3



(c) Steps 5 & 6



(d) Step 8

Figure 22. Guidance illustrations

C. *Decision levels*

We describe how to decide the decision levels TH1 – TH5 described in the previous sub-section. These decision levels are decided from measurement data. Five able-bodied students did the above eight steps. Changes of loads and center of load under the buttocks and feet were measured for them. We decided the common values for every participant plus the loosen value.

(1) TH1: Since every participant can stand upright and we could not collect data from disabled people, we decide TH1 (center of load) = 3. After collecting data from disabled people, we will reconsider this value.

(2) TH2: When participants move their knees forward, the center of loads under both the buttocks and feet move forward. However, since the change of a center of the buttocks is bigger than that of the feet, we choose the center of the buttocks as shown in Figure 23. Changes of the center of load under the buttocks for every participant are less than -4 on the Y axis, so we decide TH2 = -3 (loosen value = 1).

(3) TH3: Most participants could not perfectly raise their buttocks up from a chair. Since the worst value is 17kg (see Figure 24), we decide TH3 = 20 (loosen value = 3).

(4) TH4: We decide TH4 = 3, the same as TH1. TH4 will have to be reconsidered after data are collected from disabled people.

(5) TH5: Changes of the center of load under the feet for every participant are less than -3 in Y axis as shown in Figure 25. Hence, we decide TH5 = -2 (loosen value = 1).

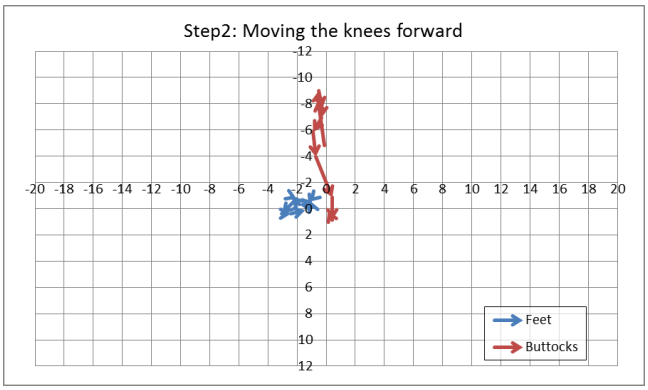


Figure 23. Change of the center of load under the buttocks (red) and feet (blue) when moving the knees forward

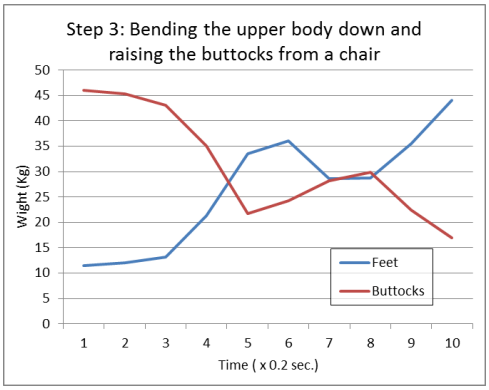


Figure 24. Change of weight under the buttocks (red) and feet (blue) when bending the upper body down and forward

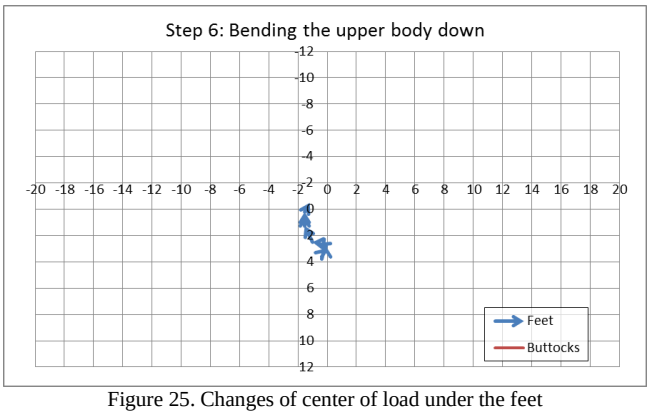


Figure 25. Changes of center of load under the feet

D. Evaluation of decision levels

We did an experiment to verify whether the above decision levels work well. There were six participants. All were able-bodied students who did not participate in the experiment to decide the decision levels. Each participant did steps 1 to 8 for five cycles. Experimental results are shown in Table II. We count 0.5 when a patient does the same step a few times. The recognition rates in steps 2, 6, and 8 are not 100%. We will reconsider these decision levels or schemes.

VII. System Design of the RRS

We have already finished designing a practical remote rehabilitation system, and some of its features have been implemented.

A. Design concepts

This system is comprised of the call center node, a patient's PC, an operator's PC, and a physiotherapist's PC as shown in Figure 3. MS-KINECT is just connected to the RRS introduced in eTELEMED 2015 [1]. However, the advanced RRS is designed for other kinds of sensors to be connected in addition to MS-KINECT. Basically, all sensors work simultaneously to measure a patient's condition in the RSS. Since output data of sensors have to be sent synchronously to the call center, all sensor data are aggregated at the same module.

Basically, we design applications as Web applications to avoid on-site maintenance.

B. Synchronizing scheme between video images and skeleton data

Since video images and skeleton data are independently output from MS-KINECT, both have to be synchronized to enable monitoring at a remote office. Thus, we serialize skeleton data in JSON format and add them to each item of video frame data, which is resized, transferred to the JPEG format, and then transferred to the Base 64 text data at the application on a patient's PC as shown in Figure 26. These data are sent to a Web server in the call center. They are separated again and individually drawn on the canvas of the html monitoring page as shown in Figure 27. Video image data are drawn on a lower layer and skeleton data are drawn in our presentation format on a transparent upper layer as shown in Figure 28. Finally, video and skeleton images formatted in accordance with our proposed method move in synchronization with a Web browser on a physiotherapist's PC as shown in Figures 9-12.

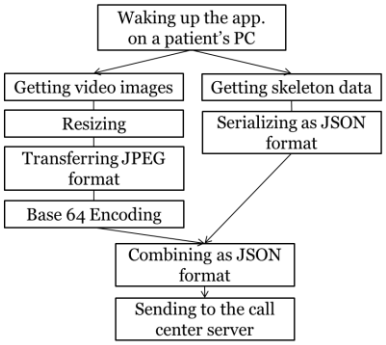


Figure 26. Flow diagram for aggregating video images and skeleton data

TABLE II. Recognition Rate for Motion in Each Step

Participant	Step 1	Step 2	Step3	Step 4	Step5	Step 6	Step 7	Step 8
A	5	4	5	—	5	5	—	5
B	5	5	5	—	5	5	—	5
C	5	4	5	—	5	4	—	4.5
D	5	5	5	—	5	4.5	—	4.5
E	5	5	5	—	5	3.5	—	4
F	5	5	5	—	5	5	—	5
Average	**5.0**	**4.7**	**5.0**	**—**	**5.0**	**4.5**	—	**4.7**
Rate	**100%**	**93%**	**100%**	**—**	**100%**	**90%**	—	**93%**

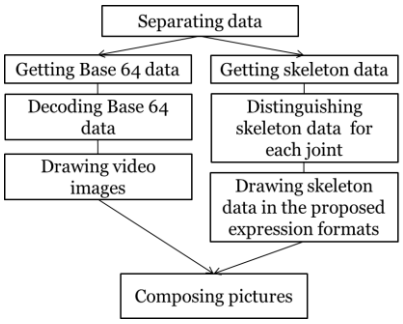


Figure 27. Flow diagram for composing pictures

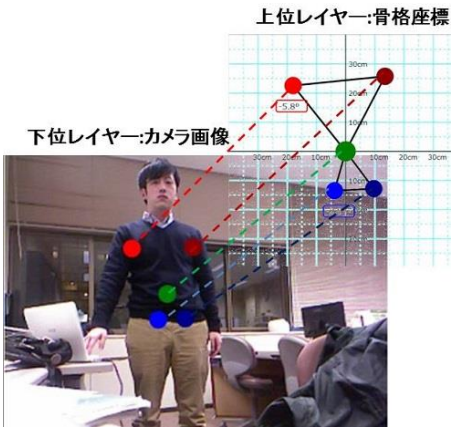


Figure 28. Example of composing video image and skeleton data.

C. *Storing measured data*

An operator monitors the video and skeleton images, change of weight, and change of center of weight, and stores important data for a physiotherapist to understand a patient's condition and reschedule a training plan. After saying to a patient something such as "Let's start measuring", the operator starts by pushing the start button to record monitored data and stops by pushing the stop button. Those data are stored as a temporarily file. The operator usually monitors this file again. If it is fine, the operator pushes the save button to save it as a permanent file. The operator can also store still image data in addition to video data. A physiotherapist can search for these data by using a patient's name, an operator's name, and date and time.

D. *Supervising function*

A physiotherapist needs conversation data between a patient and an operator to supervise an operator. These verbal communication data have to be stored synchronously with measured sensor data. Therefore, these data are recorded on the patient's PC and sent to the call center server together with other sensor data. We adopt the JASON format as the sending data format. Kinds of data sent from a patient's PC to the call center server are KINET video image data, KINECT skeleton data, Balance Wii Board data, an operator's voice, and a patient's voice. If other sensors are added in the future, output data of these sensors will also be sent together with existing data.

E. *Block diagram*

Block diagrams of the call canter node, the patient's PC, the operator's PC, and the physiotherapist's PC are shown in Figure 29.

MS-KINECT and Balance Wii Board are connected to

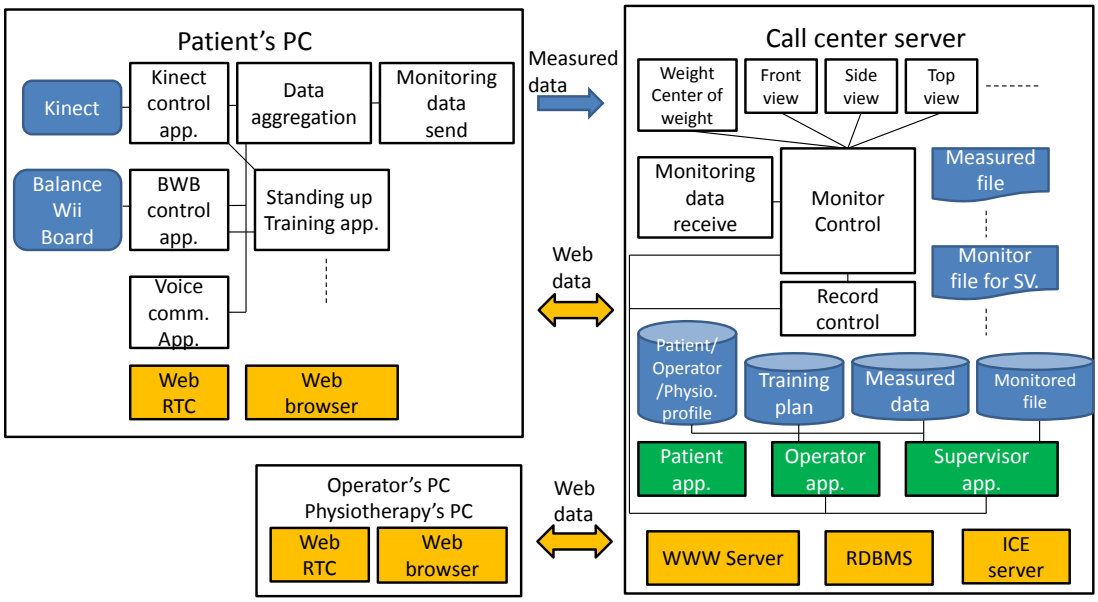


Figure 29. Block diagram of the RRS

the patient's PC. Since Microsoft has released MS-KINECT v2, we developed a remote rehabilitation system with MS-KINECT v2, not v1. Since the skeleton model in MS-KINECT v2 is slightly different from that in MS-KINECT v1, expression formats described in Section IV are modified slightly. Practically, the navel is replaced with the spine-middle, and the shoulder center with the neck.

We design applications as Web applications to make on-site maintenance unnecessary as soon as possible as described in the design concept. However, since we have no technologies to control MS-KINECT v2 and the Balance Wii Board by a Web browser, application programs controlling MS-KINECT v2 and the Balance Wii Board are implemented as native programming code and installed on a patient's PC. The standing-up training application is also developed as native programming code and installed on a patient's PC. Output data of MS-KINECT and Balance Wii Board are aggregated to the data aggregation program and sent to the call center through the monitoring data sending program. Both the data aggregation program and the monitoring data send program are developed as native programming code and installed on a patient's PC. Voice data between a patient and an operator are also aggregated at the data aggregation program. A Web browser is also installed on the patient's PC for presentation of guidance contents and voice communication.

On the other hand, no applications except a Web browser are installed on the operator's PC and the physiotherapist's PC. Coaching applications for an operator and supervising applications for a physiotherapist work on a Web browser as Web applications. A voice communication function is implemented with the Web RTC [17].

The call center server is comprised of many kinds of modules. The monitoring data receiving module receives data sent from a patient's PC. The monitor control module divides received data into each sensor data and draws them as each expression format introduced in Section IV. The record control module stores KINET video image data, KINECT skeleton data, and Balance Wii Board data produced by an operator's operation. These stored files are managed by the database management system. On the other hand, the record control module stores conversation data between a patient and an operator automatically. Patients' profiles and therapy contents are also managed by the database management system. Operators' and physiotherapists' profiles are also stored as database.

This time, a voice communication function is implemented with the Web-RTC and ICE [17].

F. System sequence

This sub-section explains the sequence of using the remote rehabilitation service. As shown in Figure 30, first, operators log in, and then a patient logs in and selects an available operator.

The designated operator selects a training content on the basis of a training menu planned by a physiotherapist. A patient who watches a presented training content follows the presentation by doing the training. The operator monitors and suggests training for the patient and saves video images and skeleton data as necessary. After training, an operator measures the strain of the patient's body.

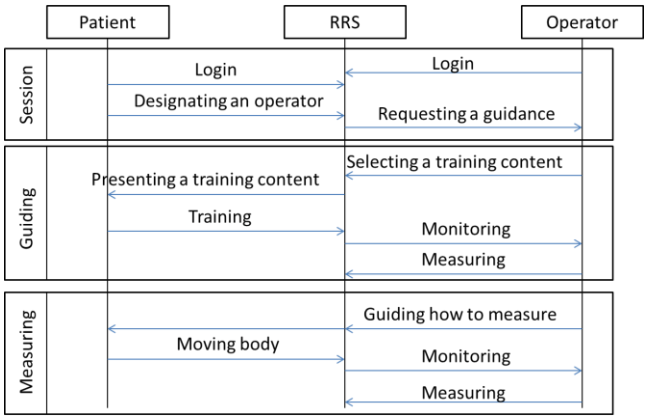


Figure 30. System sequence for using remote rehabilitation service

VIII. CONCLUSION

We proposed a remote rehabilitation system combined with a video call center to make up for the shortage of rehabilitation therapy done by visiting physiotherapists. We focused on cerebrovascular patients and adopted MS-KINECT for home usage to measure the strain of the upper body. We also proposed expressing strain of the upper body by dividing the ante-flexion, lean, and twist and developed an application for measuring them. In the results of evaluating these measuring applications, their measurement errors are sufficiently small.

We are still in the process of completing the remote rehabilitation system. The concept of employing non-professionals as operators instead of physiotherapists to hold down medical expenses is novel. We introduced the standing-up training content that adopts the Nintendo Balance Wii Board and a system configuration that realizes the above concept and introduced functions. The proposed RSS would probably suppress increment of medical expense and affect institutions of the national healthcare insurance. Thus, new business schemes have to be created in addition to developing the system to introduce it as a service.

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Gaining User Experience Patterns by Drawing from Science and Industry

A Combinatory Pattern Approach

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Abstract— **Findings from scientific disciplines with close ties to the industry – such as Human-Computer Interaction – can be useful for advancing both the scientific discipline itself as well as the associated industry. It is, therefore, an additional challenge to consolidate and convert the scientific knowledge gained into a format of which is applicable and understandable in practice in order to provide meaningful and usable tools for practitioners in their daily work routines. We used patterns to combine research results and industry know-how into solutions for distraction-related design problems in the automotive domain. In this paper, we present our pattern generation process that resulted in the creation of 16 patterns with input from scientists, as well as industrial stakeholders, in several key phases. Thereby, we discuss the advantages of patterns as a means to put scientific knowledge into practice. The contribution of this paper is a pattern generation and validation process, together with an accompanying pattern structure tailored towards combining scientific results and industry knowledge that resulted from this process.**

Kewords-basics on patterns; design patterns; pattern identification and extraction; validate patterns.

I. INTRODUCTION

This paper is an extension of a full paper presented at PATTERNS 2015 [1]. Patterns are a method to capture proven design solutions to reoccurring problems. They are a structured description of best practices and, as such, highly problem-oriented and reusable [2]. The use of patterns in design can improve the design process (regarding both time and effort spent) to a considerable degree [3][4][5]. Patterns are also a recognized way of facilitating communication between different stakeholders. Since scientific research in Human-Computer Interaction (HCI) is closely interconnected with the industry, patterns could serve as a tool to communicate scientifically proven solutions to industry stakeholders. In our work, we aimed at generating patterns for HCI researchers and industry stakeholders based on scientific findings and transform them – by directly involving industry practitioners – into solutions that are relevant for and usable by these stakeholders. The underlying research questions are (1) how scientific findings may be translated into design patterns usable for practitioners in their daily routines, and (2) how such patterns may be generated by including scientific and industry stakeholders.

The outcome of our efforts was a pattern structure that incorporates scientific results and fits industry stakeholder needs, as well as a first set of 16 automotive User Experience (UX) design patterns. We refer to UX design patterns as patterns that tackle User Experience issues in their core.

In this paper, we present the final pattern structure, as well as the phases of the pattern generation process involving both scientists and industry stakeholders (We use the term 'generation' to delineate our approach from pattern finding methods, which usually focus only on actual implementations, and not theoretical or scientific works). Furthermore, we critically reflect upon issues and problems that emerged throughout our proposed pattern generation process itself, but also about the cooperative process on generating the patterns between scientific and industry stakeholders. In this paper, we begin with an overview of current pattern literature in Section II. In Section III, we describe our pattern finding process via the concrete pattern structure example and its development. In Section IV, we provide a summary of the overall process, together with a brief discussion on the limitations and potentials of our approach.

II. RELATED WORK

In order to provide best practices and specific knowledge, the patterns approach has been well established in the domain of HCI [1]. Recently, specific domains in HCI, such as UX research, also deployed patterns to collect and structure their knowledge [4][5].

Köhne [7] (based on Quibeldey-Cirkel [8]) outlines specific steps for generating patterns. The process starts with discovering patterns, so-called *pattern mining*, by identifying whether a solution is valuable to solve a problem. The next step consists of *pattern writing*, where the problem solution is described in a defined structure. This is followed by *shepherding,* in which an expert provides support in improving the patterns content. Thereafter, a *writers workshop* is conducted. In such a workshop, a group of pattern authors discuss a pattern. Based on the feedback from the writers' workshop, the pattern author revises the pattern (*author review*). In a next step, the patterns are made public in a *pattern repository*, which is open to *anonymous peer review*. Finally, the pattern collection is published in a

pattern book making the final patterns available for a wide readership.

Similarly, Biel et al. [9] split the process of defining trust patterns for interaction design into four subtasks. The first task is *identifying a pattern* by analyzing the solutions used by designers. Second, the *pattern gets categorized* in order to make it reusable and accessible for designers. Third, the *pattern is described* following a specific structure. The fourth task is *evaluating the pattern* to prove its quality before it is introduced to a pattern library.

Aside from starting the pattern mining from designers' practical knowledge, patterns can also be harvested from scientific research findings. Martin et al. [10] use patterns to describe findings from ethnographies. For creating their patterns, they started by looking for specific examples in a particular domain in ethnographic studies and then tried to expand the observed phenomena to other domains (similar but different examples). Krischkowsky et al. [11] introduce a step-by-step guidance for HCI researchers for generating patterns from HCI study insights. According to them, the first step is giving novice and expert HCI researchers a *brief overview on the concept of patterns* and, more specifically, Contextual User Experience (CUX) patterns [5] (i.e., patterns to enhance user experience in a particular context). After this, the next step of the guidance concerns the *reflection and selection of relevant UX related results* from empirical studies conducted by the researchers. In a third step, HCI researchers *develop their own CUX patterns*, which are then internally *evaluated by researchers* following a checklist. In the last step, the researchers give *feedback on the pattern generation process*.

Following a user centered patterns generation approach, we aimed at including industry designers within a specific domain (in our case automotive user interface design) in the patterns generation process. This was done in order to bring the target group into the loop as early as possible and to avoid the error of not including industry stakeholders in the pattern finding process. In the following section, we outline and reflect on our pattern generation method. Further, we describe a seven-step approach that describes how we generated an initial set of automotive UX patterns from a scientific knowledge transfer workshop (step 1) to final pattern iteration (step 7). Based on a reflection of our work, we conclude with a novel patterns generation approach consisting of five phases. In addition, this paper presents an according pattern structure for distraction-related design problems in the automotive domain. Both, the patterns generation approach as well as the pattern structure for automotive UX patterns, are the main contributions of this paper.

III. THE PATTERN GENERATION PROCESS

Within our research activities, the need for pattern guidance occurred within a national project focusing on contextual interface research in the automotive domain. In particular, the following section outlines the process of how we developed a pattern structure that provides insights, information, and guidance on how to design for a positive User Experience (UX) for the driver. This general aim was divided into several more specific goals related to distinct UX factors (e.g., *workload*, *fun*, or *trust*). As the focus of our work was on the pattern generation process and the pattern structure, we decided to select one specific UX factor and improve the process and the structure by developing patterns for this factor. We chose to generate patterns for reducing workload that is caused by distraction, as this constitutes one of the most prevailing and severe problems in the automotive domain. In the next paragraphs, we outline each phase in the generation process in detail, reflecting on each step individually.

A. Starting from scientific knowledge

In this first phase, we started from pure scientific knowledge about distraction-related design problems in the automotive domain to create an initial draft set of patterns. This seemed like a logical first step, since we wanted to go from the science to the practice. As we would learn later on, however, a slightly different approach would have been even better. This will be reflected in the discussion section. The first phase can be segmented into four sub-steps, outlined in the following sections.

B. Scientific knowledge transfer workshop

Within the first step, a knowledge transfer workshop, organized by pattern experts and HCI researchers in the automotive domain, was conducted. Hereby, the main goal was to give experts in the automotive domain know-how on pattern generation. This know-how was provided by HCI pattern experts, in order to facilitate the development of an initial draft of patterns. The workshop lasted approximately four hours. Overall, six HCI researchers, all closely familiar with the automotive context, and two HCI pattern experts, who led the workshop, participated in this workshop.

In this initial knowledge transfer session, participants were introduced to patterns in general and the role of patterns in HCI in particular. We used the pattern definition of Cooper et al. [12]. In their definition, the authors define patterns as *'(Design) patterns capture useful design solutions and generalize these solutions to address similar problems.* We also included aspects such as the usefulness of patterns as a tool for documentation, collection, communication, and representing knowledge [1]. The participants were also introduced into the differences between patterns and guidelines. It was important for us that the participants understood the particular differences to guidelines, which are in contrast very short and concise, whereas patterns are supposed to be structured, have a well-defined context, and often provide several solutions to one problem.

After that, example patterns from other domains were presented (e.g., [13], [14], [15]). Subsequently, participants where shown the main goals for the development of patterns in the automotive domain (e.g., collect a number of UX related patterns, structured guidance on how to design for a good UX regarding advanced in-car systems). Thereafter, a presentation of the initial pattern structure was given, based on the CUX patterns approach [5]. This approach has already proven its value for collecting and structuring knowledge on UX [4]. The CUX pattern approach was chosen, as it

explicitly considers the relation of UX and contextual aspects. In order to provide a better understanding of the CUX pattern approach, an exemplary CUX pattern reflecting on *increased workload by font size* was shown to the participants. At the end of the workshop, participants were introduced to the entire, initially defined, pattern structure for UX patterns in the automotive domain (see Table I, not-underlined parts).

C. An initial set of patterns

After the workshop, the HCI researchers (and pattern experts) received the task to create two patterns each within the following 10 days based on literature, e.g., state of the art knowledge, desktop research of empirical studies, existing structured knowledge (guidelines, norms, heuristics), and/or their own research activities. They received a template with the pattern structure as a guideline for creating a first set of patterns related to a car driver's workload caused by distraction. Furthermore, the HCI researchers were also encouraged to give individual feedback to the pattern experts about issues and problems concerning the generation process, as well as the suggested structure (i.e., CUX pattern structure template). More details about the identified issues and problems are outlined in the next section.

Within this first generation phase, 16 patterns focusing on workload caused by distraction were developed (i.e., two patterns per person). All patterns were derived on the basis of scientific literature (e.g., research articles or book chapters referenced in the pattern). Also, two pattern experts were involved in this process and generated two patterns each. The generated patterns (an example is shown in Figure 1) were each about one page long and exclusively dealt with design solutions (e.g., voice interaction, interface multimodality, gesture input, or information presentations) addressing the problem of increased workload due to distraction. At this point, they were still lacking in detail, especially regarding solutions and examples.

D. First iteration based on participants feedback: and a refined pattern structure

The first round of pattern generation led to the identification of several issues with the initial pattern structure. During creating their patterns, the HCI researchers listed and forwarded encountered problems to the pattern experts. In a second workshop, the HCI researchers discussed their experiences with the provided pattern structure and the pattern creation process (i.e., reflect the different ways to generate patterns) with the pattern experts and collected further problematic issues. The pattern experts then used the feedback for improving the pattern section structure and the related instruction for how to generate patterns based on the provided structure.

The refined pattern structure, as the outcome of the third step, is presented in Table I. Changes to the section name and instruction are marked with an underline; parts not underlined are those from steps 1 and 2. The proposed pattern structure consists of nine parts: *name* (a description of the solution of the pattern), *UX factor* (the addressed automotive user experience factor), *problem statement* (a very short description of the problem that should be solved by the pattern), *forces* (a more detailed explanation of the problem), *context* (the application context of the pattern), *solution* (the proposed solution of the particular pattern), *examples* (concrete examples of best practices), *keywords* (phrases related to the pattern), and *sources* (origin of the pattern).

Most of the issues brought forward were concerned with what makes the pattern a high-quality pattern and what supports the comprehensibility of the pattern. More specifically, the HCI researchers had difficulties with *achieving the aim of a pattern to provide best practices*. The HCI researchers experienced it as challenging to judge whether the provided solutions are the "gold standard". They also felt uneasy about whether "old" literature can serve as basis for pattern creation. Thus, it would be more realistic to speak of providing existing knowledge to the best of one's judgment, i.e., preferably using the newest knowledge for underpinning a specific pattern and using as many potential evidences (studies, norms, etc.) as possible. Our patterns suggest solutions for specific UX demands in the car area based on existing knowledge (e.g., studies, best practices).

TABLE I. INITIAL AND REFINED PATTERN STRUCTURE (ITERATION CHANGES UNDERLINED)

Instructions on Each Pattern Section		
#	***Section Name***	***Instruction on Each Section***
1	Name	*The name of the pattern should shortly describe the solution suggested by the pattern (2-3 words would be best).*
2	UX Factor	*List the UX factor(s) addressed by the pattern (underpinned with a definition)*
3	Problem Statement	*As short as possible - the best would be to describe the problem in one sentence.*
4	Forces	*Should be a detailed description and further explanation of the problem.*
5	Context	*In general, our patterns should focus on the driver. Describe the detailed context in which the pattern can be applied in this section.*
6	Solution	*1) Can range from rather general suggestions to very concrete suggestions for a specific application area (e.g., " Presenting High-Priority Warnings").* *2) A successful solution is based on existing knowledge (e.g., state of the art solutions, empirical studies, guidelines, etc.).* *3) More than one solution is no problem but even better than only one.* *4) There can also be a general solution and more specific "sub-solutions".*
7	Examples	*Concrete examples underpinned by pictures, standard values (e.g., angle, size) etc. Examples should not provide a solution (this is done in the solution part) but rather underpin and visualize the solution presented above.*
8	Keywords	*Describe main topics addressed by the pattern in order to enable structured search.*
9	Sources	*Origin of the pattern (cf. the different ways to generate patterns)*

System-initiative dialog strategy

UX factor:

Workload caused by distraction

Problem:

The problems of driver information systems with a voice user interface, which require user-initiative, are the steep learning curve and the high demand on memory to recall the correct voice commands.

Forces:

In contrast to many telephone applications where the caller can use his full concentration on the task of communicating with the system, the primary task in the car is driving. So, one of the main requirements for driver information system with dialog strategy in the vehicle is to distract as little as possible.
Most of the users come up against the driver information system without previous training. Thus, if the dialog system is not to be disregarded, it is absolutely vital that it can be used intuitively with a gentle learning curve. Even experienced users might have problems with the system when they are using it in situations requiring high levels of concentration for the traffic. (Ackermann & Libossek 2006)

Context:

A system-initiative driver information system with dialog strategy is suitable for users who don't know the functionality and the limitations of the system, and who have no other means of finding out how to use it than to make a lot of mistakes and try to learn from whatever error messages they get. Whereas users who know the system by heart, and know exactly what to say, so they can skip any lengthy explanations, and detours through supermenus, will probably prefer a user-initiative dialog strategy. (Ackermann & Libossek 2006)

Solution:

Provide a driver information system which is built as command-and-control, but the strategy is system-initated, as the speech output of the system consists (mainly) of questions illiciting replies. This is done by presenting the most probable options to the user. (Ackermann & Libossek 2006)

Examples:

One example is the prompt when the user enters the navigation menu. Here he would be presented with three options "enter destination", "city" and "street" as possible input commands: "To enter a destination please say enter destination. If your destination is in Germany say city, if your destination is in Munich, say street." (Ackermann & Libossek 2006)

Key Words:

Driver information system, system-initiative, dialogue strategy, questions, mental workload

Sources:

Ackermann, C. and Libossek, M. 2006. System-versus User-Initiative Dialog Strategy for Driver Information Systems. In: Proc. of Ninth International Conference on Spoken Language Processing, Pittsburgh, PA, USA, September 17-21, 2006, p. 457-460.

Figure 1. Example of an early pattern

Another difficulty is related to *deciding on the abstraction level of a pattern.* The HCI researchers were unsure whether they should create very general patterns (global patterns) versus very specific patterns (sub-patterns, local patterns). They finally agreed on providing patterns that are abstract enough to make generalizations, while providing practical solutions at the same time, i.e., focus on the lower level with potential for higher level expansion. Thus, both elements (i.e., generalization as well as a concrete example) should be provided.

Identifying the stakeholders of the patterns was also an issue. Initially, it was unclear to the HCI researchers whom

they should address with the patterns; whether the future users of the created patterns are designers (expert or novice), domain-specific users (e.g., industrial manufacturers), researchers, or developers.

The HCI researchers also experienced difficulties in *creating a pattern name;* should the pattern name be formulated as a solution or as a problem? It was eventually decided to opt for a solution orientation of the pattern name and modified the pattern instruction accordingly. Moreover, *using technical terms in the pattern name* sometimes lead to comprehensibility problems among the HCI researchers. A pattern needs to be easy to understand and quickly assessed. Consequently, very specific technical terms should not be used in the pattern name and, if they occur in the description of the pattern, they need to be explained.

Furthermore, the first round of pattern generation revealed that the HCI researchers deployed *different ways to generate their patterns*, which are based on existing state of the art knowledge/experience in the field, on own empirical studies, on literature (desktop research of empirical studies), as well as on existing structured knowledge. For ease of use and consistency, the patterns should be as homogenous in style and structure as possible. Different methods of initial pattern mining might, in some cases, cause differences in the final patterns. In order to reflect this, the section on sources (#9) was expanded to also include ways to generate patterns, where appropriate.

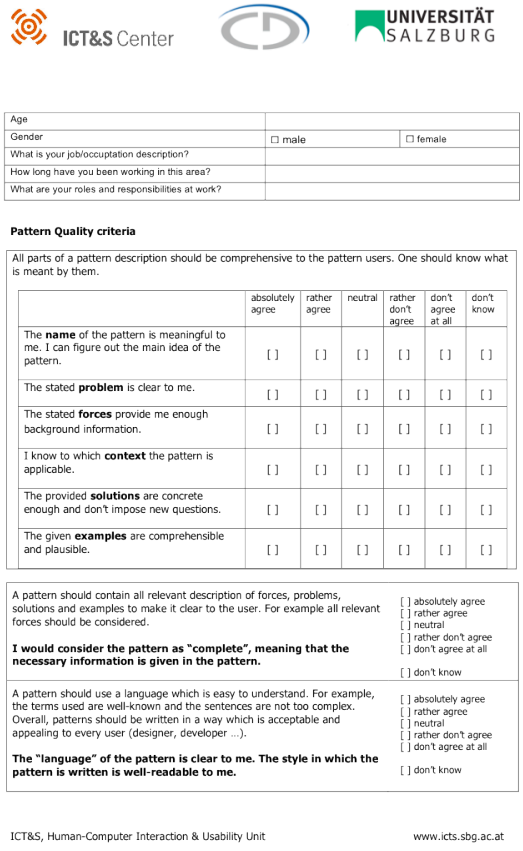
E. *Participants iterate patterns based on refined structure*

Finally, the HCI researchers' task was to iterate their initially created patterns based on the refined pattern structure. Each researcher received the detailed report from the previous workshop along with an action point list containing the necessary components (and level of detail) for the iterated patterns. Then, they converted the existing pattern they originally wrote into the new pattern structure. Parts were reformulated, where necessary, and other parts were added. After this iteration round, all patterns were reviewed by another HCI researcher for completeness and consistency. Where necessary, patterns were returned to the original authors with further instructions for revision. This process continued until the patterns were deemed complete and complying with the iterated structure by the reviewer.

F. *Industry stakeholder workshop on pattern structure evaluation*

Since the iteration and review process after the previous workshop had not involved any industry stakeholders, we felt the need for additional assessment by practitioners and industry stakeholders in order to further iterate and finalize the pattern structure. We involved the industry stakeholders in a workshop with the aim of evaluating the current pattern structure on the basis of two representative patterns.

1) Setup: The workshop was conducted at our facility with five participants (one female and four male) of our industrial partner from the automotive domain. The participants' age ranged from 20 to 45 years, job experience from 7 months to 20 years. Their professional background was software developers, engineers, and designers. After a 10-minute general introduction to patterns and our pattern structure, participants received printouts of one of our automotive UX patterns with the instruction to read through it attentively (duration: 10 minutes). After that, they had to fill in a questionnaire regarding the quality and understandability of the pattern (as seen in Figure 2). The questionnaire's general purpose was to assess how understandable, meaningful, and/or helpful the participants perceived the patterns presented to them. Items were measured on a 5-point Likert Scale; meaning 5 'do not agree at all' and 1 'absolutely agree'.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Age		
Gender	☐ male	☐ female
What is your job/occuptation description?		
How long have you been working in this area?		
What are your roles and responsibilities at work?		

Pattern Quality criteria

All parts of a pattern description should be comprehensive to the pattern users. One should know what is meant by them.

	absolutely agree	rather agree	neutral	rather don't agree	don't agree at all	don't know
The **name** of the pattern is meaningful to me. I can figure out the main idea of the pattern.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
The stated **problem** is clear to me.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
The stated **forces** provide me enough background information.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
I know to which **context** the pattern is applicable.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
The provided **solutions** are concrete enough and don't impose new questions.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
The given **examples** are comprehensible and plausible.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

A pattern should contain all relevant description of forces, problems, solutions and examples to make it clear to the user. For example all relevant forces should be considered. **I would consider the pattern as "complete", meaning that the necessary information is given in the pattern.**	[ ] absolutely agree [ ] rather agree [ ] neutral [ ] rather don't agree [ ] don't agree at all [ ] don't know
A pattern should use a language which is easy to understand. For example, the terms used are well-known and the sentences are not too complex. Overall, patterns should be written in a way which is acceptable and appealing to every user (designer, developer ...). **The "language" of the pattern is clear to me. The style in which the pattern is written is well-readable to me.**	[ ] absolutely agree [ ] rather agree [ ] neutral [ ] rather don't agree [ ] don't agree at all [ ] don't know

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Figure 2. Page 1 of the modified questionnaire (i.e., socio-demographic data, c_1, and two items of c_2)

The first part of the questionnaire collected general information about the workshop participants, such as age, gender, job/occupation description, length of professional experience, and roles and responsibilities at work. The second part focused on the pattern quality criteria framework, which we clustered into four main criteria c_1, c_2, c_3, and c_4. The first quality criterion (c_1) is an overall criterion that states that all parts of a pattern description should make sense to the pattern users. This implies they should have a meaningful name, a clear formulated problem

statement, enough background information for the provided scenario, concrete solutions, and plausible examples. The second quality criterion (c_2) goes into more detail and addresses five aspects: (1) completeness, i.e., necessary information is given in the pattern; (2) clarity of the language, i.e., the style of the pattern is well-readable; (3) problem-centricity, i.e., the scenario, solutions, and examples are coherent and clearly related to the problem description; (4) good balance between concreteness and abstractness; and (5) helpfulness, i.e., the presented patterns support stakeholders to develop better interactive systems. The third criterion (c_3) requested a subjective overall assessment of the patterns regarding their applicability and usefulness. The fourth criterion (c4) applies, as opposed to c_1 to c_3, to the whole pattern collection and not to each individual pattern. It states that the whole collection of patterns captures *relevant knowledge* about User Experience and provides a *suitable common basis* for designers, developers, and researchers. Since the participants did not receive (and would not have had enough time anyway) the whole pattern collection, they were asked to imagine a collection of patterns qualitatively similar to the ones they were presented with and then provide their ratings.

Participants then received another pattern printout and were again given 10 minutes to read it thoroughly. This was done to ensure that the participants had a means of comparison and also to reduce bias regarding the quality (or the lack thereof) of the pattern structure based on only one pattern. After these preparations a discussion session (total duration: 1.5 hours), began. This moderated discussion was audio recorded and later transcribed for further analysis. During the course of the discussion, participants could voice concerns they had encountered when reading the individual patterns, together with suggestions for improvements to the pattern structure, as well as the existing automotive UX patterns in particular.

2) *Results:* We will now outline the most important outcomes of the workshop, in reference to the iterated structure shown in Table I.

The results of the quality criterion (c_1), rated on a scale from 1 (absolutely agree) to 5 (do not agree at all), show that the patterns had clear problem statements (M=4.00, SD=0.45) and provided concrete solutions (M=3.60, SD=0.55). Lowest mean values were identified in the quality criteria c_1 until c_4: i.e., for meaningfulness of the pattern name (c_1:M=2.8, SD=0.45), clarity of the context (c1: M=3.00, SD=0.00); clarity of the language used in the patterns (c_2: M=2.80, SD=0.45), and suitability of the pattern as a communication tool (c_4: M=2.80, SD=1.10).

As our data revealed from the discussion, participants were confused by the separation of *problem* and *forces*, stating that they did not understand why those were two separate categories and that they found the term 'forces' itself difficult to understand. Additionally, the participants were not entirely sure about the context and its relation to the rest of the pattern either. Especially in one pattern, they identified a rather confusing overall structure, in which the context referred to the forces, but the solution to the problem, which also tied into their confusion regarding forces.

One of the biggest complaints was that participants found that they had to read quite far into the patterns before they knew what the patterns were exactly about. The most prevalent criticism was the explanation of the UX-Factor (i.e., a definition), which was deemed as unnecessarily long and should have appeared at a later stage. According to the participants, such (for them) auxiliary information should not be excluded from the pattern, but appear at a less prominent position and in far less detail (one or two lines, the rest as a reference).

Generally, the participants desired an "abstract" for each pattern, containing scope, context, and possibly an outlook on the solution in a very compact format. To achieve this with the current pattern structure, the participants suggested more descriptive pattern names (e.g., in the case of pattern 1: mentioning the concrete modalities as well as ADAS in the pattern name itself) as well as an expanded and weighted keyword system, with anti-keywords (i.e., keywords the pattern is *not* related to) and reference-keywords (i.e., main keywords of related patterns). The patterns should also be re-structured, so that the most important information (at the very least: *name*, *keywords*, and *problem*) is at the very beginning of the pattern. Or, as one participant put it, "*If using a pattern collection is more cumbersome than using Google and produces lesser results, then there is little reason to use that pattern collection.*"

Another interesting point that was raised during the discussion concerned examples and their visualizations: The participants considered images of actual devices as unsuitable and thought them to resemble an advertisement more than a mere illustration ("Use this device and all your problems will be solved!"). It is important to capture the essence of a pattern without too much distracting details. For pattern 2, that essence was not considered to be the actual steering wheel, but the viewing angle. An illustration of said viewing angle (side view of the driver with lines indicating viewing angle) might therefore have been appropriate in this case. The participants did not reach a consensus on whether depicting an actual implementation could be acceptable in some cases, but they expressed a general preference for graphs, schematic illustrations, and similar visualizations.

The writing style and vocabulary used in both patterns was perceived as very unusual by the participants and more "scientific" than what they were used to. More specifically, they were not used to citing sources for every claim and the rather high number of technical terms used in each pattern. While they found the scientific writing style to be an overall pleasing quality that should be kept, they suggested a minimal citation style (numbers only, full references only at the very end of the pattern collection). The issues identified in the workshop were then further discussed and transformed into concrete instructions for another pattern structure overhaul.

Assuming that patterns evolve and grow more numerous over time, the participants also considered it necessary to know, when patterns become obsolete or what to do if there were several patterns giving conflicting solutions for the same problem. According to the participants, each pattern should have a time stamp, which shows when the pattern was created. Since that information alone is not enough to know, whether a pattern has actually been superseded by another or is simply a very old pattern, an additional label for obsolete patterns should be contained somewhere in the pattern. To help users decide on which pattern might be more appropriate for their problem, a rating system for each pattern could be implemented. However, the participants were skeptical of employing a simple rating system (e.g., 1 to 5 stars), since the meaning of a certain rating would be left ambiguous (Is the pattern simply well-written? Does the solution work well?). Full comments might be more useful, but supplementing ratings with user comments users could also require administration and editing of said comments – resources that might not be available in many cases.

3) *Summary:* It can be summarized that the pattern workshop showed some very interesting discrepancies between the general intentions of the CUX pattern structure and practitioners' needs and preferences. The participants expressed a need for more brevity, which would be more fitting for traditional guidelines, while at the same time desiring an example- and solution-oriented pattern structure and approach. The patterns generated a rather positive resonance overall and were generally seen as a valuable supplement to existing work practices. We were able to collect a good number of valuable suggestions for improvement as mentioned before, which would help to increase the quality of the existing pattern set and any future patterns generated within the project.

G. Final pattern structure iteration

Based on the feedback gained from this workshop, the pattern structure underwent a final iteration, which would then become the basis for all further patterns (see Table II). Similar to the pattern structure shown in Table I, the final pattern structure consists of nine elements. Like before, the *name* of the pattern should focus on the provided solution. The *intent* should include the main category of the pattern, a short problem statement, and briefly outline the context in which the pattern should be used. It replaces the problem statement (3) and the context (6) of the initial structure presented in Table I. The new element *topics* is a structured list of keywords describing the problem scope. The element *problem* replaced the forces (4) section. The new element *scenario* gives a detailed description of the problem in a scenario like style. The *solution* section describes the solution to the problem. Within the final structure, we provide a structured approach for how to present the solution. *Examples*, as before, should show best practices of the pattern. *Keywords*, again, should aid with finding related patterns. Finally, *sources* link to the origin of the pattern. The element "UX factor" (2) from the initial pattern structure was omitted at all. The new structure focuses on informing the reader as concisely as possible about whether the pattern is relevant for them. *Name*, *intent*, and *topics* are standardized and kept brief so that only a minimal amount of time is needed to read and process them. *Context* and *forces* are combined into the new Scenario-category, since the stakeholders had a hard time differentiating between them and found the distinction to be inconsequential in practice.

TABLE II. FINAL PATTERN STRUCTURE

Instructions on Each Pattern Section		
#	***Section Name***	***Instruction on Each Section***
1	Name	*The name of the pattern should shortly describe the solution suggested by the pattern (2-3 words would be best).*
2	Intent	*Short statement in three parts:* *a) Main category of pattern (e.g., visual information presentation)* *b) Short issue/problem statement (e.g., effective display position)* *c) Short context preview (e.g., while driving)*
3	Topics	*Max. 8 Keywords describing problem scope: 1) who is affected (driver, co-driver, etc); 2) which modalities are addressed (visual, haptic, acoustic)*
4	Problem	*Should be a detailed description and further explanation of the problem.*
5	Scenario	*Provide a detailed example of a case, in which the problem occurs*
6	Solution	• *First, provide a general (either high level or one that is applicable in the most cases) solution.* • *Then provide alternative solutions, together with delineating criteria to determine, when such alternative solutions apply.* • *Whenever possible, reuse (modified) figures, illustrations, etc. from other patterns, for a more consistent style and easier combination of pattern solutions.* • *A successful solution is based on existing knowledge (e.g., state of the art solutions, empirical studies, guidelines, etc).* • *More than one solution is no problem but even better than only one.*
7	*Examples*	*Concrete examples underpinned by pictures, standard values (e.g., angle, size) etc. Examples should not provide a solution (this is done in the solution part) but rather underpin and visualize the solution presented above.*
8	Keywords	*Describe main topics addressed by the pattern and related patterns in order to enable structured search.*
9	Sources	*Origin of the pattern, related literature, related patterns (if they are not part of the same pattern collection), norms and guidelines, other references. Citations format: Numbers and endnotes, to distract the reader as little as possible.*

Pattern 7: Intuitively used voice user interface

Intent:

This pattern is about a system-initiated, question-based approach to reduce distraction by voice user interfaces of driver information systems while driving.

Topics:

Workload caused by distraction, driver, acoustic, input/output

Problem:

The problems of driver information systems with a voice user interface, which require user-initiative, are the steep learning curve and the high demand on memory to recall the correct voice commands. This can lead to elevated mental workload while driving.

Scenario:

A system-initiative driver information system with dialog strategy is suitable for users who don't know the functionality and the limitations of the system, and who have no other means of finding out how to use it than to make a lot of mistakes and try to learn from whatever error messages they get. Whereas users who know the system by heart, and know exactly what to say, so they can skip any lengthy explanations, and detours through supermenus, will probably prefer a user-initiative dialog strategy (Ackermann & Libossek [16]).

In contrast to many telephone applications where the caller can use his full concentration on the task of communicating with the system, the primary task in the car is driving. So, one of the main requirements for driver information system with dialog strategy in the vehicle is to distract as little as possible.

Solution:

Most of the users come up against the driver information system without previous training. Thus, if the dialog system is not to be disregarded, it is absolutely vital that it can be used intuitively with a gentle learning curve. Even experienced users might have problems with the system when they are using it in situations requiring high levels of concentration for the traffic.

The solution is to provide a driver information system which is built as command-and-control, but the strategy is system-initiated, as the speech output of the system consists (mainly) of questions illiciting replies. [16]

This is done by presenting the options (e.g., FM menu, AM menu, CD menu in the example dialogue, see Figure below) to the user (Hassel and Hagen [17]).

Examples:

One example is the prompt when the user enters the navigation menu. Here he would be presented with three options "enter destination", "city" and "street" as possible input commands: "To enter a destination please say enter destination. If your destination is in Germany say city, if your destination is in Munich, say street." [16]

Another example is given by Hassel and Hagen [17]. Their speech interfaces were implemented as part of BMW's iDrive system. Over the speech channel, users can operate functions in the areas entertainment, communication and navigation. Users activate the speech recognizer with a push-to-talk (PTT) button on the steering wheel or in the middle console near the controller. The dialogue style is command and control

Img. 2: Display Control

Img. 1: Controller and PTT Button

Figure 3. Example of an iterated pattern, page 1 of 2

Examples (continued):

Novice	Expert
user: <presses PTT button>	user: <presses PTT button>
system: Speech input <beep>	system: <beep>
user: Entertainment.	(user: Entertainment.)
system: Entertainment. Say 'FM menu', 'AM menu', or 'CD menu'.	(system: Entertainment.)
user: FM menu.	(user: FM menu.)
system: FM menu. Say 'choose frequency', 'choose station', ...	(system: FM.)
user: Choose frequency.	user: Choose frequency.
system: Which frequency do you want?	system: Enter frequency.
user: 96.3	user: 96.3
system: You are hearing 96.3 MHz.	system: <music is heard>

Samples of system initiated dialogues (see Novice column) and user initiated dialogues (see Expert column). (from Hassel [17])

Reference Key Words:

User initiative driver information system, system-initiative, dialogue strategy,

Sources:

[16] Ackermann, C. and Libossek, M. 2006. System-versus User-Initiative Dialog Strategy for Driver Information Systems. In: Proc. of Ninth International Conference on Spoken Language Processing, Pittsburgh, PA, USA, September 17-21, 2006, p. 457-460.
[17] Hassel, L., & Hagen, E. (2005). Evaluation of a dialogue system in an automotive environment. In 6th SIGdial Workshop on Discourse and Dialogue.

Figure 4. Example of an iterated pattern, page 2 of 2

H. Final pattern iteration

The entire set of 16 patterns was then revised, based on the above-mentioned structure (see Table II for the revised structure and Figures 3 and 4 for a pattern example). Some example details were removed and/or reduced in order to reduce the overall image size and not bloat the paper unnecessarily.

The iteration procedure was the same as the one described in Section E and was overseen by a team of two HCI researchers. Based on the results from the workshop, *Scenario*, *Solution* and *Examples* were focused on in particular and were adapted according to the stakeholders' requirements. If possible, solutions were also represented graphically or illustrations from cited publications were added. Concrete examples (state of the art) from recent production vehicles illustrated, if appropriate, the examples section. In general, care was taken to present the information in every pattern in a compact form, easily comprehensible and practicable. They were kept as short as possible to conform with the stakeholders' requirements.

I. Validating the patterns

For the final validation of the iterated pattern set, we conducted a second workshop at our facility with seven participants (4 employees from our industrial partner and 3 researchers; 6 male and 1 female). Age ranged from 21 to 48 years, job experience from one month to eight years. Regarding their professional background, they were software developers, engineers, designers, and HCI experts. Some of the participants from the first workshop also participated in the second one. To have a good mix of informed and fresh views, we involved two stakeholders who had already participated in the previous workshop, and two who were completely new to the topic. The overall goal of the second workshop was to assess the quality of the first UX pattern set, as well as to iterate the pattern set based on the industry stakeholders' feedback. Since the initial 16 patterns are only one part of a larger planned pattern collection, we also wanted to collect input on problems for the remaining two planned CUX-Factors (i.e., *Perceived Safety* and *Joy of Use*) to facilitate the generation of these pattern sets and ensure that the problems that will be tackled in the future are actual problems relevant to the industry.

In this workshop, the full iterated pattern set was presented to the participants and evaluated on a peer judgement basis. After a 10-minute general introduction to patterns and explanations of the iterated UX pattern structure from the first workshop, a researcher explained the purpose and the agenda of the one-day workshop to the participants. After that, the rating categories (c_1 to c_4) were shown and

explained to the participants. They were informed that they would later have to rate each pattern according to these criteria.

Then, each participant received one pattern to read through thoroughly. Each of the 16 existing patterns was rated by each participant individually. To avoid serial positions effects and similar forms of bias, the patterns were presented to participants in different orders. Based on the various length of the pattern, we classified the patterns into short and long ones, which led to two separate rating sessions.

In the first pattern rating session, each participant was given a set of 6 patterns (printouts). They were then asked to read and rate them sequentially. Additionally, they were also asked to note any issues they find particularly note-worthy. Furthermore, they were briefed to keep all printouts for the discussion session in the end.

In the second pattern rating session, the participants were asked to read and rate the additional 10 patterns with the same instructions as mentioned before. The rating was done via the previously employed questionnaire (see Figure 2), in which the participants had to rate each pattern with regards to four quality criteria (c_1, c_2, c_3, c_4). The only change to the rating system was a slight modification to c_4: This criterion was intended to measure the overall quality of the pattern collection. We initially included this as a questionnaire item since we only had two patterns during the first workshop.

Thus, a rating of a potential pattern collection was sensible and could even have further highlighted quality differences in the patterns themselves (if differences in rating had been observed), but a discussion would not have been very useful since a representative pattern collection simply had not existed at that point. Since the participants now had a larger number of patterns to look at, it made more sense to exclude c_4 from the questionnaire and, instead, discuss it in plenum at the end of the workshop for a qualitative, *overall assessment* of the pattern set quality and applicability. This helped decrease workload and fatigue for the participants while still providing the necessary results (Ratings for c1 to c3 gave a good numerical indicator of the pattern quality, whereas c4 would be better suited as qualitative consensus with consolidation of further potentials for refinement).

After the rating of the patterns had concluded, the moderated discussion session took place, which was divided into two parts. The first part was the aforementioned discussion of c_4. During this first session, participants could voice all concerns they had encountered when reading the 16 existing patterns, together with suggestions for future improvements to the existing UX patterns. In order to trigger the discussion, two questions of criterion (c_4) from the quality framework were asked to the participants; these were: "Do you think that the presented patterns support the communication of designers, developers and researches by providing common basis?" Do you think the presented patterns capture relevant knowledge about user experience?" In a second discussion session, a researcher explained CUX-Factors 2 and 3 (*Perceived Safety* and *Joy of Use*) to the participants. The session was conducted as a brainstorming, in which the participants were asked to come up with any

Figure 5. One participant is filling out the questionnaire during the rating process

problems they had encountered (regularly or semi-regularly) and which they would desire solutions for. During the brainstorming, the problems were collected and compiled in a preformatted list, which would then be used to rate the problems with regard to importance and relevance. Each participant received a printout of the list and was then asked to rate each problem with regard to relevance on a scale of *very relevant – relevant – not very relevant*.

The two discussion sessions were audio-recorded and later on transcribed for further analysis. Due to the low number of participants, the questionnaire results were analyzed in descriptive form.

The results of the first quality criterion (c_1), rated on a scale from 1 (absolutely agree) to 5 (do not agree at all), show that the pattern set had a meaningful name (M=1.86, SD=1.08), a clear stated problem (M=1.48, SD=0.80), and enough background information of the stated scenario (M=2.03, SD=1.02). The two last categories of c_1, i.e., the solution (M=2.69, SD= 1.15) and the examples (M=2.60, SD=1.16), were rated as neutral.

The questionnaire responses of the second quality criterion (c_2) indicated a very positive overall picture with mean values all in a positive spectrum (lowest was 1.55) and the most negative responses being neutral ones (2.78). The responses were also rated on a scale from 1 (absolutely agree) to 5 (do not agree at all). Lowest mean values were identified clarity of the language used in the pattern (M= 1.55, SD=0.73) and the problem-centricity (M=2.16, SD=0.88).

Regarding the third criterion (c_3), the participants perceived only one pattern as implausible. Regarding c_4, the overall consensus was that the presented patterns support the communication of designers, developers and researchers, provide a common basis, and capture relevant knowledge about user experience.

The participants generally preferred to have various approaches to a solution that are underpinned with concrete examples to make a pattern more useful. Interestingly, however, they also made the suggestion to not only integrate

state of the art solutions but also examples with "exotic" or creative designs. Unfortunately, we did not have enough time during the discussion to dive deeper into the motivations behind and feasibility of such pattern solutions, but the fact that this was explicitly desired by the participants, who were all industry practitioners, was very interesting nonetheless and worth mentioning.

The participants also missed a guidance that would help software developers, engineers, or designers work with the provided knowledge of a pattern – a sort of guideline to use patterns at the beginning of the pattern collection. As paradoxical as it might sound, this appears to be an interesting side effect of the decision to keep the patterns as short and to the point as possible (which happened based on feedback by the practitioners themselves). Since the participants often had different priorities and did not always encounter the same problems in their work, they also wanted to have the opportunity to rank the patterns. This means that the participants suggested providing a ranking system, which would allow them to rank each pattern regarding its importance for future reference

One recurring problem, which had sporadically been voiced during the previous workshop as well, was the (lack of) relevance of the problem statements in the discussion. The participants felt that the problems stated in some patterns were only partly relevant for them and while they appreciated the solutions, they would often have desired to be involved when identifying the problem statements beforehand. Our decision to identify potential problems together with the workshop participants during the validation workshop was, therefore, perceived as a very welcome change. This led us to modify our overall pattern generation approach to involve the industry stakeholders already during the very first step in the pattern generation process. This might seem obvious in hindsight, but we consider it a nonetheless interesting result of our focus on literature before practice in the initial pattern finding process.

The list of design problems that patterns are then generated for should, together with a rating regarding relevance and importance, come from the industry stakeholders themselves. Ideally, this should happen with guidance and assistance from researchers. Contextual inquiries or brainstorming with subsequent problem rating sessions with the industry stakeholders are both suitable methods to achieve this.

As for the pattern collection itself and the UX factors, *Perceived Safety* and *Joy of Use,* the following problems/topics were estimated as very relevant and suitable bases for future patterns:

Perceived Safety

- When should the information be presented to the driver?
- Where should the information be presented to the driver?
- What information should appear in the cockpit?
- How should the system status be displayed?
- When should warnings be displayed?
- What kind of modalities should be used to give warnings?

Joy of Use

- How much feedback does a button need?
- How long can you press a button until a reaction occurs?
- How useful is a double-assigned button?
- How long should a short or long button press be?
- How big should a touch display be?
- How many menus are useful?
- What kind of depth should a menu have?
- How can we use or design the front-seat passenger's place for work tasks?

Overall, the pattern validation workshop showed that the existing pattern set supports the communication between designers, developers and researchers by providing a common basis. The existing pattern set 1 generated a positive overall resonance and was generally seen as a valuable supplement to existing work practices.

The feedback from the two discussion sessions was particularly fruitful and will help us to increase the quality of existing patterns on *Mental Workload Caused by Distraction* and any future pattern sets (regarding the other UX factors *Perceived Safety* and *Joy of Use*) generated within the project. Strong focus will have to be put on two aspects: Does it make sense to rank the patterns? If so, who shall rank them and how can this issue be implemented in database and paper based solutions?

IV. DISCUSSION

In this paper, we have described a seven-step approach to generate (automotive) UX patterns. It started with a scientific knowledge transfer workshop (step 1), which led to an initial set of patterns (step 2). A first iteration based on participants' feedback and the identification of problems in the generation process resulted in a refined pattern structure (step 3). An iteration of the patterns led to a refined pattern structure (step 4), with which we conducted a pattern structure evaluation workshop with industry stakeholders (step 5). Another pattern structure iteration (step 6) led to a final pattern iteration (step 7).

The industry practitioners were involved in most parts of these steps, but as mentioned earlier, it might have been beneficial to include the industry stakeholders before the first generation phase of the patterns. We came to understand that not all of the patterns that were initially developed were actually urgent problems for the practitioners from industry. By involving the industry practitioners in subsequent steps in the pattern generation process, we were able to better understand the practitioners' perspectives and the respective evaluation of identified problems derived from research. This different angle of how problems are perceived, allowed us to translate scientifically proven results into proven solutions for industry stakeholders.

The valuable cooperation between research and industry brought up implications for how to improve the pattern generation process according to the respective stakeholders' needs. From the industry perspective, they would have

appreciated an approach by which they could identify problems of high priority right from the beginning (i.e., before the first generation phase of the patterns) of the development process to better identify problems to be dealt with in subsequent steps. From the researchers perspective, we focused on the pattern generation process and the pattern structure and less on the decision for and criticality of particular problems, to be selected for subsequent steps. We decided right at the beginning to develop patterns just for one specific UX factor in order to improve the process and the structure of the patterns. For us this was a logical step, as we wanted to go from science to practice. However, throughout this entire cooperation we came to understand that it is very critical to decide *when* to actually involve your industry partners also as active decision makers, to maybe also allow for bidirectional exchange of knowledge already in very early stages.

Nonetheless, the insights we gained have resulted in a pattern structure suitable for industry stakeholders' needs in the automotive domain. The structure focuses on clarity and brevity and should, with slight modifications, be adaptable for other industry domains as well. Furthermore, we have documented our pattern generation process, together with both scientists and industry stakeholders. A high level overview of the process can be seen in Figure 6. We broke down our seven steps into five main phases: The first phase is industry focused, in which industry problems are identified, and where patterns might be a beneficial way of helping to solve these problems. In phase 2, we suggest generating an initial set of patterns. Phase 3 includes evaluation and iteration through a scientific lens. Phase 4 includes evaluation and iteration with a focus from industry. In phase 5, the patterns are validated.

Apart from the patterns generation process, this paper presents a structure for automotive user experience patterns. It consists of nine elements (*name, intent, topics, problem*, *scenario, solution, examples, keywords*, and *sources)*, which

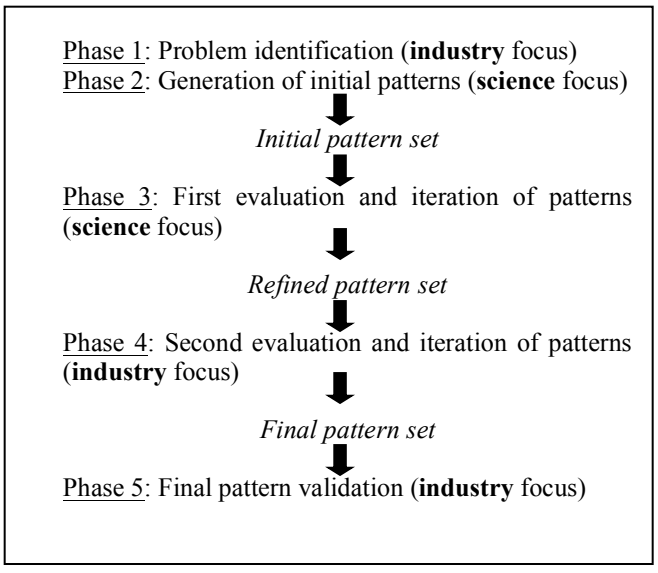

Figure 6. The five phases of the pattern generation process

proved to be a useful way to structure UX patterns in the automotive domain.

The focus on brevity and quick solutions that resulted from iterations based on the industry stakeholders' needs presents an interesting perspective on the differentiation between guidelines vs. patterns.

In contrast to well-known strategies of how to capture patterns, i.e., where a pattern emerges from at least three uses of the same solution for a given problem (Gamma et. al), this paper presented a new and different approach to generate patterns. On the one hand, our approach draws from the large amount of already existing research knowledge (i.e., scientific literature) within specific domains (e.g., automotive), thereby complementing traditional observation-based approaches with scientifically proven results and knowledge. On the other hand, our approach furthermore allowed us to go beyond traditional observational strategies and research knowledge towards the involvement of practitioners' expert knowledge in the development process of the patterns as being part of truly *inclusive* cooperation.

V. Conclusion, Limitations and Future Work

The approach described in this paper is a departure from the common practice of documenting already working solutions, to a way to convert (proven) scientific results to working problem solutions. It is an extension of our efforts to apply the pattern approach to a wide variety of disciplines and areas [17], fostering knowledge preservation and exchange both within and among said disciplines and areas. The approach described in this paper focused on fusing scientific and industry expertise, more specifically scientific UX and industrial driver space design know-how. Branching out into other disciplines, even ones entirely unrelated to HCI, is planned in the future. Areas currently under consideration are knowledge transfer for study setups in Biological Neuroscience to reduce beginner's mistakes, as well as argument analysis patterns for Analytic Philosophy. These further expansions of the patterns scope are still situated well in the future, however, they are dependent on the success of – and iterations based on – the current, intermediary approach.

The evaluation of the approach described in this paper was based mainly on feedback of practitioners from the HCI car domain. We did not compare the quality of our patterns' problem solutions to those of other HCI patterns in our research. While the positive assessment of the overall process and its results (the patterns) provides a positive outlook, further evaluations (and possible iterations) are certainly needed to fully validate it as a reusable standard procedure in the community.

Overall, the pattern generation process and structure we gained will be used for generating additional UX patterns for the automotive domain. More specifically, we intend to also cover the factors *perceived safety* and *joy of use* and generate patterns for these. We have already begun the generation

process by identifying common design problems related to these factors in a workshop together with the industry stakeholders. In the future, we intend to implement the full pattern collection as an online database based on the pattern framework proposed in [17]. We will continue using our inclusive pattern generation process to translate scientifically proven results into proven solutions for industry stakeholders and encourage others to employ and further refine our proposed method.

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Contribution to the Knowledge of Plant Diversity in the Malopolska Region

Focus on Invasive Plants in Kraków and Vicinity

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Abstract— **The objective of this paper was to identify plant species around the water bodies and examine the possible impact of alien plants. Sixteen locations were examined referring to the vegetation and alien species in particular. The locations were the areas surrounding anthropogenic water bodies in Krakow and vicinity. Most of them were borrow pits left to the process of natural succession. Only one water body was of natural origin. In all the locations alien species were found. In total, alien species made 20.9% of all species found in these locations, which is slightly less than overall percentage in Poland (27.4%). There were 30 neophyte species found in total, six of them invasive transformers. One species – the bur marigold (*Bidens frondosa*) – was found in nine locations. Three species were found in eight locations: the Canada golden-rod (*Solidago canadensis*,), Canadian horseweed (*Conyza canadensis*) and annual fleabane (*Erigeron annuus*). Most neophytes (16 species), including the four mentioned above were of North American origin. 18 archaeophytes were found. Four species had uncertain status. Most alien species were covering less than 5% of surveyed vegetation plots. Only the cockspur (*Echinochloa crus-galli*) covered more than 50% and the sweet flag (*Acorus calamus*) covered more than 25% (in both cases in one location). In urban areas, alien species are common, usually without making much problem (exceptions are allergy-causing plants), however; in rural semi-natural areas the monitoring is recommended.**

Keywords – vegetation; alien species; water bodies; suburban areas.

I. INTRODUCTION

The paper is based on the authors' work [1] on plant species around the selected water bodies in the Krakow city and the surrounding area. Compared to [1] three more locations were added, including one natural water body. In [1] only artificial water bodies were examined. The present paper provides the list of all the plant taxa found in the studied locations, including the native ones, which was not possible in the previous work.

Water bodies (natural and artificial) attract many plant and animal species, both native and alien. The region of Krakow is not very rich is natural lakes, but human-made water bodies are abundant there [2]. They have various origin, including: borrow pits of various size, made after the exploitation of limestone, gravel, sand or clay, fishing ponds, former decantation ponds, etc. Natural water bodies in the area can be an effect of the karst phenomena or the formation of oxbow lakes [3]. Not knowing the history of a specific water body it is sometimes difficult to say about its origin, because in the process of natural ecological succession and sometimes due to human-made reclamation measures, human-made ponds get covered with vegetation and become inhabited by animal species [4]. Finally, they form semi-natural environment and can contribute to biodiversity of the region. The objective of the study is to examine the vegetation of selected water bodies focusing on the presence of non-native species and the attempt to assess their possible influence on the environment in the area, looking at their abundance and frequency of the occurrence.

Non-native species can be divided into two groups: archaeophytes and neophytes. Archaeophytes are plants which arrived in the area in pre-historic or early historic times and neophytes were introduced in modern times and the usual border date is accepted as ca. 1500 – the beginning of the era of great geographical discoveries [5]. Most archaeophytes in Europe arrived with the agriculture, as weeds growing in the fields and nowadays they make an integral part of the flora, although can also be invasive. Neophytes, however, are usually regarded more dangerous to biodiversity.

Cross-breeds between native and non-native plants are regarded non-native and crossbreeds having a neophyte as one of the parental species are regarded neophytes [5].

Apart from the origin, the degree of naturalization in the environment is important; Pyšek et al. [5] distinguished casual species - alien species that do not form self-sustaining populations and naturalized species (synonym: established species) that form self-sustaining populations for several life cycles. Invasive species make a subset of naturalized species forming self-replacing populations, having the potential to spread over long distances. Tokarska-Guzik et al. [6], after Richardson et al. [7] also differentiated the category of transformers (a subset of invasive plants) for the species which change the character of ecosystems.

In Section II and Figure 1, respectively, the list and map of locations are given. In the same section a short description of every place and methods of studies are provided. In Section III and Tables I-III the results are presented. Section IV provides the conclusions and recommendations for further studies.

II. STUDY AREA AND METHODS

The study on the vegetation taken in the areas of the water bodies in Krakow and vicinity was carried out in summer 2009 (in the case of Bagry and Zakrzówek also 2008). The studied areas are named below. More detail descriptions of the water bodies can be found in [4] [8] [9] [10] [11]. The geographic distribution of the sites is presented in Figure 1. The given below area of the water bodies was calculated by the program Quantum GIS, based on the airborne images of the Central Cartographic and Surveying Resource. The area included:

1. Two borrow pits situated south-east from the centre of Kraków in the area called Płaszów. The area of the bigger pond, called Bagry is 30.1 ha and the smaller one – called Staw Płaszowski (the Płaszów Pond) is 9.0ha. Formed after the exploitation of sand and gravel in 1930s [11]. In Table I, they are marked as BG and SP, respectively.
2. Staw Dąbski (the Dąbie Pond, marked as D), 2.1 ha – situated in Kraków, east from the centre, formed in 1930s after the exploitation of clay - by the Resolution no. XC/1202/10 of the City Council of Krakow the pond was established "Ecologically Useful Area" [12].
3. Zakrzówek (marked ZK) - a borrow pit south-west from the centre of Kraków of 17.0 ha surface, made in 1990s after quarrying limestone [2].
4. The Pond of the Kaczeńcowa Street (KA) – by the Resolution no. XXXI/405/07 of the City Council of Krakow established Ecologically Useful Area – the area is 0.82 ha [13]. The pond is situated in the quarter of Nowa Huta in Krakow. The pond was formed as a result of clay exploitation.
5. Former decantation pond of the Steelworks in Nowa Huta in the region called Kujawy (marked KU), the area of 2.9 ha.
6. Przylasek Rusiecki (PR) – a group of 10-11 gravel borrow pits (the number is changeable, because some water bodies can temporarily be joint or separated), of the total area of 82.19 ha, situated in the eastern part of Kraków, quarter Nowa Huta.
7. Borrow pits in Wola Batorska (WB) – the gravel quarrying is still going on, so the area has been changing. In 2005 it was 13.8 ha.
8. Two borrow pits (exploitation of gravel) of Zabierzów Bocheński (ZB), commune of Niepołomice area of 13.03 ha and 3.43 ha, respectively.
9. The oxbow lake (of the Drwinka River) in Ulesie (UL) – the only natural water body [4] investigated in this paper – 1.0 ha.
10. The fish pond in Zakrzowiec (ZC) - area 1.94 ha - used for commercial angling.
11. Three ponds in the town of Niepołomice – Zamkowa Street (near the castle – 0.1 ha), Mokra street (0.1 ha) and Akacjowa street (0.2 ha). Marked as ZM, MK, and A, respectively.
12. The pond on the border between the localities of Niepołomice, Podłęże and Staniątki (c.a. 0.6 ha), marked as S.
13. Two borrow pits in the Commune of Liszki called Zalew na Piaskach and Budzyń, formerly known as 'Kryspinów' area 24.5 ha and 20.3 ha, respectively. Marked as ZP.

In each location, plots of the area of 10 m^2 were randomly chosen and the plants growing there were identified to the species or – if not possible – to the genus. The plants were listed and identified as native, archaeophytes or neophytes, invasive or not invasive, harmful or not harmful. In the latter case "not harmful" means that harmful effects have not been known. However, the expression "not harmful" may be a simplification, because it cannot be excluded that such effects will be found in the future. To identify the species and define their status literature data from Poland [6] [14] [15] and other countries of Central Europe [5] [16] [17] [18] were used. In most locations the Brown-Blanquet method was applied. The plant cover abundance was given according to the scale:

5 - 75-100%,
4 - 50-75%,
3 - 25-50%,
2 - 5-25%,
1 - <5%, numerous individuals,
+ - <5%, few individuals,
r – solitary, with small cover.

Some more characteristic species were also noted even if found outside the plot. In case of smaller ponds, where it was difficult to mark the plots, only the list of species was given.

III. RESULTS AND DISCUSSION

The results are given in Tables I-III. There were 30 neophyte species found (Table I), which makes 12.0% of all the taxa found. Eighteen archaeophytes (Table II) constituted 7.2% of all the species and four species of uncertain status made 1.6% (Table II). In total alien species constituted 20.9%, which is slightly less than the percentage of alien species in the whole Polish territory, which is 27.4% - 939 out of 2537 species [15]. According to the same study, neophytes (together with casual plants) made 22% of the total number of species. Archeophytes and species of uncertain status constituted 4.5% and 0.05%, respectively, which is less than in the areas studied in this paper. This fact can be explained by the character of sites chosen for this paper, which are rural or semi-rural areas, where species connected with agriculture would be common. Such species are often archaeophytes.

In the studied area there were six species regarded invasive transformers. The most common of them was the bur marigold *Bidens frondosa* found in 9 locations. Three species: the Canada golden-rod *Solidago canadensis*, Canadian horseweed *Conyza canadensis* and annual fleabane *Erigeron annuus* were found in 8 locations. All of them are invasive species. The most dangerous are invasive transformers, able to change the character, condition, form

or nature of ecosystems over substantial areas relative to the extent of that ecosystem [7]. Such species include *Bidens frondosa* and *Solidago canadensis*. Nevertheless, in the study area these species never exceeded 5% of the area. *Conyza canadensis* is regarded invasive weed. *Erigeron annuus* is invasive, but its negative impact on environment is not known.

There were 10 casual species found in the study area, eight of them occurring only in one place and the Mokra street was the most abundant in casual species (4). This was a residential area and some 'exotic' trees (e.g., *Liriodendron tulipifera* and *Catalpa bignonioides*) were planted there. Three casual species were found near the pond at the Zamkowa street, one of them was *Phellodendron amurense* (6 trees planted near the pond), which is rarely grown in Poland. Nevertheless, casual species were also found in less human influenced place, such as Zakrzówek.

The sweet flag *Acorus calamus* is quite common in Poland, although in this study it was found only in one location - Ulesie – the only natural pond studied here. Unlike most alien plants in the study, it was covering a relatively large area of the surveyed plot: between 25 and 50%.

Archaeophytes were represented by 18 species. Four species had uncertain status: one can be archaeophyte or neophyte, depending on subspecies, which was not determined and the origin of three species is still debatable. The most widespread archaeophyte species were *Melilotus albus* and *Setaria pumila*, occurring in 4 locations.

The number of alien species in each location ranged from 1 in Ulesie to 12 in the Zamkowa Street in Niepołomice. Nevertheless, in the Zamkowa and Mokra Street (9 alien species) planted trees distort the real picture. Considering this, the highest number of non-native species would be in Zakrzowiec (9). In that place two locations were examined – one near the pond and the other in the place of the dry pond. In the dried pond an archaeophyte - *Echinochloa crus-galli* was predominant – the plant cover abundance reached 4 in the Braun-Blanquet scale, which makes the highest cover by a non-native species in the whole study. The detail characteristic of the studied sites looks as follows.

A. *Bagry*

The studies in Bagry were carried out on 2/07/2008 by Samalzhan Tleubayeva and Aleksandra Wagner in two locations: (1) – north-western shore of the water body and (2) – northern shore of the water body. Every location included coastal plants like *Juncus effusus*, *Phragmites australis* and *Schoenoplectus lacustris*. In place (1) there was one alien species noticed - *Phalaris canariensis*, a neophyte coming from southern Europe. This was the only alien species among 7 species scored in that place. The 2008 survey in place (2) did not show any alien species, however, more detail survey of 3/08/2009 by Dario Hruševar, Aleksandra Wagner, Uroš Ljubobratović, and Barbara Patuła showed 7 out of 31 alien species, among which 3 (9.7%) were archaeophytes: *Melilotus albus*, *Melilotus officinalis* and *Pastinaca sativa*. The latter was considered native for a long time, but recent studies have shown it was alien [15]. Neophytes were represented by two (6.5%) species: *Acer negundo* and *Robinia pseudoacacia*, both of them classified as invasive transformers. The encountered individuals (one of each species) were young and belonged to the undergrowth. Figure 2 shows the typical vegetation of the northern shore of the Bagry borrow pit.

B. *Staw Płaszowski*

On the western shore, the studies were carried out on 2/07/2008 by S. Tleubayeva and A. Wagner. Eleven species were found, among them two neophytes, none of them invasive: *Oenothera biennis* L. and one of North American ash trees, probably *Fraxinus pennsylvanica*, rarely encountered in natural environment in Poland. The study of 20/08/2009 by D. Hruševar and A. Wagner in the eastern side of the pond showed 22 species, among which the dominant was *Phragmites australis*. There were four (18.2%) neophytes: *Solidago gigantea*, *Solidago canadensis*, *Bidens frondosa*, *Acer negundo* – all of them invasive transformers. There was also a feral cultivar - *Humulus lupulus*. Apart from the plot yet another neophyte was found: *Conyza canadensis*, according to [15] the most common alien species in Poland.

C. *Staw Dąbski (the Dąbie Pond)*

The survey of 07/08/2009 by D. Hruševar, U. Ljubobratović and A. Wagner showed 12 species in the plot in the eastern part of the pond. Significantly dominant was *Typha angustifolia*. There was only one alien species: *Bidens frondosa* L. In other parts around the pond 32 more species were observed, including *Nuphar lutea* – a native species protected by the Polish law – the only place in the city of Krakow where it occurs naturally. There were also three invasive neophyte plants: *Acer negundo*, *Solidago canadensis* and *Erigeron annuus*. The first two are regarded transformer species and the latter is regarded harmless. On the southern part of the pond *Physocarpus opulifolius* was grown. This shrub species has become very popular as an ornamental plant in the green areas of Krakow over the recent 10 years. It originates from North America.

D. *Zakrzówek*

Two surveys were carried out in Zakrzówek – on 18/06/2008 by Samalzhan Tleubayeva, Aleksandra Wagner and Robert Mazur – on the hill in the eastern part of the area and on 13/08/2009, by D. Hruševar, U. Ljubobratović and A. Wagner – in the place slightly further from the previous one. In the first place 17 species were observed, including one archeophyte *Echium vulgare* and one neophyte *Fraxinus pennsylvanica*, usually occurring only as a cultivated plant. In the second place 23 species were present. Among them three alien species were found. One of them was *Lathyrus tuberosus* – an archaeotype, regarded

invasive, but not harmful. Two other species were neophytes: *Juglans regia* – a cultivated tree (originating from Caucasus and Central Asia), now expanding into natural and semi-natural habitats and *Solidago canadensis*, classified as a transformer. None of them was numerous.

Outside the marked area an archaeophyte *Odontites verna* was observed. This is a weed of Scrophulariaceae family. It occurs in the fields and becomes rarer and rarer because of the mechanization of agriculture. It was even included in the Polish Red Book of Plant Species, nevertheless, the exact level of threat is unknown [19].

E. The Pond of the Kaczeńcowa Street

Around the water body 26 species were found, four of them neophyte invasive transformers - North American: *Bidens frondosa*, *Solidago canadensis*, *Robinia pseudoacia* and Asian - *Impatiens parviflora*. The study was carried out on 19/08/2009 by D. Hruševar and A. Wagner.

F. Former decantation pond of Kujawy

The survey carried out on 19/08/2009 by D. Hruševar and A. Wagner showed 15 species, where *Calamagrostis epigejos* was dominating. One of them was archaeophyte - *Melilotus albus* and two invasive neophytes: *Conyza canadensis* and *Solidago canadensis*. Outside the plot one more neophyte species - *Erigeron annuus* was observed as well as 8 native species, including *Centaurium erythraea*, protected by the Polish law.

G. Przylasek Rusiecki

The survey carried out on 25/07/2009 by D. Hruševar, U. Ljubobratović and A. Wagner in two places near the only pond available for bathing: in eastern part of the shore, near the beach and in the northern part – a popular place for angling.

In the first place 39 species were found and the ones occurring in the biggest quantities were *Achilea millefolium* L. and *Melilotus albus*. The latter is archaeophyte and both are characteristic for pastures. The habitats in Przylasek Rusiecki are typically rural despite the fact of being situated in the administrative borders of the city of Kraków. Another archaeotype was *Humulus lupulus*. Neophytes were represented by 3 species: *Erigeron annuus*, *Bidens frondosa* and *Solidago canadensis*. In the second place the most common species was *Euphorbia virgata*. This plant has an uncertain status in the Polish flora. There was an archaeopophyte species - *Melilotus albus*.

Apart from the neophyte plants known from the previous place, i.e., *Erigeron annuus* and *Solidago canadensis*, four more species: *Medicago sativa*, *Conyza canadensis*, *Oenothera biennis* and a tree species: *Populus* × *euramericana* were found.

H. Wola Batorska

The survey was conducted on 19/08/2009 by D. Hruševar and A. Wagner, near the ponds in the eastern part of the water bodies complex. Place (1) was near the bigger pond and place (2) near the smaller pond. In place (1), 36 species were found, among them 7 of alien origin: archaeophytes: *Matricaria perforata*, *Capsella bursa-pastoris* and *Lactuca serriola*, all of them invasive, but usually not harmful. *Panicum miliaceum* was also found. The subspecies was not defined, which in this case, does not allow stating if the plant was archaeophyte or neophyte, but it is invasive. Other alien species included *Phalaris canariensis*, *Acer negundo* and *Bidens frondosa*. In place (2) twelve species were found, including one archaeophyte - *Echinochloa crus-galli* and one neophyte - *Conyza canadensis*. In the area outside the plots, one more neophyte was found - *Picea pungens*. The specimen was in a very poor shape. Probably it was deliberately planted.

I. Zabierzów Bocheński

On 10/08/2009 D. Hruševar, U. Ljubobratović and A. Wagner surveyed two plots in the area: (1) in the central part of the complex – near the beach and (2) in the southern part of the area. In place (1), 34 species were found, where *Bolboschoenus maritimus* in the part near water and *Trifolium repens* – further from the shore were predominant. There was only one neophyte: *Bidens frondosa* and one of uncertain status *Cirsium vulgare*. In site (2), there were 39 species recorded and only one - *Solidago canadensis* was neophyte. There were also *Rumex crispus* – a plant of an uncertain status and *Prunus cerasus* – a cultivated species, in that site occurring as feral. In the water a protected by the Polish law species was found - *Salvinia natans*. Allien species included *Bidens frondosa* and *Conyza canadensis*.

J. Ulesie

The Ulesie oxbow lake is the only natural pond in the area. The survey done on 12/08/2009 by D. Hruševar and A. Wagner showed the occurrence of 14 species in the examined area and 6 more species outside the area.

Only one species was not native. It was the sweet flag *Acorus calamus*, a species originating from Asia (India and China [20] [21]), although also having a subspecies occurring in North America. The date of bringing the species to Poland (accidentally or deliberately as a medicinal plant) is a subject of controversy: several dates are given in literature: 16th century (1557 is the probable date of the introduction to Europe), 1613, 1652 and 1824. It is unclear if the three first dates refer to the cultivated plants or plants growing in the wild [15].

Other sources suggest earlier introduction, during the Tatar invasions (13th century) [20] [21] (the Polish name of the plant is *tatarak*, which suggests connection with Tatars). In that case the plant would be classified as archaeophyte, nevertheless, most sources give later dates of introduction. The plant is invasive, nevertheless not regarded harmful, on the contrary, sometimes used to strengthen embankments [20]. In Ulesie it covered 25-50% of the surveyed plot; the plants were situated very compactly, which is typical of this species [21], but different from non-native plants of other

locations. Other plants included native species, among which *Glyceria maxima* and sedges *Carex* spp. covered between 5 and 25 per cent of the plot. The species dominant in water included *Salvinia natans*, protected by law. Another characteristic species in water was *Stratiotes aloides*.

K. Zakrzowiec

The survey was carried out on 17/08/2009 by D. Hruševar and A. Wagner in two sites. Site (1) was close to the pond and site (2) was in the place of the pond that was dried out several years before the survey. In the site (1) 37 plant species were found. The dominant species was *Phragmites australis* covering more than 75% of surveyed plot.

There were only two neophytes: *Erigeron annuus* and *Conyza canadensis* and one archaeophyte: *Lactuca serriola*. In place (2) 24 species were found. The dominant one was an archaeophyte *Echinochloa crus-galli*.

Other archaeophytes included *Setaria pumila* and *Matricaria perforata* Merat. There was also *Cirsium vulgare*, an invasive plant of uncertain status. Neophytes included *Bidens frondosa*, *Conyza canadensis* and *Erigeron annnus*.

L. Zamkowa Street – Niepołomice

The pond is situated in the centre of the town of Niepołomice, near the Niepołomice Castle. The area was rich in ruderal species, as well as ornamental plants. Altogether, on 5/08/2009 Hruševar and Wagner found 47 species.

Neophytes included herbaceous plants: *Bidens frondosa*, *Conyza canadensis*, *Erigeron annuus*, *Amaranthus retroflexus* as well as trees: 6 specimens of *Phellodendron amurense* (Figure 3), one specimen of *Robinia pseudoacacia* and shrubs such as *Kolwitzia amabilis* syn. *Linnaea amabilis* and *Philadelphus coronarius*. Archaeophytes included: *Digitaria sanguinalis*, *Setaria viridis*, *Setaria pumila* and *Malva neglecta*.

M. Mokra Street – Niepołomice

The survey was carried out by D. Hruševar and A. Wagner on 17/08/2009. There were 31 plants found in the plot near the pond. Archaeophytes included: *Pastinaca sativa* and *Setaria pumila*. Neophytes were: *Erigeron annuus*, *Conyza canadensis* and *Veronica persica*.

The presence of privet *Ligustrum vulgare* could be of anthropogenic or natural origin, but anthropogenic origin was more likely, nevertheless, it was not counted as alien species.

The water body was in the residential area and many non-native species were planted: *Picea pungens*, *Liriodendron tulipifera*, *Catalpa bignonioides*, *Pinus nigra*, *Abies concolor* and *Thuja occidentalis*.

N. The Akacjowa Street – Niepołomice

Around the water body 40 plant species were recorded on 17/08/2009 by D. Hruševar and A. Wagner. There were two archaeophytes: *Lactuca serriola*, *Echinochloa crus-galli* and three neophytes in the area: *Bidens frondosa*, *Robinia pseudoacacia* and horseradish *Armoracia rusticana*. The latter is a cultivated plant, invasive, but not harmful.

O. Staniątki

Near the pond situated in Staniątki on the border with the village of Podłęże and Staniątki on 11/08/2009 D. Hruševar and A. Wagner recorded 11 plant species. The dominant species was native reed mace (cattail) *Typha latifolia* covering more than 50% of the area (degree four in the Braun-Blanquet scale). Alien species included *Bidens frondosa* and *Conyza canadensis*. Six more species were observed out of the plot, including one neophyte – the horseradish *Armoracia rusticana* and one archaeophyte - *Setaria glauca*.

P. Zalew na Piaskach

The place selected for the survey on 31/07/2009 (by D. Hruševar U. Ljubobratović and A. Wagner) was in the area where the pond was shallower and overgrown by macrophytes such as *Typha latifolia* L. There were 40 vascular species and a moss *Sphagnum* spp. There was one neophyte there: *Erigeron annuus*.

The study showed the presence of alien plants, including neophytes in each location. Many of them are invasive, although only in few survey plots they were dominant or even made a significant proportion in the land cover. The most commonly found species (in terms of the number of locations) - *Solidago canadensis* - never covered more than 25% and often less than 5% of the survey plot. This seems to be compliant with an interesting study done by Orczewska [22] suggesting that some native species (such as *Urtica dioica* and *Galium aparine*) can be more dangerous for the habitat than neophytes (such as *Solidago gigantea*). The study also confirms the data suggesting higher presence of non-native plants in human-influenced areas [4], [15]. The lowest number, which was scored in Zabierzów Bocheński and Zalew na Piaskach, places relatively distant from residential areas. The eastern part of the study area (Zabierzów Bocheński) is situated near the Niepołomice Forest, a place with some amount of strictly protected areas, where invasive plants pose serious danger for biodiversity. Fortunately, in that area the influence of invasive species is relatively small (*Solidago canadensis* and *S. gigantea*), nevertheless cannot be neglected. The origin of neophytes is given in Table I. The majority - 18 out of 30 species originated from North America, 5 species come from Southern Europe, 2 from the Caucasus Mts. and 5 from Asia (Central and East).

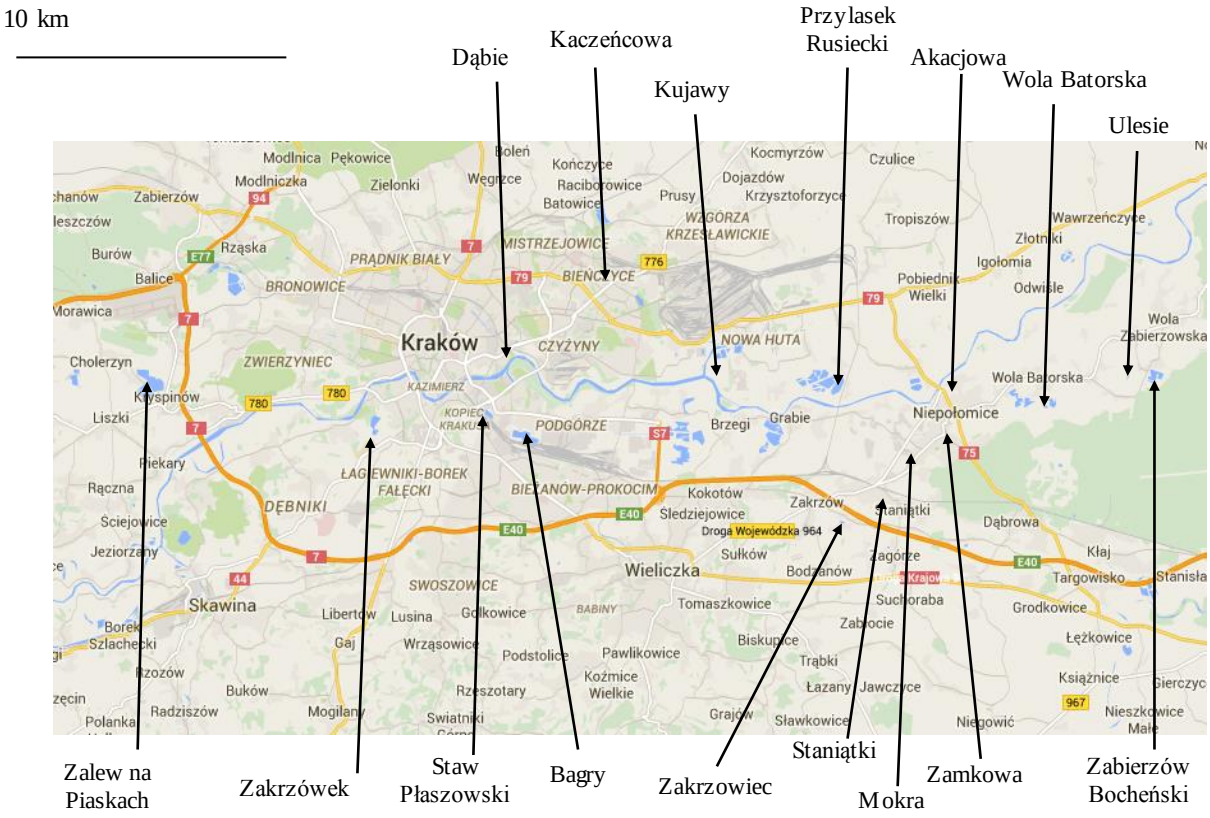

Figure 1. The study area, based on google maps.

Figure 2. *Solidago canadensis*, invasive plant on the grassland above the zone of *Phragmites australis*. The borrow pit of Bagry 8/08/2015, photo: A. Wagner

Figure 3. The pond of the Zamkowa Street – general view, on the top of the photo branches of *Phellodendron amurense*, 5/08/2009, photo: A. Wagner

IV. CONCLUSIONS

In total, 52 alien taxa were recorded for 16 locations near the water bodies in the Krakow region, which made 20.9 per cent of all the species found in the studied area. From that number, 30 taxa are neophytes, and 18 are archaeophytes, the status of four was uncertain. The percentage of alien species was lower than the one found for the whole Polish territory [15], while the percentage of archeophytes was higher. Although alien species occurred in every location in the study area, only two species: the sweet flag *Acorus calamus* and cockspur *Echinochloa crus-galli* reached 3rd and 4th degree of cover, respectively, in the Braun-Blanquet scale. Other species, on surveyed vegetation plots, usually could only be marked by "+".

Among the alien species a particular attention should be paid on invasive transformer species: the ash-leaved maple (*Acer negundo*), black locust (*Robinia pseudoacacia*), Canadian golden rod (*Solidago canadensis*), giant goldenrod (*Solidago gigantea*), bur marigold (*Bidens frondosa*) and small-flowered touch-me-not (*Impatiens parviflora*).

In the residential areas many alien tree species are grown. Apart from two species (the ash-leaved maple and black locust) they are not invasive and most of them can be only sporadically found in the wild.

Further monitoring of invasive plant species is necessary, also because of the perspective of climatic changes. Warming the climate will provide better conditions for the reproduction of southern species so that they could become invasive. The example can be the common walnut (*Juglans regia*), which was found in one location, but, according to literature [11] this species is in the initial phase of invasion, so it is likely to extend its range.

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TABLE I. NEOPHYTE PLANTS IN THE AREA OF WATER BODIES NEAR KRAKÓW

Plant cover-abundance according to the Braun-Blanquet scale: 5 - 75-100%, 4 – 50-75%, 3 -25-50%, 2 – 5-25%, 1- <5%, numerous individuals, + - <5%, few individuals, r – solitary with small cover; * – plant cover was not assessed, only the presence was recorded.

I – invasive, IT - invasive transformer, IW – invasive weed, INH- invasive, harmful effects not detected, NI - not invasive, C-casual.

TAXA	LOCATION																					Invasiveness	Origin
	BG1	BG2	SP1	SP2	D	ZK1	ZK2	KA	KU	PR1	PR2	WB	ZB1	ZB2	UL	ZC1	ZC2	ZM	MK	A	S	ZP	
Aesculus hippocastanum L.								*															Balkan Peninsula
Abies concolor (Gordon & Glend.) Lindl. ex Hildebr.																			*				C	North America
Acer negundo L.		r		+	*							r											IT	North America
Acorus calamus L.															3									Asia
Amaranthus retroflexus L.																		*						North America
Armoracia rusticana P. Gaertn., B. Mey. et Scherb.																				*	*		INH	SE Europe & West Asia
Bidens frondosa L.				r	+			*		+		+	+				r	*		*	1		IT	North America
Catalpa bignonioides Walter																			*				C	North America
Conyza canadensis (L.) Cronquist				*					+		1	*				*	+	*	*		1		IW	North America
Erigeron annuus (L.) Pers.		1			*				*	+	+					r	r	*	*			+	INH	North America
Fraxinus pennsylvanica Marshall			2			+																	C	North America
Galinsoga spp.					*																			North America
Impatiens parviflora DC.								*															IT	Central Asia
Juglans regia L.							+																I	Caucasu
Kolkwitzia amabilis Graebn.																		*					C	East Asia

TABLE I. - continuation

TAXA	LOCATION																					Invasiveness	Origin
	BG1	BG2	SP1	SP2	D	ZK1	ZK2	KA	KU	PR1	PR 2	W B	ZB 1	ZB 2	U L	ZC 1	ZC 2	ZM	MK	A	S	ZP		
Liriodendron tulipifera L.																			*				C	North America
Medicago sativa L.		+									+												INH	South-Central Asia
Oenothera biennis L.			1								+												NI	North America
Phalaris canariensis L.	1											+												Southern Europe
Phellodendron amurense Rupr.																		*					C	East Asia
Philadelphus coronarius L.																		*					C	Southern Europe
Physocarpus opulifolius (L.) Maxim.					*																		C	North America
Picea pungens Engelm.												*							*				C	North America
Pinus nigra Arnold																			*				NI	Southern Europe
Populus x canadensis Moench											1												NI	Hybrid: Europe and North America
Robinia pseudoacacia L.		r						*										*		*			IT	North America
Solidago canadensis L.		1		+	*		+	*	2	r	r			+									IT	North America
Solidago gigantea Aiton				1																			IT	North America
Thuja occidentalis L.																			*				C	North America
Veronica persica Poir.																			*				IW	Caucasus

TABLE II. ARCHAEOPHYTES AND PLANTS OF UNCERTAIN STATUS IN THE AREA OF WATER BODIES NEAR KRAKÓW

Plant cover-abundance according to the Braun-Blanquet scale: 5 - 75-100%, 4 – 50-75%, 3 -25-50%, 2 – 5-25%, 1- <5%, numerous individuals, + - <5%, few individuals, r – solitary with small cover; * – plant cover was not assessed, only the presence was recorded.

I – invasive, IW – invasive weed, INH- invasive, harmful effects not detected, NI - not invasive.

TAXA	LOCATION																		INVASIVENESS
	BG2	SP2	D	ZK1	ZK2	KU	PR1	PR2	WB	ZB1	ZB2	ZC1	ZC2	ZM	MK	A	S	ZP	
Capsella bursa-pastoris (L.) Medik.									+										INH
Cichorium intybus L.			*																INH
Cirsium vulgare (Savi) Ten.									+	+			+						Uncertain status, invasive, not harmful
Digitaria sanguinalis (L.) Scop.			*											*					
Echinochloa crus-galli (L.) Beauv.									*				4			*			IW
Echium vulgare L.				+	*														
Euphorbia virgata Waldst. et Kit.								3											Uncertain status, not invasive
Humulus lupulus L.		+					+												
Lactuca serriola L.									r			*				*			INH
Lathyrus tuberosus L.					2														
Malva neglecta Wallr.														*					
Matricaria perforata Mérat									+				1						IW
Melilotus albus Medik.	+					1	3	+											
Melilotus officinalis (L.) Lam.	+																		
Odontites vernus (Bellardi) Dumort.					*														Antropophyte, weed
Panicum miliaceum L.									+										Archaeophyte or neophyte, depending on subspecies
Papaver rhoeas L.			*																INH
Pastinaca sativa L.	+		*												*				
Rumex crispus L.											+							r	Uncertain status
Senecio vulgaris L.			*																
Setaria pumila (Poir.) Schult.													2	*	*		*		IW
Setaria viridis (L.) P.Beauv.			*											*					IW

TABLE II. NATIVE PLANTS IN THE AREA OF WATER BODIES NEAR KRAKÓW

Plant cover-abundance according to the Braun-Blanquet scale: 5 - 75-100%, 4 – 50-75%, 3 -25-50%, 2 – 5-25%, 1- <5%, numerous individuals, + - <5%, few individuals, r – solitary with small cover; * – plant cover was not assessed, only the presence was recorded.

TAXA	LOCATION																						
	BG 1a	BG 1b	BG 2	SP1	SP2	D	ZK1	ZK2	KA	KU	PR1	PR2	WB	ZB1	ZB2	UL	ZC1	ZC2	ZM	MK	A	S	ZP
Acer platanoides L.				*							3					r			*				
Acer pseudoplatanus L.																			*				
Achillea millefolium L.			+		+	*		+				+	+		1		*	+	*	*	*		
Aegopodium podagraria L.					*				*										*				
Agrimonia eupatoria L.					*								*										
Agrostis canina L.																							2
Agrostis gigantea Roth												+											
Agrostis spp.					+						1												
Agrostis stolonifera L.												1			1				*				
Alchemilla spp.									*														
Alisma plantago-aquatica L.			*						*					+							*		+
Alnus glutinosa (L.) Gaertner									*					r		r					*		
Alopecurus pratensis L.																			*				
Angelica spp.													+										
Anthemis spp.						*													*				
Arctium lappa L.													*								*	*	
Arenaria serpyllifolia L.										1													
Arrhenatherum elatius (L.) P.Beauv. ex J.Presl et C.Presl					*							r											
Artemisia vulgaris L.			+		*					+	1	2	+		2		1		*		*		
Astragalus glycyphyllos L.										*			+										
Avenula pratensis (L.) Dumort.							2																

TABLE III. – continued

TAXA	LOCATION																						
	BG 1a	BG 1b	BG 2	SP1	SP2	D	ZK1	ZK2	KA	KU	PR1	PR2	WB	ZB1	ZB2	UL	ZC1	ZC2	ZM	MK	A	S	ZP
Ballota nigra L.					*																	*	
Berula erecta (Huds.) Coville																					*		1
Betula pendula Roth			r		r					1					+								+
Bidens cernua L.									*														
Bromus hordeaceus L.						*													*				
Calamagrostis canescens (Weber) Roth		1					1																
Calamagrostis epigejos (L.) Roth			4		1			3		4			2	2	2								
Calamagrostis spp.						+					1												2
Calystegia sepium (L.) R. Br.				2	+	+									+		*					1	
Carex spp.															+	2							
Centaurea jacea agg.					*						2	+	*	1	+								+
Ceratophyllum spp.											+			*									
Chenopodium album L.						*							*				*		*				
Cicuta virosa L.													r	1									
Cirsium arvense (L.) Scop.					+			1			+	+		1	1			+	*		*		1
Cirsium oleraceum (L.) Scop.																	r	r					
Cirsium rivulare (Jacq.) All.													r										
Cirsium spp.																	+						
Convolvulus arvensis L.			1	2		*		+			1								*	*			
Crataegus monogyna Jacq.								1								r							
Crepis spp.			r			*	1												*				r
Cucubalus baccifer L.																					*		
Cynosurus cristatus L.																							+
Dactylis glomerata L.				1			2	+				+							*	*			
Daucus carota L.			+			*		+			1	+	*	+	1			+		*			+

TABLE III. – continued

TAXA	LOCATION																						
	BG 1a	BG 1b	BG 2	SP1	SP2	D	ZK1	ZK2	KA	KU	PR1	PR2	WB	ZB1	ZB2	UL	ZC1	ZC2	ZM	MK	A	S	ZP
Deschampsia cespitosa (L.) P.Beauv.													*		2				*				
Deschampsia media (Gouan) Roem. et Schult.														+									
Deschampsia spp.																+							
Dipsacus fullonum L.															+								
Eleocharis palustris (L.) Roem. et Schult.																							+
Elymus repens (L.) Gould		2		2											2				*				
Epilobium angustifolium L.					*																		
Epilobium dodonaei Vill.								*		*													
Epilobium hirsutum L.			*		+	r			*		+	+	1	r					*		*		+
Epilobium palustre L.						r									r				*				+
Epilobium parviflorum Schreber											+												
Epilobium spp.																			*			r	
Equisetum arvense L.			+										+				*		*				
Equisetum palustre L.																1							
Equisetum ramosissimum Desf.															*								
Equisetum spp.																					*		+
Eupatorium cannabinum L.						*				r													
Festuca ovina L.							2																
Festuca spp.																			*				
Fraxinus excelsior L.									*														
Galium album Mill.							1																
Galium mollugo L.			1		*																		
Galium spp.														1									+
Galium verum L.							1																
Geranium lucidum L.							2																

TABLE III. – continued

TAXA	LOCATION																						
	BG 1a	BG 1b	BG 2	SP1	SP2	D	ZK1	ZK2	KA	KU	PR1	PR2	WB	ZB1	ZB2	UL	ZC1	ZC2	ZM	MK	A	S	ZP
Geranium pratense L.			+		*			1					*										
Geranium spp.																			*				
Glechoma hederacea L.													+						*		*		
Glyceria fluitans (L.) R.Br.									*														r
Glyceria maxima (Hartm.) Holmb.			*													2					*	2	
Heracleum sphondylium L.			+		*						r		+	+	1				*		*		
Hieracium pilosella L.							+																
Hieracium praealtum Vill. ex Gochnat										+													
Holcus lanatus L.											+												
Holcus mollis L.																							+
Hypericum perforatum L.												r					*						
Hypericum tetrapterum Fr.																	r						
Juncus bulbosus L.						*					+										*		1
Juncus effusus L.	2				+									1	1		+		*				2
Lamium album L.																			*				
Lathyrus pratensis L.														+									
Lemna minor L.						*										*							1
Leontodon autumnalis L.					*	*						r	*		1				*	*			+
Ligustrum vulgare L.																				*			
Lolium perenne L.			+		*	*					+	+		3	2		*	+	*	*	*	*	+
Lotus corniculatus L.			+					*										r		*			+
Lycopus europaeus L.			*		1	+			*		+		1	+	+	+	+			*	*		1
Lysimachia nummularia L.									*												*		
Lysimachia vulgaris L.													1										
Lythrum salicaria L.						*					1		+		+		+	r		*		r	+
Malva sylvestris L.						*													*				

TABLE III. – continued

TAXA	LOCATION																						
	BG 1a	BG 1b	BG 2	SP1	SP2	D	ZK1	ZK2	KA	KU	PR1	PR2	WB	ZB1	ZB2	UL	ZC1	ZC2	ZM	MK	A	S	ZP
Matricaria perforata Mérat													+										
Medicago falcata L.			1		*			1				+											
Medicago lupulina L.						*				*								1		*			+
Mentha aquatica L.									*								1						
Mentha longifolia (L.) Huds.																	*			*			
Mentha x verticillata L.													+	+									
Milium effusum L.				1																			
Myosotis spp.													+										
Myriophyllum spicatum L.														*			*				*		
Nuphar lutea Sibth. et Sm.						*																	
Ononis arvensis L.					*																		
Ononis natrix L.								*															
Petasites albus (L.) Gaertn														+	+		*		*				
Peucedanum palustre (L.) Moench							1																
Phalaris arundinacea L.		3		3																			
Phleum pratense L.					*	+					+	+		+	1						*		
Phragmites australis (Cav.) Trin. ex Steud.	2	2		2	5	*		1			+	+	2	1			5			*		*	
Pimpinella spp.					*																		
Pinus sylvestris L.										*													
Plantago lanceolata L.				1		*					+				1					*	*		+
Plantago major L.	1			1		*	1	1			+	+			2		*	1		*	*		+
Plantago media L.														2									
Poa annua L.						*									+						*		
Poa pratensis L.							2																
Poa trivialis L.															1			+					
Polygonum aviculare L.													*				*		*				

TABLE III. – continued

TAXA	LOCATION																						
	BG 1a	BG 1b	BG 2	SP1	SP2	D	ZK1	ZK2	KA	KU	PR1	PR2	WB	ZB1	ZB2	UL	ZC1	ZC2	ZM	MK	A	S	ZP
Polygonum lapathifolium L.											+												
Polygonum mite Schrank					+								+										
Polygonum persicaria L.									*		r							+					
Populus alba L.						*		1		+	+	r											
Populus canescens Moench												+											
Populus nigra L.						r				1													
Populus tremula L.										r													1
Potamogeton spp.																							
Potentilla anserina L.								1	*									+			*		
Potentilla reptans L.			1					1	*						1		*			*			
Prunella vulgaris L.										1										*			
Prunus cerasus L.															r								
Prunus padus L.							+																
Prunus spp.			*																				
Prunus spinosa L.													1										
Quercus robur L.														r	r								
Ranunculus acris L.					*				*						+					*			
Ranunculus repens L.																		+			*		+
Ranunculus spp.														+									
Rosa canina L.								r	*														
Rubus caesius agg.			1					+				+											
Rubus spp.													1										
Rumex acetosa L.					*	*					r	+							*				
Rumex hydrolapathum Hudson																*							
Rumex obtusifolius L.					*																		
Rumex spp.																	*					+	

TABLE III. – continued

TAXA	LOCATION																						
	BG 1a	BG 1b	BG 2	SP1	SP2	D	ZK1	ZK2	KA	KU	PR1	PR2	WB	ZB1	ZB2	UL	ZC1	ZC2	ZM	MK	A	S	ZP
Salix alba L.						2					r	2		r						*	*		+
Salix caprea L.					r																		
Salix cinerea L.						r				r	r			+	+								+
Salix fragilis L.					+								1							*			
Salix purpurea L.						r		*			r			r						*			
Salix spp.								r											*				1
Salix viminalis L.													1										
Salvinia natans (L.) All.														*		*							
Sambucus nigra L.			+					r															
Sanguisorba officinalis L.			*										1		+	*							
Scirpus lacustris L.	2		*																				
Scirpus maritimus L.									*					3	1								
Scrophularia spp.																			*				
Scutellaria galericulata L.											r												
Securigera varia (L.) Lassen												1											
Silene latifolia Poir. ssp. *alba* (Mill.) Greuter et Bourdet																						*	
Silene nutans L.			r																				
Solanum dulcamara L.									*														
Sonchus arvensis L.											r												
Sonchus oleraceus L.						*													*		*	+	
Sorbus spp.																				*			
Sparganium erectum L.						*							+										
Sphagnum spp.																							3
Spirodela polyrhiza (L.) Schleiden																*							
Stachys palustris L.							2							+	+				*				

TABLE III. – continued

TAXA	LOCATION																						
	BG 1a	BG 1b	BG 2	SP1	SP2	D	ZK1	ZK2	KA	KU	PR1	PR2	WB	ZB1	ZB2	UL	ZC1	ZC2	ZM	MK	A	S	ZP
Stenactis annua (L.) L.						*																	
Stratiotes aloides L.																*							
Symphytum officinale L.													+										
Tanacetum vulgare L.			1		+	*				1		2	1				+			*	*		+
Taraxacum officinale Weber			+								r	r		1			*			*	*		
Tilia cordata Mill.							+																
Trifolium arvense L.						*											*						
Trifolium campestre Schreber			+																				
Trifolium hybridum L.													*					+					
Trifolium medium L.																				+			
Trifolium pratense L.	1				*	*		+			1		*	1			+	+		*	*	1	+
Trifolium repens L.	1				*	*		1			r	1		3	2		+	+		*	*		+
Trisetum flavescens (L.) P.Beauv.					+								*										
Tussilago farfara L.																					*		+
Typha angustifolia L.					+	5									*		1						
Typha latifolia L.			*						*				1	2	1						*	4	3
Ulmus glabra Huds.																			*				
Ulmus minor Miller									*														
Urtica dioica L.					+				*						1		*		*		*	2	
Valeriana officinalis L.					*																		
Veronica chamaedrys L.						*																	
Vicia cracca L.					*					*		r		+			*						
Vicia cracca agg.			+			*					+		+										

A New Biodiversity Composite Indicator Based on Anthropentropy and Forest Quality Assessment

Framework, Theory, and Case Studies of Italian Territory

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***Abstract*— This paper describes a new environmental composite indicator, which is based on two previously defined single indicators, related to land use (the Anthropentropy Factor) and to quality of forests (the Forest Status Quality Indicator). The framework for the definition of the composite indicator is an innovative formalization of the multidisciplinary approach, which connects knowledge and expertise of two different scientific fields: vegetation science and computer science. The proposed method for the indicator computation combines the classical algorithms of computer vision, to process data from Geographic Information Systems, and the phytosociological approach, to assess the floristic composition of the forests. The goal is to build a deep knowledge about the impact of land use and forest quality, at a landscape level, on biodiversity conservation, by studying the impact of anthropic activities, both inside (urban and rural areas) and outside (forests) the areas occupied by human activities. The knowledge is expressed by a single composite indicator and its assessment can be used for environmental preservation policy actions, to guide local government decisions for a biodiversity conservation in the landscape. The new indicator and the methodological approach is validated by presenting experimental results on two case studies in the North-West of Italy.**

Keywords - biodiversity; land use; environmental indicator; forest status quality; Anthropentropy Factor; composite indicator.

I. INTRODUCTION

This paper describes the continuation and the extension of the research project reported in [1]: theory have been improved and the number of case studies has been increased, in order to validate the original ideas and to enlarge the scope of applications of the proposed approach. The target is still the same: to propose and measure indicators related to some specific aspects of biodiversity, within a given territory. Biological diversity means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems [2]. Actually, the habitat loss and fragmentation due to agriculture and urbanization, the introduction of alien species and the climatic changes are among the most important causes of biodiversity loss. Thus, the recent Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets [3] include, among the others, two important goals: to reduce the direct pressures on biodiversity and to improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity. The vision of this Strategic Plan is a world of "living in harmony with nature," where "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people." The goal of this work is not only to give a quantitative description of the biodiversity, but also to identify the sub-areas, within the territory under investigation, where the application of policy actions for its conservation is a more serious and pressing issue. In particular, two specific aspects of environmental preservation have been considered in [1]: land use and forest quality. In order to motivate this fundamental choice, it is important to understand the relationships between these two aspects and biodiversity conservation.

Land use can be defined in different ways, and for this reason its meaning is often a source of misunderstanding. In our research, we adopt its broadest sense: the definition and classification, within a limited territory, of the areas of *anthropic places*, i.e., places occupied by human activities (for every-day life, economic and productive activities), and of the areas of wild nature. According to this definition, the territory under investigation is *de facto* partitioned into two classes: the areas of anthropic activities, where the human presence is fairly continuous and has ousted the wild, and the "wild areas", where the opposite occurs. A correlated term is *land take*: it expresses the variation of the land use over time, (e.g., one year for *annual land take*).

The limitation of land use against the threat of an exceeding, out of control, urban sprawl and the mitigation of the loss of wild habitats are very important for biodiversity conservation. This is evidenced by the fact that the European Environment Agency considers land use and biodiversity in the same target and objective for the policy actions of 2010-2050 decades [4]. The relationship between land use and biodiversity conservation can be motivated also referring to the well-known DPSIR framework [5], which describes the impact of human activities on the environment as a chain of causes-effects. The chain connects five rings: the Driving forces (D), the Pressures (P), the State (S), the Impacts (I), and Responses (R). If we use this framework to investigate

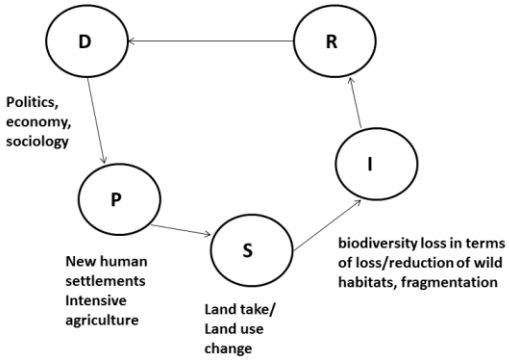

Figure 1. The DPSIR framework and the relationships between land take and biodiversity loss (D: driving forces, P: pressures, S: state, I: impacts, R: responses).

the possible relationships between land use changes and biodiversity loss (see Fig. 1), we can identify examples in which the driving forces, which are the starting point of the chain, are the same for both the phenomena, or, at least, are closely related. For example, social motivations (D), such as demographic expansions, generate pressures on the environment in order to increase the areas occupied by new settlements, roads, and services (P). As a consequence, the environment enters in a new state S, where land use changes over time, with an increase of anthropic areas, at the expense of natural, wild areas. In turn, this state change has two possible negative impacts on biodiversity: (a) the loss of the territory, both for vegetal and animal species, and (b) the territory fragmentation, which is considered as one of the most dangerous threats to biodiversity [6], [7]. Demographic expansion is one of the most simple and intuitive examples of pressures that can act as a strong motivation for both land use changes/land take and biodiversity loss. There are plenty of examples that lead to the loss of wild natural areas: urban and rural expansion, new roads and communication lines, settlements for industries, tourism and services, intensive farming. Moreover, processes that cause land use change are specific for the different parts of Europe [8]: forest management affects the Boreal and Alpine regions, abandonment and intensification are mainly encountered in the Mediterranean areas, urbanization and drainage are typical of the Continental and Atlantic regions. Concerning Italy, further studies [9], [10], [11] identified a distinction between the planar belt, where urbanization and agricultural intensification are the main pressures of biodiversity loss, and the hilly-montane belt, which is more affected by abandonment and the consequent forest re-colonization.

If we consider the problem of land use from a quantitative point of view, the most complete research regarding Europe is the Corine Land Cover Project [12]; the artificial areas (intended as soil sealed territories) cover only the 4% of the land in Europe, as compared to a 34% of forests. However, this percentage rises to a global value of 51%, if we consider the areas that support all the anthropic activities, the economic growth and food production (agriculture, crops, pasture and semi-natural vegetation). The situation is particularly dramatic if we consider the phenomenon of land take over the past years. For example, in Italy, the most recent report on land take [13] shows an annual value of 7.3%, equal to 21.890 square kilometers, the equivalent of 70 ha/day, or 8 square meters/s.

The second aspect of environmental preservation considered in [1] is the presence, in a given territory, of forests, and their quality, expressed by some quantitative measure. This is consistent with the chosen definition of land use: as the territory is partitioned into two areas, i.e., anthropic places vs. natural, wild areas, we are interested into the study of one aspect (at least) referring to each of the partitions: land use is related to the first one (anthropic places), the presence of forests to the second one (wild areas). We have chosen the forests for their importance and benefits for the human well-being (the so-called ecosystem services), such as flood prevention, erosion control, CO_2 absorption, climate regulation, *refugium* function for wild plants and animals, recreation, science and education.

Moreover, even if this partition is clearly visible on the territory, the two worlds are far to be completely separated. In particular, the quality of the forest can be influenced by human activities, such as pollutions, climate changes, use of pests and the introduction of invasive species. In other term, it is important not only the quantitative presence of forests, but also their quality [14], [15]. Indeed, in the "wild area", due to the sporadic presence of humans (for example, for agriculture), old-growth forests, with a high degree of biological richness, are sometimes replaced by young forests with poor species.

Also, intensive forests and plantations are far to be "true wildness", even if they are clearly outside the anthrophized areas. For all these reasons, it is important to give a quantitative measure of the quality of the forests, as the simple measure of the area percentage is a too simplistic parameter to understand the actual contribution the forests give to the biodiversity of the territory.

A. Novelties of this contribution

In previous researches, we have proposed new indicators, both for land use measurement [16], [17], i.e., the *Anthropentropy Factor* (*AF*), and for the forest quality assessment [1], i.e., the *Forest Quality Status Indicator* (*FSQ*). In addition, a first attempt to study the correlation between the two indicators [1], with regard to a precise area of the North-West of Italy, the Province of Pavia, has become our first case study. However, it is evident that the distinct computation of the two indicators, although promising and interesting, does not provide an overall view of the impact of the two critical aspects on the biodiversity of a given territory. Therefore, the research continued with the challenging goal to define a new composite indicator, based on both *AF* and *FSQ*, in order to give a more significant measure of the state of the biodiversity inside a given

territory, at least for the two major phenomena, i.e., land use and forest quality. This can be considered a relevant improvement on the state of the art; in fact, biodiversity can be measured [18] by considering different parameters (composition, structure or function) and at different levels of biological organization (genetic, population-species, community-ecosystem, landscape). Usually, the produced indicators in literature refer only to *one* of such organization levels. On the contrary, the composite indicator here built relates, at the same time, to *two* organization levels: landscape (considering urban and forest patches) and community-ecosystem level (considering forests and their quality).

Moreover, the main novelties carried out with this new research activity, if compared to the previous one [1], can be summarized as follows:

1. The definition of a new composite indicator, called *Biodiversity Composite Indicator* (*BCI*). It is based on the two "simple" indicators, i.e., *AF* and *FSQ* that become, in turn, the two sets of variables on which the composite indicator is built on. Building a composite indicator is not a simple matter of crunching numbers, but a clear stated and well-defined method has to be followed [19]. For this purpose, it is very important to define a theoretical framework (see point 2).
2. The formalization of multidisciplinary approach, which is the core of the theoretical framework. The goal of the formalization is to describe how the two sciences, vegetation science and computer science, can cooperate and under what constraints.
3. A new case study has been proposed, and the comparison with the first one [1] has been fully investigated, by considering the two indicators *AF* and *FSQ*.
4. The new *BCI* indicator has been calculated for both the two case studies, in order to give a global assessment on the environmental issue of biodiversity conservation for the two target areas.

The paper is organized as follows. Section II describes the multidisciplinary approach and the new conceptual framework for the definition of the composite indicator. Section III summarizes the theory about the two indicators and presents the results for the two case studies. Section IV describes the fundamental steps for the definition of the composite indicator and shows the experimental results on the two case studies on the Italian territory. Conclusion and considerations about future work in Section V close the article.

II. The Multidisciplinary Approach

One of the most important and distinctive characteristics of our research is its highly multidisciplinary approach, which bridges across two important fields of our modern scientific research: vegetation science and computer science. Both of them have knowledge, tools and paradigms that are able to assess the impact of human activities for a sustainable

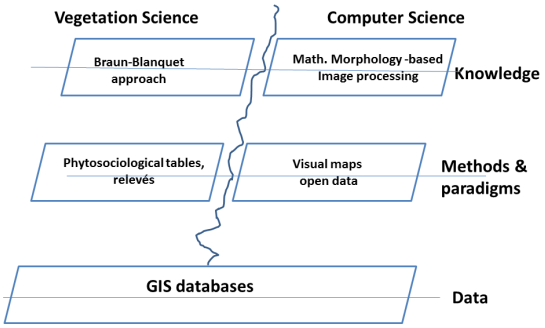

Figure 2. The formalisation of the framework of cooperation between computer science and vegetation science.

future. In particular, we have identified three hierarchical levels of "integration": knowledge, methods (or paradigms) and data (see Fig. 2) .

At the first level, we find the concepts, approaches and algorithms useful to process data and information at the lower levels. In particular we have, for computer science, the mathematical morphological operators applied in 2D digital images processing of computer vision [20]. They have been used for the computation of the AF indicator. Concerning vegetation science, we use the Braun-Blanquet approach [21], [22], [23], [24] to determine in the FSQ definition the floristic composition of the forests and to assess their quality from the authenticity perspective [14]. Authenticity is a measure of the health and integrity of the ecosystems; it can be assessed considering different aspects, and we have chosen the composition (number of layers, presence and percentage of alien and protected species) and the continuity (in particular, we have considered the areas occupied by the forests.)

At the second level of the hierarchy of our framework, we find the methods and the paradigms used to translate the "knowledge" level in practical tools, in order to process the lower levels (data). For vegetation science, we used the phytosociological tables [25] and, in some cases, information have been integrated by bibliographic references and phytosociological *relevés*, collected in the area where the forest type occurs. For computer science, we have used Quantum GIS [26], an open source Geographic Information System (GIS), and its primitives to compute areas and intersect boundaries in the territories of the case studies.

At the lowest, third level of the hierarchy, we find the raw data, expressed in a visual form (maps of GIS systems). It consists of three databases: the ERSAF (Ente Regionale Servizi Agricoltura e Foreste) database [27], the Corine Land Cover database [12], and the ISTAT (Istituto Nazionale di Statistica) database of Italian administrative boundaries [28]. We consider the portion of these databases, which refers to the same territory, i.e., the region Lombardia in the North-West of Italy. The first two databases are used to represent the presence of forests and the land use classification, respectively. The third one is used to focus the attention on the two case studies, namely two of the twelve provinces of

region Lombardia, i.e., the provinces named "Pavia" and "Lodi". Some interesting characteristics of the territory of Lombardia and of the two case studies are reported in Table I. The level of GIS databases is the conceptual bridge, which connects vegetation science and computer science, the channel through which the two disciplines can communicate and exchange information and knowledge. In order to assure that this communication is valid and generate useful and meaningful information, some constraints are to be respected. We have defined five constraints, described as follows.

Format constraint: data are expressed in a common format: in this way, the visual maps of the same territory (geodata) can be processed by GIS tools. To adhere to this constraint, the ERSAF database (raster GIS data) has been vectorized, in order to be consistent to the other vector geodata.

Temporal constraint: data stored in the databases have to be referred to equal or very close temporal periods. In our case, data of Lombardia refer to the period 2007-2011.

Granularity constraint: the different databases has to consider the same data granularity as reference in the different computations. As our databases refer to a geographical territory, adopting the same data granularity means that both the indicator computations refer to the same geographical unit. In our research, we have chosen the municipality as common data granularity. This choice is motivated by the fact that, in Italy, the municipality is the administrative division, which is in charge of adopting local policy on the territory for land use and/or environmental requalification. Therefore, it is important to consider this granularity if we want to use the indicators to support decision-makers.

Precision constraint: in all the indicator computations and geometrical transformations (vectorization, change of coordinates), we have a maximum error less of 50 meters, which is consistent to the definition of the most important aspect of the *AF* indicator computation, the dilation step (see Section III).

Availability constraint: all the GIS databases are public and available according to the open access paradigm. This choice is particularly important in the construction of the composite indicator, as underlined in Section V.

Once we have formalized the framework, we can use it to explain how to create the composite indicator, starting from the two "simple" ones, i.e., *AF* and *FSQ*. The framework and the method here proposed are quite general, and can be applied also adding more than two simple indicators. In the following sections, a brief recall of the theory of the two indicators is summarized. Moreover, data of the two case studies are reported and compared.

III. THE SIMPLE INDICATORS

In this section, the two simple indicators are presented, for land use and forest quality evaluation, respectively. In Section II.A, the flow chart of the algorithm for land use estimation is described, with some fundamental considerations about the computer science paradigms and tools, and their innovative aspects in this research field.

TABLE I. REPRESENTATIVE DATA FOR THE TERRITORY UNDER INVESTIGATION: THE REGION OF LOMBARDIA, NORTH WESTERN ITALY, AND THE TWO CASE STUDIES, PAVIA AND LODI.

Territory	**Main characteristics**	
Region Lombardia	Area	23.844 square km
	Minimun Altitude above sea level	11 m
	Maximum Altitude above sea level	4.021 m
Case study °1: Province of Pavia	Area	2.965 square km
	Number of municipalities	190
	Average Minimun Altitude above sea level	53 m
	Average Maximum altitude above sea level	951 m
Case study °2: Province of Lodi	Area	782 square km
	Number of municipalities	61
	Average Minimun Altitude above sea level	40 m
	Average Maximum Altitude above sea level	101 m

In Section II.B, the forest quality indicator is defined by following the same theoretical framework.

A. Land use indicator

The Anthropentropy Factor [16], [17] is an environmental indicator of type B, using the standard European Environmental Agency taxonomy [5]. The AF expresses in an absolute, continuous scale, from 0 to 1, the degree of the impact of anthropic human activities due to the land use. Furthermore, it is a performance indicator; in fact, besides its definition, also a metric is given, which describes a table of reference to assess the environmental situation, in an optimum or near-optimum condition.

The metric maps the *AF* values to five intervals (class of land use), where only the first one is very desirable, the second one is near-optimum, until the last one, which refers to the worst situation of irreversible environmental degradation. In Table II, the metric of the *AF* indicator is described. For a reasoned treatment of the metric and its relationship with a possible policy making for a sustainable development, see [17]. Here, we recall the basic definition and concepts that are essential to understand the metric and analogies and differences between this indicator and the *F*orest *S*tatus *Q*uality Indicator (see Section III.B).

Anthropentropy is a neologism, from the ancient Greek term *Anthropos* (*Ἀνθρωπος*) = "man", and *entropy*, that, in turn, derives from the ancient Greek terms *en* (ἐν) = "inner", and *tropé* (τροπή) = "transformation".

TABLE II. THE METRIC ON THE *AF* INDICATOR FOR LAND USE.

Class of land use and map color	Evaluation of Land Use	
	Intervals of AF	***Meaning***
1 light green	0 <= *AF* <= 0.2	Very low level of anthropentropy, *ideal* situation for nature and human beings
2 green	0.2 < *AF* <= 0.4	A first worrying level of anthropentropy, but the situation is still *good*
3 yellow	0.4 < *AF* <= 0.6	A serious level of anthropentropy, with a beginning negative impact of anthopization on the environment.
4 red, light violet	0.6 < *AF* <= 0.8	A very serious level of anthropentropy, with a great negative impact of anthopization on the environment.
5 violet, black	0.8 < *AF* <= 1	The worst situation, with an irreversible environmental degradation.

In fact, the *AF* indicator means to express the transformations and the consequent "disorder" introduced in natural ecosystems by the presence and disturbance of human beings. The algorithm for *AF* computation is described in the block-diagram in Fig. 3. The first step of the algorithm is the identification of a delimited part of a geographic territory under consideration and the computation of its *area S*, in squared kilometers. As previously discussed in the general framework, data granularity refer to the Italian municipalities; thus, in our computation, S is the area of a given municipality the indicator refers to.

The second step for the *AF* computation algorithm is the identification of all the land parcels occupied by anthropic places, such as human settlements, factories, roads, and so on (for a complete taxonomy of the anthropic places, see [15]). We call these parcels *anthropic sub-regions*. This is performed by using the Corine Land Cover database [10] and primitives of GIS software to extract, intersect and subtract areas that are identified by the 44 classes of land use of Corine Land Cover project.

The third step takes into consideration the shapes and the contiguity of the anthropic sub-regions. In fact, each sub-region is geometrically enlarged by the morphological operator of dilation [20] (along both the two Cartesian dimensions X and Y) with a factor of "buffering" (radius of the circular dilation) of 50 meters, to give rise to anthropic sub-regions. The choice of a 50 meters distance/limit has been discussed in [16], and it seems a good compromise between a too restrictive and a too permissive limit. After performing the dilation on each of the anthropic sub-regions of the municipality, the union of all of them is taken and it corresponds to the *Death Zone*. Let define *DA* as the area (in square kilometers) of the Death Zone. We think that this step of the algorithm makes the AF indicator a "true" naturalistic evaluation of land use, because it not only compute the percentage of land occupied by human activities, but also takes into consideration the *shape* of the areas subtracted to nature, and their relative positions, thus incorporating the important aspect of land fragmentation and its impact on biodiversity.

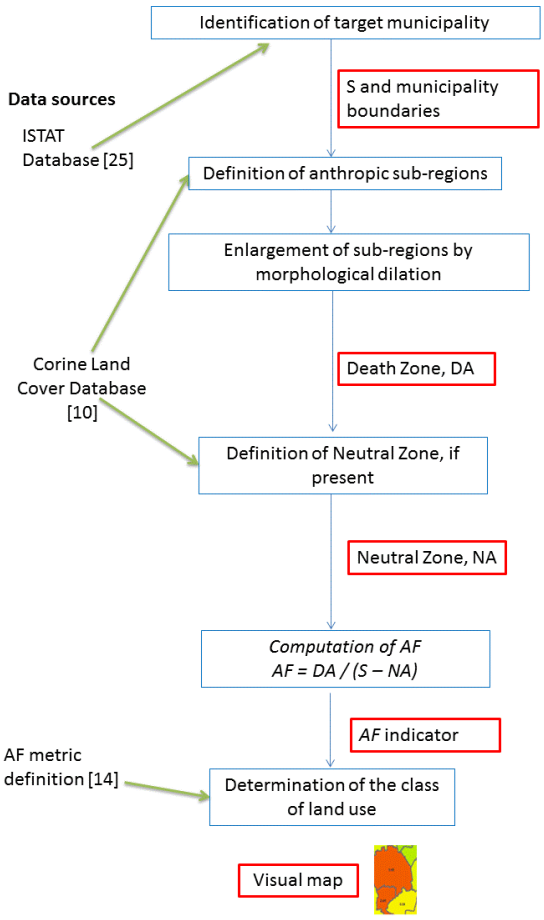

Figure 3. The flow chart of the algorithm for the AF computation: in blue the computational steps, in red the outputs. Shadowed green arrows show where data sources are used.

In order to understand the importance of the dilation, a simple example can be useful: in Fig. 4, the situation for the municipality of Monte Cremasco (Lombardia, latitude 45°22'31"80 N, longitude 09°34'20"64 E) is shown. The anthropic sub-regions are depicted in red. This example is particularly meaningful, as the anthropic sub-regions are scattered in different part of the territory, with a lot of "hole" and unconnected areas, thus the territory has a high degree of fragmentation. In Fig. 5, the result of the dilation on the red areas is shown. The new areas, which have been added by the dilation of the original ones, are shown in violet. The dilation causes the phenomena of filling the little "holes" and connect unconnected regions that are not so far. In fact, the dilation is performed with a radius of 50 meters, but in our example this has relevant effects, because the original anthropic area was highly fragmented. A little hole in an anthropic sub-regions is not a "wild" area, because the influence of anthropic activity on the nature is still very high. By filling holes and enlarging the outside perimeter of the anthropic sub-regions, the algorithm actually rises the areas occupied by humans, by taking into account the bad side effect of fragmentation of the territory on animal and plant species. In this example, the effect of the dilation is a gain of

the Death Zone of about 18%, if compared to the case of simply measuring the area of the anthropic sub-regions (without dilation).

The third step of the algorithm excludes the regions where human settlements are not possible, i.e., the part of the municipality, if any, occupied by inland waters (e.g., lakes or lagoons) or lands located more than 3,000 m above sea level. We define all these sub-regions as *neutral sub-regions.* The union of all the neutral sub-regions (if present), corresponds to the *Neutral Zone*. Let define *NA* as the area (in square kilometers) of the Neutral Zone.

After the computation of *S*, *DA*, and *NA*, we can define the *Anthropentropy Factor AF* [16] as the ratio:

$$AF = DA / (S - NA) \quad (1)$$

We have computed the *AF* indicator for all the municipalities of the two case studies.

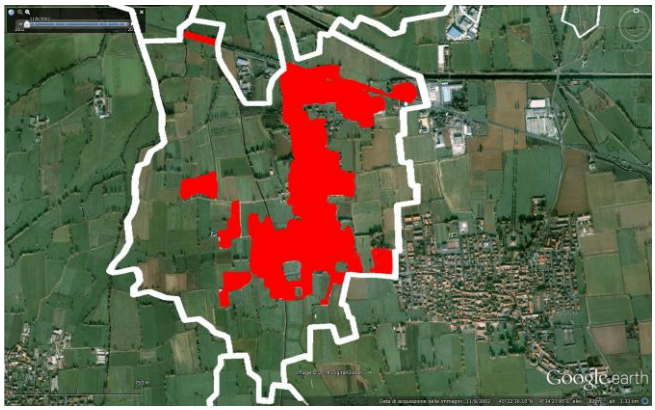

Figure 4. The anthropic sub-regions for the municipality of Monte Cremasco (Lombardia): in red, the anthropic regions are superimposed on the standard Google Earth map of the municipality, in white the boundaries of the municipality.

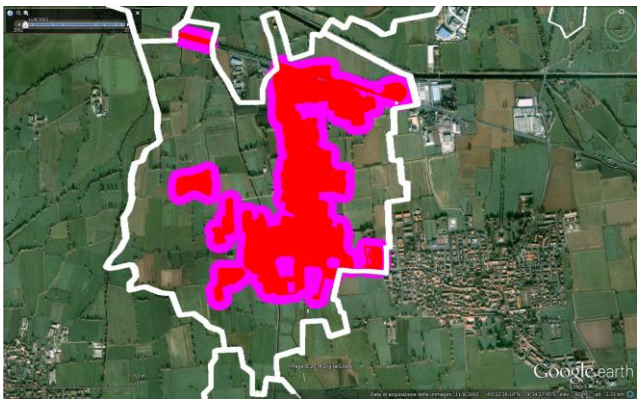

Figure 5. The anthropic sub-regions after the dilation: in red, the original sub-regions, in violet the added area. The Death Zone is the union of red and violet regions.

The first one is the province of Pavia, which is located around its chief town, Pavia (latitude, longitude: 45°11'7"44 N, 09°9'45"00 E), in the North-West of Italy. The province consists of 190 municipalities. In Fig. 6, the map of the area of the province of Pavia is shown: for each municipality, its territory is depicted in a color related to the class of land use, as specified in Table II (from green, yellow, red and black). In Fig. 7, the equivalent map is shown for the second case study, the province of Lodi, which is located around its chief town, Lodi (latitude, longitude: 45°18'52"20 N, 09°30'14"04 E). The province consists of 61 municipalities. The first case study has been already investigated in [1]. We have chosen the province of Lodi, as second case study, because it is close to the province of Pavia along the Po river (the longest and most important Italian river); therefore, it includes a territory very similar, for geomorphology and climate, to a great part of the province of Pavia. However, differences are notable, as the province of Pavia includes also a montane territory in the South part, which is completely missing in the province of Lodi. In the discussion of the results (See Section IV.B), it will be interesting to discover how differences and analogies on the geomorphology and altitude of the municipalities can affect the composite indicator. For all these reasons, we consider the second case study a good term of comparison to the first one.

The novelties of this algorithm, from the computer science side of the multidisciplinary approach, are the application of the mathematical morphology operator of dilation, for the computation of the *Death Zone*, to GIS data, and the application of the constraints of our framework in each of the computational steps of the algorithm. In particular, mathematical morphology have been widely use in computer vision theory as useful spatial data analysis [29]. However, morphological operators have been used on GIS data mainly for preprocessing and filtering in data acquisition phases [30], for extracting simple information on the spatial disposition of primitives (such as roads lines [31]) or to better detect areas that have to be categorized [32]. In our approach, the mathematical operator is used to generate new knowledge about the territory, as it is related to the definition of the concept of *Death Zone*, with its impact on the fragmentation of the territory and, consequently, on the biodiversity. The second aspect is that, without a careful study or precision and granularity of data, the application of mathematical morphology operators on GIS maps cannot give reliable and significant results. Therefore, the *joint use* of the operator dilation with the constraints of our framework (in particular, granularity and precision constraints in computational steps of Fig. 3) is a new and distinctive contribution of algorithms and tools of computer science, in particular in the computational sustainability field [33].

Even if the *AF* indicator is able to take into considerations quantitative extensions, shapes and relative positions of the anthrophized areas of a territory, it does not give any hints on the state of the green areas *outside* the anthropic areas, which is the goal of the second indicator here described.

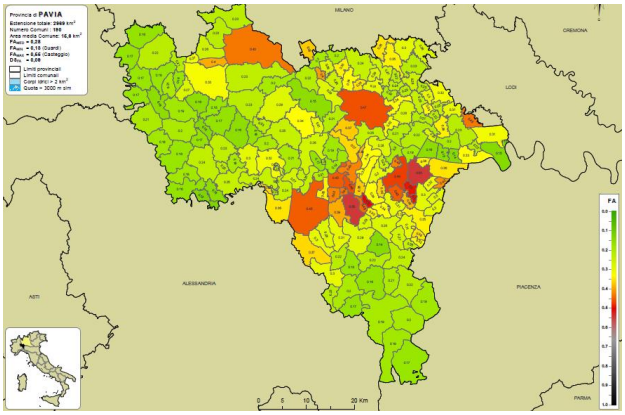

Figure 6. The visual map for the *AF* land use indicator for the municipalities of the first case study (Pavia Province, Lombardia, North Western Italy); the meaning of the colors is explained in Table II.

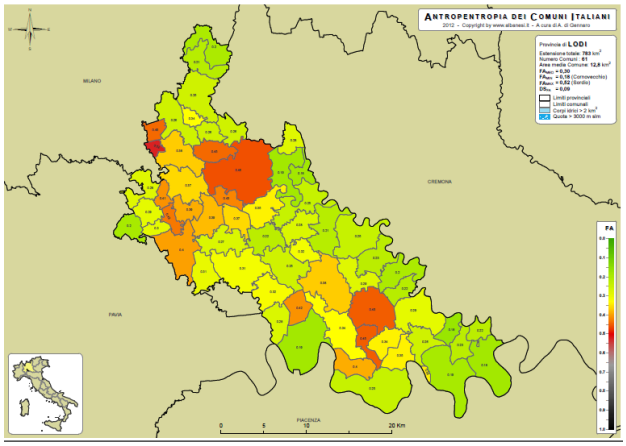

Figure 7. The visual map for the *AF* land use indicator for the municipalities of the second case study (Province of Lodi, Lombardia, North Western Italy)); the meaning of the colors is explained in Table II.

B. *Forest quality indicator*

The assessment of forest quality differs according to the different components that can be evaluated (ecological, social and/or economic components associated to forests). In many assessment systems, environment has been relegated to a relatively unimportant element, if compared with other issues such as economic importance, although there are now also some specialized indicator sets relating to the environment, such as WWF's Living Planet Index [34]. Other examples include: the IUCN well-being index [35], that divides indicators into two classes, the first relating to human well-being (socio-economic) and the second to the environment (ecological, environmental services etc.) and the Montreal Process criteria and indicators [34], for temperate and boreal species outside Europe, which uses seven criteria (and 67 indicators) including the conservation of biological diversity. For our purposes, the *FSQ* indicator [1] expresses the forest quality status as the value of its ecological components, with particularly reference to the biodiversity conservation. We have chosen the following components:

- the number of forest layers: more layers correspond to higher biodiversity;
- the presence of protected species according to the Lombardia regional law [L.R. 10/2008]: more protected species mean higher and better biodiversity;
- the presence of alien species: a lower number of alien species mean higher and better biodiversity.

For the target area of region Lombardia, in Figs. 8a and 8b, examples of protected and alien species are shown, respectively. We have imposed some limitation on the GIS data, following two important constraints:

- In the *FSQ* computation, only natural forests have been considered, i.e., plantations were excluded.
- Only forests occurring on areas greater than 10.000 square meters have been considered. In fact, floristic richness, in forest patches smaller than 1 ha, is generally very low [36].

Following the theoretical framework, in particular the granularity constraint, also the *FSQ* indicator is computed for each municipality of the target territories. We define a set of sub-regions occupied by natural forest F_i (i = 1, 2, n). Each of F_i may have one or more occurrences, denoted by the index k, in the territory (k = 1, 2, max(i)). Each k-th occurrence is characterizes by: (a) an area A^k_i, expressed in square meters, for i= 1,2,,,…n and k = 1, 2,… max(i) and (b) a type of T_i, derived from the GIS ERSAF Database "Map of the Forest Types of Lombardia" [27], which classifies forests on the basis of their physiognomy (dominant woody species) and the ecological characteristics of the site where they occur (geological substrate, type of soil, etc.) [37]. As for the *AF* computation, we take into consideration the same two target territories: the province of Pavia and the province of Lodi. In the first one, there are 66 different forest types, but only 32 of them have occurrences whose areas are greater than 10.000 square meters. Therefore, for the *FSQ* computation of the province of Pavia, n = 32. In the second case, the province of Lodi, only 11 forest types survive the area constraints. Therefore, for the province of Lodi, n = 11. As described before, the province of Pavia includes a portion of montane territory, which is not present in the province of Lodi. For this reason, the province of Pavia is characterized by a higher number of forest types. In Table III, a list of the types T_i and the relative reference *syntaxa* is provided, referring to the types, which are present in *both* the two provinces. The two provinces have ten forest types in common, therefore, the T_i are listed for i=1, 2,. 10. In Table IV, the forest types for the province of Pavia are listed. The province of Pavia has twelve forest types, which are not present in the province of Lodi, therefore, the T_i are listed for i=11, 12,. 32. There is only one forest type in the province of Lodi, which is not in the province of Pavia (labeled T_{33}, see Table V). The Type Lab field in the tables is a data label, which refers to the database [27] used as input source. Moreover, the difference between the two case studies is related not only to the number of forest types, but also to the

(a)

(b)

Figure 8. Examples of protected (a) and alien (b) species, according to the regional law of Lombardia: (a) *Convallaria majalis* (b) *Parthenocissus quinquefolia*. Photos have been acquired during the relevés in the target territories.

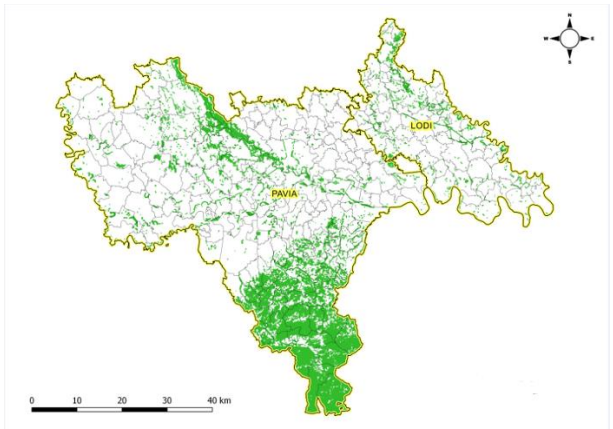

Figure 9. The two provinces of Pavia and Lodi: the areas of the forests are depicted in green.

TABLE III. FOREST TYPES IN COMMON BETWEEN THE TWO CASE STUDIES, THE PROVINCE OF PAVIA AND THE PROVINCE OF LODI.

Type Lab[a]	**Description of forest types T_i and relative reference *syntaxa***
1	T_1: Oak-Hornbeam wood of the lowlands *Syntaxa: Polygonato multiflori-Quercetum roboris* subass. *carpinetosum* and *anemonetosum* Sartori 1984; *Quercus robur*, *Carpinus betulus* and *Physospermum cornubiense* community; *Quercus robur*, *Carpinus betulus* and *Holcus mollis* community
12	T_2: Oak wood of inland sand dunes *Syntaxa: Quercus robur* community
13	T_3: Oak wood of stony river beds *Syntaxa: Quercus robur* and *Brachypodium rupestre* community
14-15	T_4, T_5: Oak-Elm wood (also including the Black Alder variant) *Syntaxa: Polygonato multiflori-Quercetum roboris* subass. *ulmetosum* Sartori 1984
173	T_6: Typical Black Alder wood *Syntaxa: Osmundo regalis-Alnetum glutinosae* Vanden Berghen 1971; *Carici elongatae-Alnetum glutinosae* W. Koch 1926 et R. Tx. 1931; *Carici acutiformis-Alnetum glutinosae* Scamoni 1935
177	T_7: Willow wood of bank *Syntaxa: Salix alba* community*; Salicetum albae* Issler 1926
180	T_8: *Salix cinerea* wood *Syntaxa: Salicetum cinereae* Zolyomi 1931
188	T_9: Pure *Robinia pseudoacacia* wood *Syntaxa: Robinia pseudoacacia* community
189	T_{10}: Mixed *Robinia pseudoacacia* wood *Syntaxa:Robinia pseudoacacia*, *Quercus robur* and *Ulmus minor* community

a. According to ERSAF database [27]

areas occupied by the forests, which is significantly lower in Lodi. This is evident by observing Fig. 9, where the two neighbor provinces are shown, with the forest areas depicted in green (without any differentiation among forest types): the province of Pavia has a considerably presence of forest in the South, where the altitude is higher. On the contrary, the province of Lodi has forests only near the boundaries, as the rest of the planar belt is occupied mainly by agricultural crops.

For each forest T_i of Tables III, IV, and V, we found the correspondence with one or more phytosociological tables [25]. When this correspondence was not reported by the above mentioned authors, we used other bibliographic references or phytosociological *relevés* collected in the area the forest type occurs.

For each forest type T_i, we defined a set of the following indicator components (s_i, a_i, p_i):

- Stratification (number of layers) of a forest type i (s_i): this component analyzes the quality of the forest structure. The tree and the herb layers are always present in a forest. The shrub layers (high-shrub and/or low-shrub layers) were considered valuable if their total cover were > of 10% of the sampled forest area (indicated in the phytosociological tables) or at least one species presented an abundance value equal to 2.
- Percentage frequency of alien species (a_i) in the corresponding phytosociological table/s. When more phytosociological tables described a forest type T_i, a

mean value between the percentages of each table was calculated.

- Percentage frequency of protected species (p_i) in the corresponding phytosociological table/s. When more phytosociological tables described a forest type T_i, a mean value between the percentages of each table was calculated.

The three components can assume only discrete values, from 0 to 3, according to an *if – then – else* algorithm described in the following of this paragraph.

TABLE IV. FOREST TYPES THAT ARE PRESENT ONLY IN THE PROVINCE OF PAVIA.

Type Lab[a]	Description of forest types T_i and relative reference *syntaxa*
20, 23	T_{11}, T_{12}: *Quercus pubescens* wood of the carbonatic substrates (also including the Chestnut variant) *Syntaxa: Quercus pubescens, Euphorbia cyparissias* and *Epipactis helleborine* community
26, 27	T_{13}, T_{14}: *Quercus petraea* wood of the carbonatic substrates and mesic soils (also including the Chestnut variant) *Syntaxa: Physospermo cornubiensis-Quercetum petraeae* Oberd. et Hofm. 1967
28	T_{15}: *Quercus cerris* wood *Syntaxa: Quercus cerris, Cruciata glabra* and *Anemone trifolia* community
45, 48, 49, 50, 57	T_{16}, T_{17}, T_{18}, T_{19}, and T_{20}: Chestnut wood on drift; Chestnut wood of the carbonatic substrates (mesic soils, meso-xeric soils, xeric soils); Chestnut wood of the siliceous substrates and mesic soils *Syntaxa: Physospermo cornubiensis-Quercetum petraeae* Oberd.et Hofm. 1967*; Castanea sativa* and *Corylus avellana* community
63, 64, 65	T_{21}, T_{22}, and T_{23} *Ostrya carpinifolia* and *Fraxinus ornus* wood (of layer, of cliff, typical) *Syntaxa: Knautio drymeiae-Ostryetum* Mondino et al. 1993
84	T_{24}: Birch wood *Syntaxa: Betula pendula* community
88	T_{25}: Primitive Beech wood *Syntaxa: Trochiscantho-Fagetum* Gentile 1974; *Fagus sylvatica* and *Acer opulifolium* community
89, 96, 97, 105	T_{26}, T_{27}, T_{28}, and T_{29}: Beech wood of the carbonatic substrates (high-montane, montane, montane of xeric soils, submontane) *Syntaxa: Trochiscantho-Fagetum* Gentile 1974; *Fagus sylvatica* and *Acer opulifolium* community
99	T_{30}: Beech wood of the siliceous substrates *Syntaxa: Trochiscantho-Fagetum* Gentile 1974; *Fagus sylvatica* and *Acer opulifolium* community
172	T_{31}: Black Alder wood of gulley *Syntaxa: Alnus glutinosa*, *Populus alba* and *Ulmus minor* community
183	T_{32}: White Poplar formation *Syntaxa: Populus alba* community

a. According to ERSAF database [27]

TABLE V. THE UNIQUE FOREST TYPE THAT IS PRESENT ONLY IN THE PROVINCE OF LODI.

Type Lab[a]	Description of forest types T_i and relative reference *syntaxa*
5	T_{33}: Oak-Hornbeam of the hills *Syntaxa*: *Castanea sativa*, *Carpinus betulus* and *Quercus petraea* community

a. According to ERSAF database [27]

While the definition of quality of stratification is independent on the altitude of the forest, the definition of values related to the percentages of alien and protected species is different, according to the altitude, because usually the impact of human activities decreases with the altitude. Thus, naturalness is higher in the montane belt than in planar belt. We differentiate between forest types belonging to the class "high hilly and montane" (altitude > = 500 m) and forest types belonging to the class "planar and low hilly" (altitude < 500 m). The three components (s_i, a_i, p_i) are defined according to an empirical *if – then – else* algorithm:

If the number of layers = 2, then $s_i = 1$
Else if number of layers = 3, then $s_i = 2$
Else if number of layers = 4, then $s_i = 3$
For altitude <500 m:
If the percentage of alien species is > 40 then $a_i = 0$
Else if alien species range is (15- 40] then $a_i = 1$
Else if alien species range is (5- 15] then $a_i = 2$
Else if alien species range is [0- 5] then $a_i = 3$
If percentage of protected species range is (0.5-3] then $p_i = 1$
Else if protected species range is (3- 6.5] then $p_i = 2$
Else if protected species range is > 6.5 then $p_i = 3$
For altitude > = 500 m:
If the percentage of alien species is > 10 then $a_i = 0$
Else if alien species range is (5-10] then $a_i = 1$
Else if alien species range is (2-5] then $a_i = 2$
Else if alien species range is [0- 2] then $a_i = 3$
If percentage of protected species range is (0.5-5] then $p_i = 1$
Else if protected species range is (5- 10] then $p_i = 2$
Else if protected species range is > 10 then $p_i = 3$

For each of the forest type *i* of Tables III, IV, and V, we computed the relative value set of (s_i, a_i, p_i), according to the *if – then – else* algorithm and the phytosociological tables and/or relevés: the complete value set is reported in Table VI.

After determining the values of the set of components for stratification, alien and protected species, it is now possible to define the *F*orest *S*tatus *Q*uality Indicator (in the following, *FSQ*) of a given territory of a municipality as

$$FSQ = \Sigma_i \ \Sigma_k (s_i + a_i + p_i) * A^k_i / S \qquad (2)$$

where *i* is one of the significant forest type (*significant* means that at least one occurrence of the forest has A^k_i >= 10.000 square meters) that is present in the territory under investigation (Tables III and IV for Pavia, Tables III and V for Lodi), A^k_i is the area of the *k-th* occurrence of forest type *i*, and *S* is the area of the municipality. The number of occurrences may vary, from a minimum of 1 to a maximum, which depends on the forest type. The *FSQ* definition is the weighted values of the components, where the weights are the ratios between the areas of the forests and the area of the territory under investigation. The wider is the area occupied by a forest, the higher is its contribution to the global quality of the territory. Besides, its contribution is weighted by the values of the components (stratification, alien, and protected species) as described in the *if – then – else* algorithm.

TABLE VI. THE VALUE SET OF COMPONENTS FOR STRATIFICATION, ALIEN AND PROTECTED SPECIES, FOR EACH FOREST TYPE OF BOTH THE CASE STUDIES.

Type Lab[a]	Components (s_i, a_i, p_i)
1	3,2,3
5	3,2,3
12	2,2,1
13	3,3,3
14-15	3,2,2
20, 23	3,3,1
26, 27	2,3,3
28	3,3,2
45, 48, 49, 50, 57	2,3,3
63, 64, 65	3,3,2
84	1,3,0
88	3,3,3
89, 96, 97, 105	3,3,3
99	3,3,3
172	3,3,1
173	2,3,2
177	1,1,0
180	2,2,0
183	3,1,0
188	2,1,0
189	3,2,0

TABLE VII. THE METRIC ON THE *FSQ* INDICATOR FOR FOREST QUALITY.

Class of forest quality	Evaluation of Forest quality and policy	
	Intervals of FSQ	***Suggested policy***
1 Unsatisfactory	0 <= *FSQ* <= 0.9	Very low level forest quality. A high-impact policy of restoration and/or requalitication of forest is mandatory.
2 Satisfactory but improvable	0.9 < *FSQ* <= 1.8	Sufficient forest quality but improvable. A policy for forest biodiversity conservation is preferable.
3 Good	1.8 < *FSQ* <= 3.6	Good forest quality, the first level of satisfactory situation. A policy for the conservation of existing forests is suggested.
4 Optimum	3.6 < *FSQ* <= 4.5	The optimun situation, with a high quality of forests. A policy for the conservation of existing forests is suggested. Anyway, if shrublands and grasslands are scarse or absent, a policy for their biodiversity conservation has to be considered.
5 Overbalanced	*FSQ* > 4.5	The overbalanced situation, forests have overcome other ecosystems. A policy for shrubland and grassland biodiversity conservation is highly suggested.

The summation in (2) is for all the forest types of the territory under investigation, and for all the occurrences of the forests. The *FSQ* value can range from 0 (no forests are present in the territory with at least one occurrence of A^1_i> 10.000) to a maximum of 9, which refers the "perfect", quite unrealistic, situation of forests of very high quality (set of components (s_i, a_i, p_i) =(3,3,3)), which occupy the entire territory of the municipality ($\Sigma_t \Sigma_\kappa A^k_i = S$). By using an approach similar to the *AF* metric, we have defined a set of ranges for the *FSQ* indicator. In Table VII, the metric for the *FSQ* indicator and the suggested policy actions are shown.

C. Results for the two indicators

By referring to the general framework of the multidisciplinary approach, the different knowledge of vegetation science and computer science has been combined, by following the stated rules (format, temporal, granularity and precision constraints), on the GIS databases, and the results are the values of *AF* and *FSQ*, computed for all the municipalities of the province of Pavia and Lodi, according to eqs. (1) and (2), respectively. In Figs. 10 and 11, the plot of *AF* and *FSQ* are reported for Pavia and Lodi, respectively. On the X-axis, the municipalities are listed according the alphabetical order on their names, and each of them is labeled by a numerical value (from 1 to 190 for Pavia, from 1 to 61 for Lodi), to increase readability. On the Y-axis, the values of the two indicators are plotted. By comparing the two provinces, it is clear that the *AF* values are comparable for the two cases: on the contrary, the *FSQ* values are considerably lower for the second case (Lodi, see Fig. 11, blue lines) than for the first one (Pavia, see Fig. 10, blue line). The *FSQ* indicator is even considerably lower than the *AF* indicator for the second case (the red line is over the blue line, for most of the cases), and this is more surprising, if we consider that the two indicators have different scales (from 0 to 1 for *AF*, from 0 to 9 for *FSQ*). This is evident also from the scatter plot, where the relations *FSQ* vs. *AF* are depicted (see Figs. 12 and 13, for Pavia and Lodi, respectively). From the scatter plot, we see a similar dependency between the two indicators in the two provinces, with most of the municipality with the *FSQ* values agglomerated around the Y-axis (*FSQ* = 0), but with different performance in terms of class of metrics. In fact, we can see that the *AF* indicator shows a comparable land use level for both the two provinces: almost all the *AF* values are below the first worrying level of *AF* = 0.4 (classes 1 and 2 of land use, see Table II) and few are in class 3, no one in classes 4 and 5. However, performance in terms of forest quality are very different. The *FSQ* values for Pavia cover all the classes (see Table VII), while for Lodi, the *FSQ* values are all in the first, unsatisfactory class (*FSQ* < = 0.9). This means that in the second case study, not only forests are less present in the landscape of Lodi (as it can be infer by simply analyzing the cumulative GIS image of the forests, see Fig. 9), but also that their quality is not so high to compensate the quantitative negative situation. The dispersion plots (Fig. 13 and Fig. 14) show that the two indicators are quite independent and this is a positive result, this means that the two indicators are related to independent and different pressures on the

environment: land use and forest quality. This is also confirmed by the correlation between the *AF* and *FSQ*, which is very low: the correlation coefficients are equal to -0,197651 and -0,205527, for Pavia and Lodi, respectively. The analysis of the dispersion plots also reveals that all the municipalities with serious levels of *AF* (> 0.4) have very low levels of forest quality (*FSQ* < 0.9), for both the provinces. This underlines a worrying trend to neglect the ecological compensations to mitigate the impact for increasing urbanization. This suggest the fact that in both the two provinces environment and biodiversity loss are scarcely considered in the land use policies.

It is evident that the two indicators, *AF* and *FSQ*, express different pressure on the biodiversity, and that it is not simple to get an overall view of the situation of a territory, if we consider the two environmental indicators separately. This is due, not only to the fact that they are assessed according to two different metrics, but also because it is difficult to compare different municipalities by using a couple of un-normalized values, instead of only one. For this reason, a further step in this research has been taken in the direction of building a composite indicator, described in Section IV.

IV. THE COMPOSITE INDICATOR

After the definition of the two simple indicators and their computation on the case studies, it is now possible to build a unique, composite indicator, with the aim to give an overall description of the two aspects of environmental preservation: land use and forest quality.

A. Theory of composing AF and FSQ indicators

Composite indicators are increasing recognized to be very relevant in policy action assessment and communication to citizens about social, economic and environmental issues. They have undisputed advantages, against known or otherwise controllable disadvantages. In fact, a composite indicator is able to summarize, in a more compact and powerful way, multiple concepts, related to different "single" indicators. Moreover, it reduces the set of considered data and for this reason it is easier to be interpreted and to be communicated to the citizens. The last aspect is particularly important in environmental issues, where communication of the state of the territory is relevant, as it is the first step to raise awareness on the environment preservation. The main disadvantages of composite indicators are related to the accuracy of their definition: as data and dimensions are reduced, relevant information may be missed, if the construction process lacks of statistical or conceptual knowledge, or if it is not transparent and fully described, in terms of data selection and applied algorithms. Concerning data selection, we use the availability constraint of our framework, which is implemented by the open data paradigm: all the databases we have used are fully available on Internet and they can be processed by open source GIS software [26]. Concerning the algorithm for the composite indicator computation, in our research we follow a rigorous method [19]. The method consists of several steps, which can be summarized in the following paragraphs.

Theoretical framework: in this step, the basis for the selection of the single indicators are to be settled. This step generally involves knowledge of experts and stakeholders of the target issue. As already discussed in Section II, the formalization of the multidisciplinary approach individuates vegetation science and computer science as the fundamental disciplines, and a set of *constraints* to assure a robust communication between the two sciences.

Data selection: this step has been already described, as it consists of the choice of the databases and the computation of *AF* and *FSQ* indicators. The formulas for the definitions of the two environmental indicators (see (1) and (2)) and the data set of the two case studies (see Section IV) are the outputs of this step.

Imputation of missing data: this step is relevant whenever the collected data are not complete, and missing data has to be replace in some way. In our case, Corine Land Cover [12] and ERSAF [27] databases are very detailed, and the problem of missing data is quite irrelevant, as the classification of land use and the forest areas are quite enough for the granularity and the precision adopted in the framework. There is only one aspect that can be reported to the problem of missing data: in the ERSAF databases, some typologies of forest cannot be assigned with the component of stratification, alien and protected species, because their description is too vague. They are two typologies of forest labeled as "unclassified forest areas" (ERSAF [27] Type Lab Fields 900 and -100). However, these data occupy an area of 3.6% of the entire region Lombardia, therefore, it is reasonable to omit these data and to adopt a Complete Cases approach [19], where data are simply discarded, as their irrelevance on the entire set of data. As a rule of thumb, if a variable has less of 5% of missing data [38], the cases can be omitted and the Complete Case Analysis is a simply but robust choice.

Statistical analysis: in Table VIII, the main statistical data measured on *AF* and *FSQ* indicators are provided for the two case studies.

Normalization: this step is fundamental to compose indicators, which are expressed in different scales or measure units. In our case, *AF* range of definition is [0-1], while *FSQ* range is [0-9]. Moreover, the two indicators are *discordant* [39]: in fact, low values of *AF* expressed a positive assessment on the environmental issue (See Table II), while, on the contrary, low level of *FSQ* expresses a negative assessment (See Table V). In the general theory, a composite indicator *X* can be written in the form:

$$X = F\,[N_1(x_1), N_2(x_2), \ldots, N_j(x_j)] \qquad (3)$$

where F is a function of aggregation, x_j are the single j-th indicator, N_j is a normalization function. In our case, j = 2 and $x_1 = AF^m$ and $x_2 = FSQ^m$, where the variable *AF* and *FSQ* can assume *m* distinct values (*reference data-set*), corresponding to all the municipalities of our case studies, namely *m* = 190 + 61 = 251. There are plenty of possibility in choosing the normalization and aggregation functions [39]. In our study, we start with the simplest linear

normalization, which reports the range of indicators from 0 to 1:

$$x_j - \min(x_j) / [\max(x_j) - \min(x_j)] \quad (4)$$

For the case of *AF* indicator the normalization is the concatenation of two linear transformations: the first one considers the complement to 1, (1 – *AF*), in order to make the two indicators concordant, and the second is the linear transformation of (4). Therefore, we have:

$$N_1 (AF^m) = [(1 - AF^m) - \min(1 - AF^m)]/ [\max(1 - AF^m) - \min(1 - AF^m)] \quad (5)$$

$$N_2 (FSQ^m) = [FSQ^m - \min(FSQ^m)]/ [\max(FSQ^m) - \min(FSQ^m)] \quad (6)$$

Aggregation and Weighting functions: after normalization, the choice of the aggregation function is the final step for the definition of the composite indicator. It allows to merge the information of the two normalized indicators to give, as output, a unique value for each item of the reference data-set. In our case, we have chosen the simplest solution of the linear aggregation with equal weights (0.5), in order to give the same importance to the two phenomena, i.e., land use and forest quality. This operative choice is the most common in the case of a limited number of indicators with a low degree of correlation [19], as in our study.

Therefore, we can define the Biodiversity Composite Indicator (*BCI*) as:

$$BCI^m = 0.5 * N_1 (AF^m) + 0.5 * N_2 (FSQ^m) \quad (7)$$

where N_1 and N_2 are the normalized functions defined in (5) and (6), respectively, and the index *m* cover all the municipalities of both the provinces, i.e., $m = 1,2,\ldots 251$.

B. Results for composite indicator

The Biodiversity Composite Indicator gives a value, for each municipality, in the range of [0-1], where 0 means the worst situation and 1 the best one. Obviously, in the composite indicator, we lose the distinction of what factor influences the result (if land use or forest quality), but we have an overall, absolute assessment of how the two aspects are combined in the impact on biodiversity.

In Fig. 14 and Fig. 15, the *BCI* values for the two provinces of Pavia and Lodi are shown, respectively. On the X-axis, the municipalities are listed according the alphabetical order of their name, and each of them is labeled by a numerical value (from 1 to 190 for Pavia, from 1 to 61 for Lodi), to increase readability. On the Y-axis, the values of the Biodiversity Composite Indicator are plotted. If we define a metric for the *BCI* similar to the two metrics for the simple indicators (see Table II and Table VII), we can settle five classes of situations (see Table IX), of increasing performance in term of global impact on biodiversity of both the two aspects (land use and forest quality).

TABLE VIII. REPRESENTATIVE STATISTICAL DATA FOR THE TWO INDICATORS FOR THE TWO CASE STUDIES, PAVIA AND LODI.

Territory	**Main characteristics**	
	AF indicator	***FSQ indicator***
Range of indicator	[0-1]	[0-9]
Case study °1: Province of Pavia		
Number of computed values	190	190
Minimum value	0.133	0
Maximum value	0.548	5.34978
Average value	0.2757	0.4949
Standard Deviation	0.091	1.01
Case study °2: Province of Lodi		
Number of computed values	61	61
Minimum value	0.175	0
Maximum value	0.524	0.58
Average Value	0.305	0.0832
Standard Deviation	0.088	0.162

By comparing the values of *BCI* for the two case studies (Fig. 14 and Fig. 15), we can infer that the composite indicator expresses a more serious situation for the province of Lodi, than for Pavia. In fact, in the second case study, none of the municipalities shows a value greater than 0.6 of the composite indicator, while in the first case study, few but existing cases refer to good or excellent situation (*BCI* > 0.6, classes 4 and 5).

In order to compare directly the two case studies, we can report on the same plot the percentage of municipalities that fall in each of the class of impact on biodiversity (see Fig. 16). Also, in this analysis, the first case study (Pavia) outperforms the second one (Lodi). In fact, the percentages of the municipalities belonging to the classes 1 and 2 (see Table IX), which refer to the dramatic and serious impact on biodiversity, are always higher in the second case study (Lodi) than in the first one (Pavia).

The last issue we want to discuss refers to the question if the altitude may influence the *BCI* performance. The results from the experiments seem to indicate that the altitude influences the *BCI* values, only if its range includes a significant percentage of municipalities of "high" altitude (previously defined as altitude > 500 m). In fact, in the first case study, the correlation between the *BCI* and altitude is enough good (0.584), while in the second case the correlation is weak and, even, negative (-0.196). This is visually confirmed by comparing Fig. 17 and Fig. 18. In these two plots, the *BCI* values are reported for the two provinces, as a function of the average altitude of the municipality the *BCI* value refers to. In the first case study, it is true that in the higher classes of our composite indicator (classes 4 and 5) we find *only* montane municipalities.

TABLE IX. THE METRIC ON THE *BCI* INDICATOR.

Evaluation of the Biodiversity Composite Indicator		
Class of impact on biodiversity	***Intervals of BCI***	***Meaning***
1	0 <= *BCI* <= 0.2	The worst situation, with a dramatic impact on biodiversity.
2	0.2 < *BCI* <= 0.4	A very serious level of pressures on biodiversity.
3	0.4 < *BCI* <= 0.6	A first worrying impact on biodiversity of the compound effect of land use and forest quality.
4	0.6 < *BCI* <= 0.8	A good situation, with a satisfactory impact of land use and forest degradation on biodiversity.
5	0.8 < *BCI* <= 1	The excellent situation, with a very low impact of land use and forest degradation on biodiversity.

In the second case study, where the altitude range is very limited (40-101 m), the dependency between altitude and *BCI* is not significant at all. A better idea of the correlation between altitude and *BCI* could be obtained considering the whole region of Lombardia, where the altitude range is considerably wide (11-4021 m).

V. CONCLUSION AND FUTURE WORK

In this paper, we presented a new composite indicator, which can express the pressures on biodiversity, by considering two distinct phenomena: land use and forest quality status. In order to define the composite indicator, a conceptual framework has been proposed, starting from the multidisciplinary approach used in the research.

The framework states clearly the constraints, the methodologies and knowledge used by the two scientific fields involved in the research: vegetation science and computer science. We defined the composite indicator, based upon two simple indicators, the *Anthropentropy Factor* and the *Forest Status Quality Indicator*, and we analyzed two case studies, for a total number of 251 municipalities of the North-West Italian territory, i.e., region of Lombardia.

Current and future developments of this work include the computation of the composite indicator for the entire region of Lombardia. It is an ambitious goal, as the region ranks first in Italy for the population and the number of local municipalities (1530), second for population density and the fourth for area. Moreover, the region is also the most invaded by non-native species, which represent 16.9% of the total vascular flora [40]. The region Lombardia is a complex territory with very different geological, geomorphological, and climatic, bioclimatic, and phytogeographical characteristics. As a consequence, a high floristic and vegetation richness is present: the vascular flora includes 3220 entities [40], while the forest vegetation includes 174 forest types [27], [37]. For all these reasons, the computation of the Biodiversity Composite Indicator on the whole region can give interesting hints and priorities on the biodiversity conservation in different environmental conditions and contexts.

ACKNOWLEDGMENT

The authors greatly appreciate Antonio di Gennaro for his collaboration, and for importing and pre-processing of data from GIS databases.

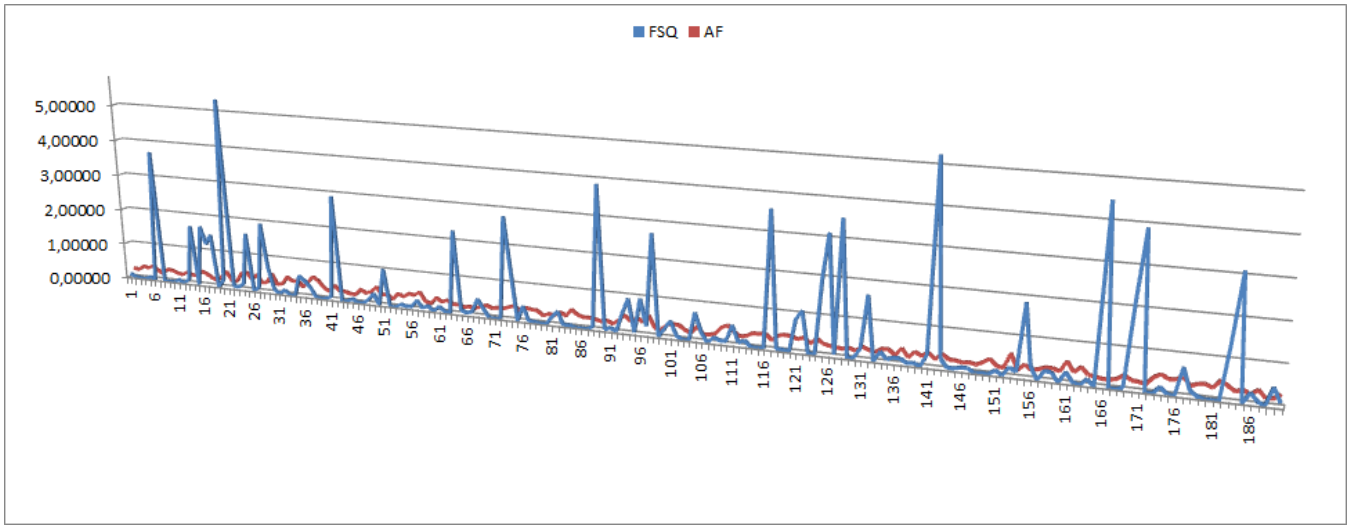

Figure 10. The two indicators, Anthropentropy Factor (*AF*) and Forest Status Quality (*FSQ*), for all the 190 municipalities of the province of Pavia.

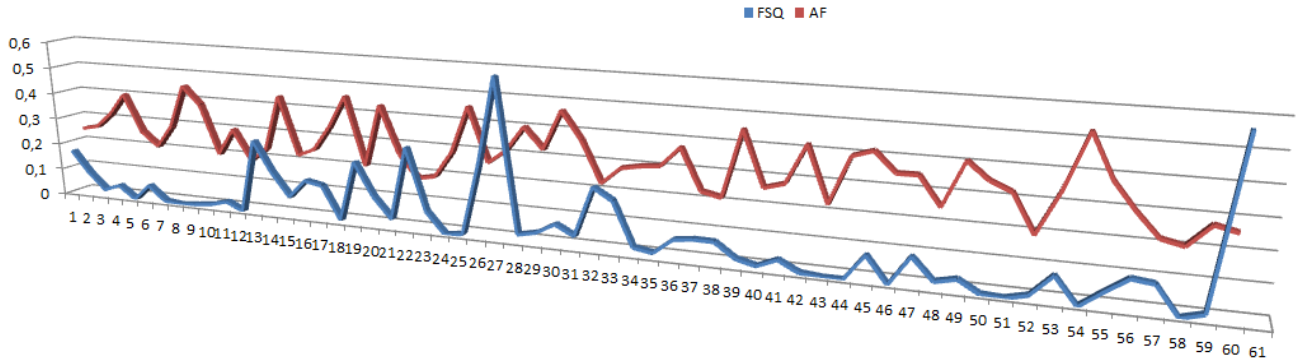

Figure 11. The two indicators, Anthropentropy Factor (*AF*) and Forest Status Quality (*FSQ*), for all the 61 municipalities of the province of Lodi.

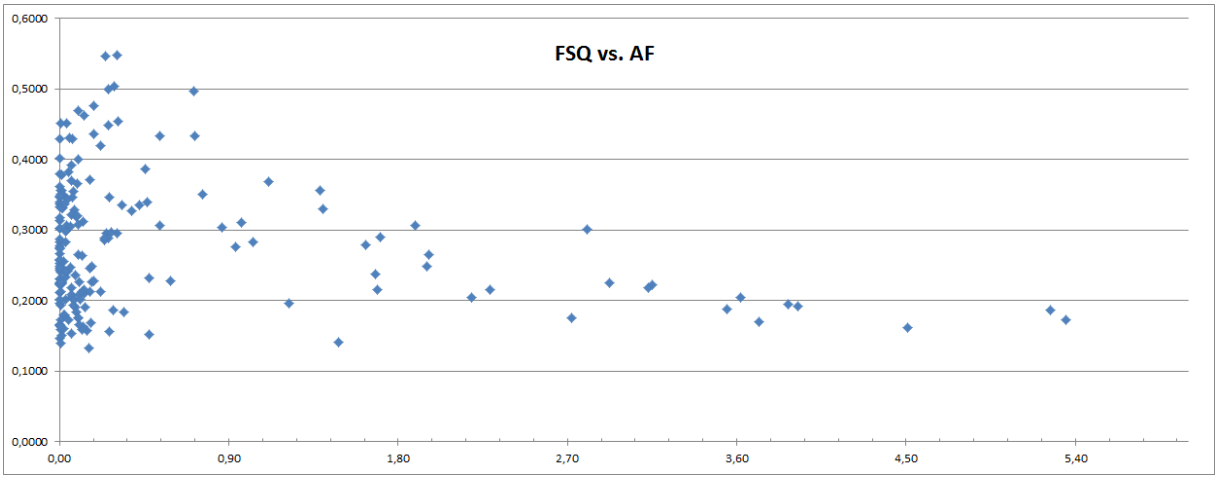

Figure 12. The relationship between the two indicators for land use and forest quality: dispersion plot of *FSQ* (on the X axis) vs. *AF* (on the Y-axis), for all the municipalities of the province of Pavia.

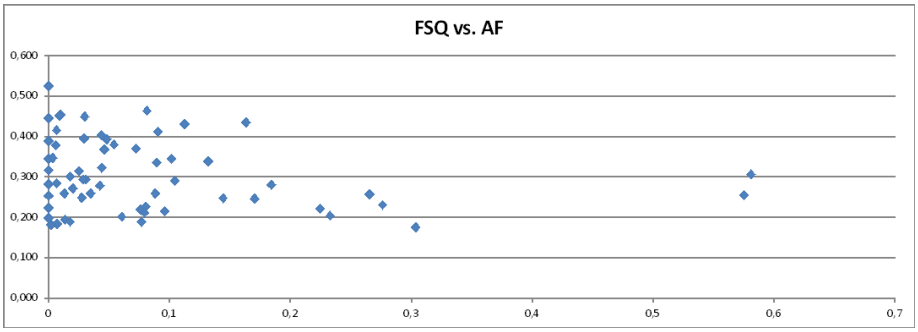

Figure 13. The relationship between the two indicators for land use and forest quality: dispersion plot of *FSQ* (on the X axis) vs. *AF* (on the Y-axis), for all the municipalities of the province of Lodi.

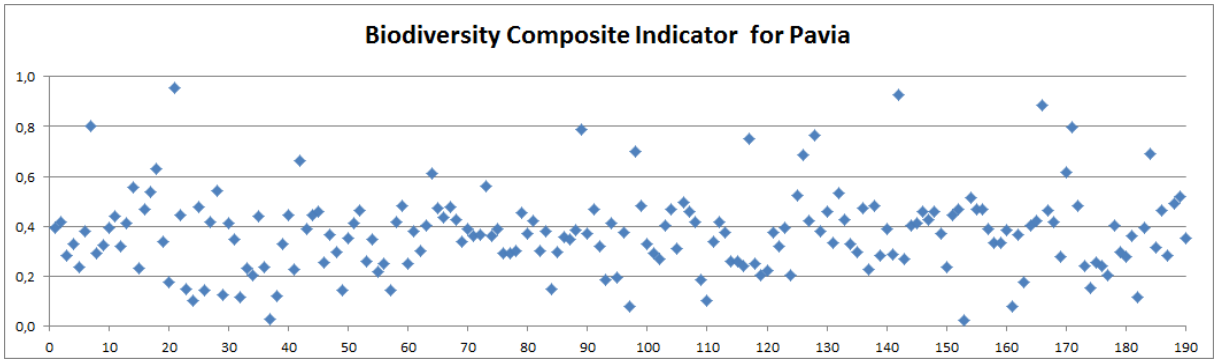

Figure 14. The Biodiversity Composite Indicator for all the municipalities of the first case study, the province of Pavia.

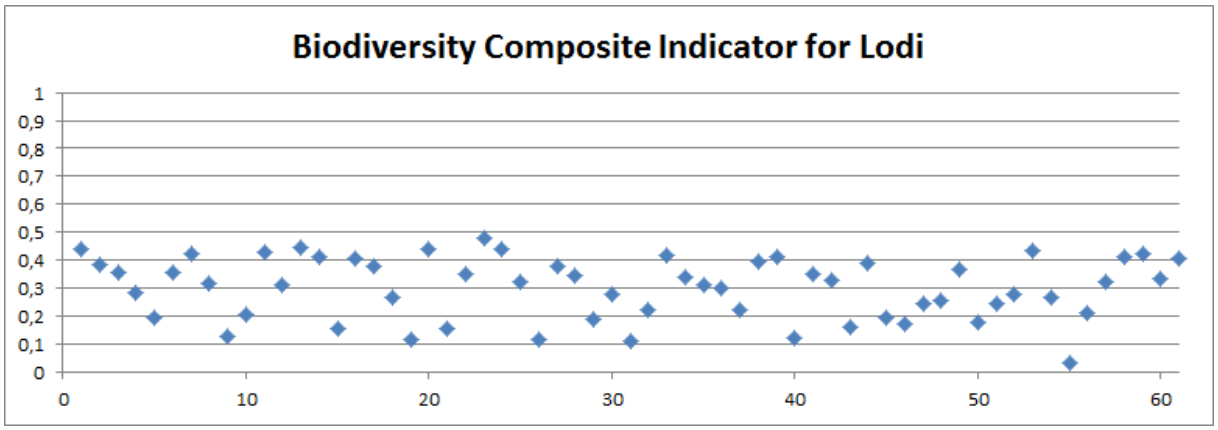

Figure 15. The Biodiversity Composite Indicator for all the municipalities of the second case study, the province of Lodi.

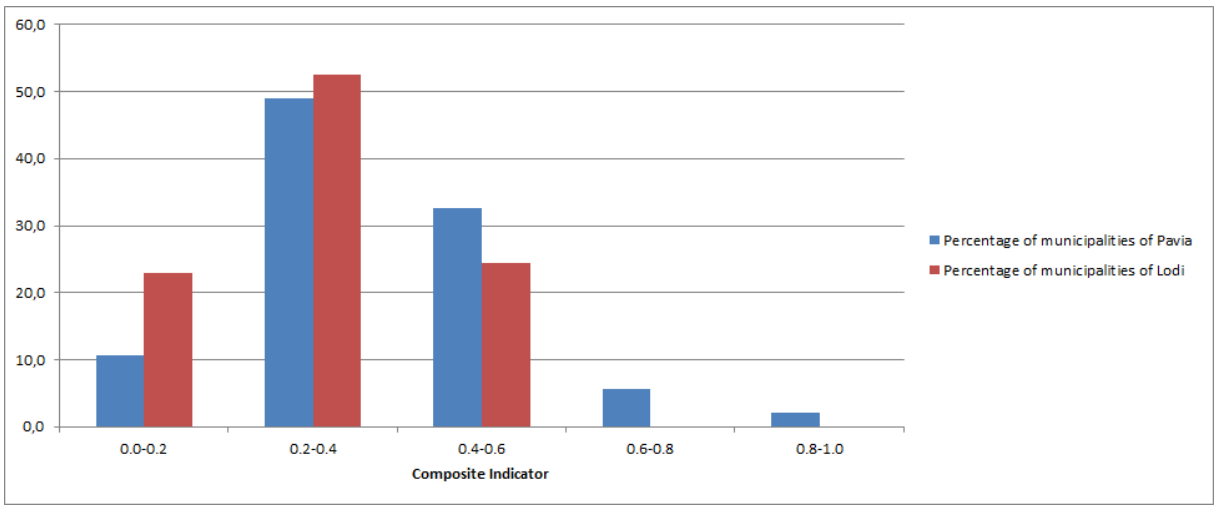

Figure 16. The percentage of municipalities falling into the five classes of pressure impact expresses by the sub-ranges of the Biodiversity Composite Indicator, for the two case studies (Pavia and Lodi).

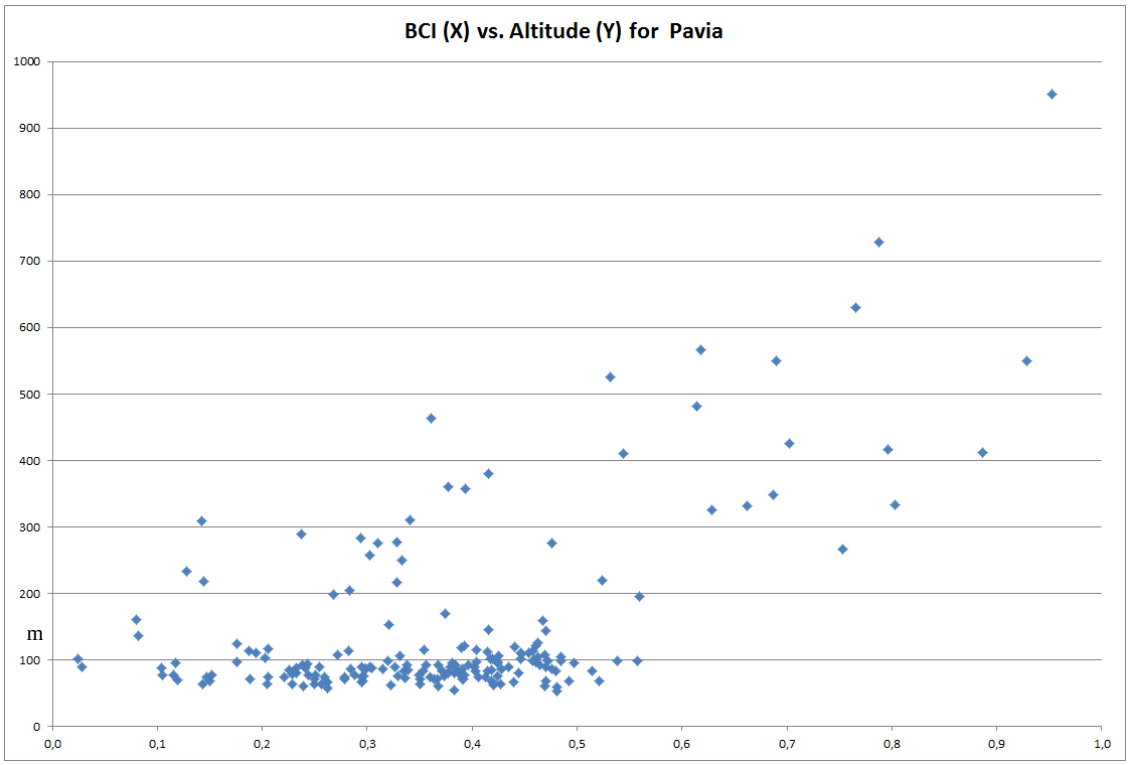

Figure 17. The relationship between the *BCI* and the average altitude (in meters) of the municipalities of Pavia.

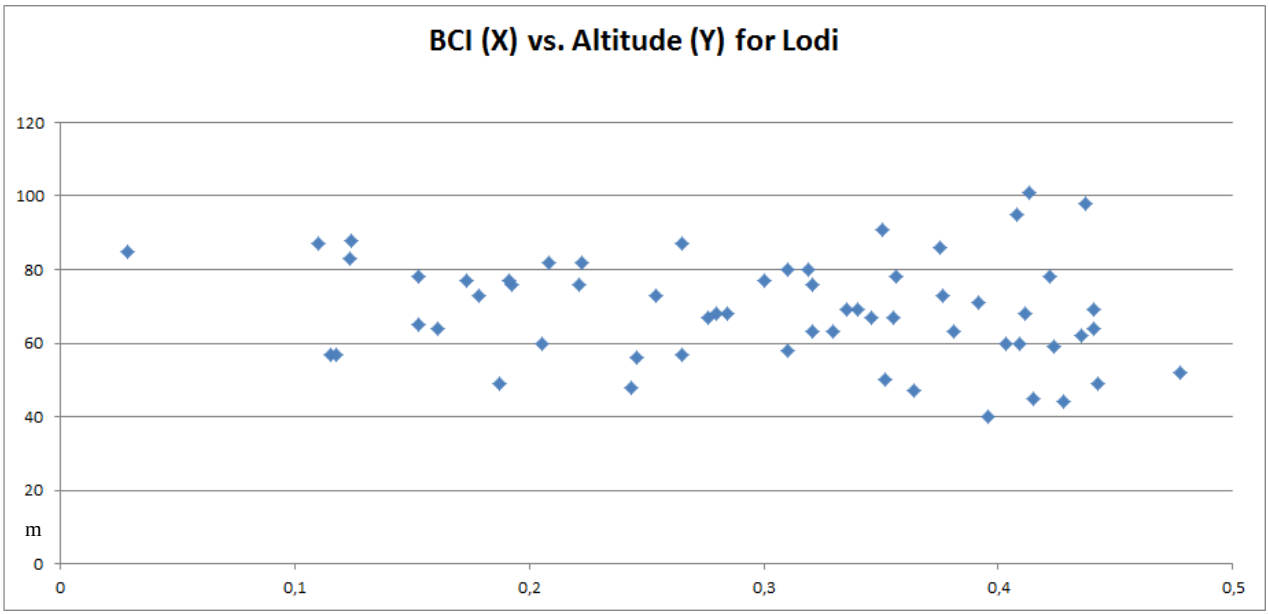

Figure 18. The relationship between the *BCI* and the average altitude (in meters) of the municipalities of Lodi.

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