An Improved Model for GUI Design of mHealth Context-Aware Applications

Mario Quinde[1,2](✉) and Nawaz Khan[2]

[1] Universidad de Piura, Piura, Peru
mario.quinde@udep.pe
[2] Middlesex University, London, UK
MQ093@live.mdx.ac.uk, N.X.Khan@mdx.ac.uk

Abstract. One of the main challenges of mobile health is using the smaller screens of mobile devices efficiently to show information supporting the health decision-making process. This research proposes a model that can be used to design and evaluate GUIs of mHealth context-aware applications with the aim of ensuring a proper distribution of key information among the screens. The proposed model is then evaluated based on the Health-ITUEM usability parameters description. The results of this evaluation show the attributes related to usability that have been enhanced.

Keywords: Mobile health · GUI design · Usability
Decision-making · GUI · Context-awareness

1 Introduction

The use of smartphones and devices connected to Internet has increased in recent years and it will keep increasing in the future [1–3]. This spread has given users the opportunity to change from software that worked in PC with wired Internet to software that works in mobile devices with wireless Internet.

Mobile technology has brought a new paradigm that has improved efficiency and quality of processes by delivering ubiquitous and user-centered solutions. This is reflected in terms as m-learning, m-health, m-commerce or m-banking [1]. Mobile health (mHealth or m-health) can be defined as a part of eHealth that avoid location boundaries [4] by using mobile devices and wireless communication technologies to support healthcare systems [5]. mHealth provides powerful tools for improving health processes through the use of mobile devices [6].

Table 1 shows relevant benefits that mHealth brings to the main stakeholders involved in the health process: patients, healthcare givers and management staff. The main benefits for patients are empowerment, communities building and learning. Healthcare givers receive benefits from decision-making, communities building and learning. Finally, the main benefit for management staff is the increase of efficiency, accuracy and procedural tracking in their tasks.

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Table 1. Benefits of mHealth

Patients	Healthcare givers	Management staff
Empowerment	Decision-making	Efficiency
Communities building		Accuracy
Learning		Procedural tracking

mHealth allows *patients' empowerment* as it increases self-awareness [1,7,8] and self-monitoring [9], which leads to the improvement of patients' decision-making and self-management [10,11]. An example of this is the delivery of support and guidance to patients through mobile devices [12]. Mobile technology also provides ubiquitous communication schemes [13] facilitating the *building of social-communities*. This permits patients to receive feedback and encouragement [11], to share and manage knowledge [11,14], and to receive advice from healthcare givers located around the world [9,10,15]. Mobile devices can also improve *patients' learning process* as it favours the delivery of instructions to react properly to emergencies, to be aware of risks and to improve preventive behaviours [1].

Mobile devices benefit the *decision-making process* of healthcare givers by facilitating the input of patients' data and the reception of targeted health information [5]. This eases the creation of context-aware solutions [14] as a consequence of gathering data from tracking patients and their contexts, and using it to offer recommendations based on well-grounded decision making [3,14]. Healthcare providers benefit from *communities building* in a similar way than patients. The fact that doctors use their personal mobile phones for work issues [16] allows them to perform their activities flexibly by working remotely [17] and to consult with specialists allocated in different places around the world [9]. mHealth also enhances the *learning process* of health workforce because mobile devices have the appropriate technology to offer services that are used to train and increase knowledge of the health workforce [7,18]. Some examples are the use of TB Detext [19] -a mobile application providing health workers with access to up-to-date educational content about tuberculosis-, and the use of PDAs to provide nurses with access to tools and health information [5].

mHealth is improving *efficiency, accuracy and procedural tracking* of healthcare processes. It provides digital ecosystems reducing waste and improving quality [9]. mHealth solutions have been able to engage remote workers, reduce administrative burden, improve the data quality, increase the reliability on records and boost confidence at the point of contact with patient [20]. More specific benefits are: monitoring efficiently patients attributes and environment [1], reducing admissions and readmissions [21], and cutting the cost of care by patients spending more time out of hospitals [9]. Some mHealth solutions that have improved efficiency and quality are applications for consulting information of a patient [22], booking appointments, renewing prescriptions and consulting with healthcare providers [15].

Despite of these benefits, mobile devices still have several challenges to face in order to keep improving health processes [1,3,6,7]. One of the main issues that stops mobile technology from delivering more benefits is the small screen size of mobile devices [5,23]. This is relevant given the complex decision-making environment of health processes [23] and the limited technological background of potential users [10]. Because of this, it is important to find efficient ways of using the screens of mobile devices to show relevant information supporting decision-making [23].

This research contributes to face this challenge by proposing and validating a model that enhances the design of usable Graphic User Interfaces (GUI) of mHealth context-aware applications. The research question answered is how to design usable GUIs of mhealth context-aware applications supporting decision-making. Hence, this work aims to close the gap between the potential benefits of mHealth and the challenge of using efficiently the available space of mobile devices to show information.

The description of the benefits of mHealth shows a strong link between them and the context-aware features that mHealth applications provide. *Context-awareness* (also known as *context-aware computing*) is defined in [24,25] as "*the use of context to provide task-relevant information and/or services to a user*", where *context* is defined as "*any information that can be used to characterize the situation of an entity, where an entity can be a person, place, or physical or computational object*". Because of this link, the proposal of this research will also be analysed from the perspective of context-awareness in order to show the potential benefits that the proposed model could bring to the development of mHealth context-aware applications.

The methodology used to develop this research is shown in Fig. 1. The outcomes of the literature review were used to develop the model and to design the questionnaire. The benefits and challenges of mHealth showed the importance of GUI design when developing mHealth application, and both the Information Supply Chain (ISC) Framework [26] and the analytical model proposed by

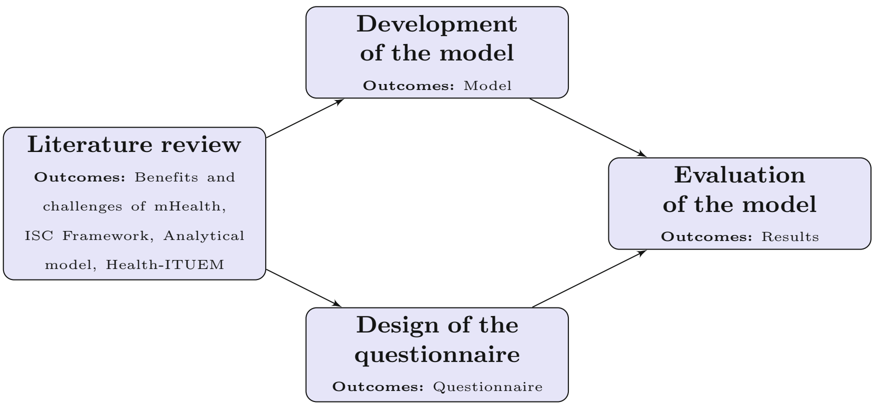

Fig. 1. Methodology process

Varshney [23] set the foundation of the model. The Health IT Usability Evaluation Model (Health-ITUEM) was the basis to design the questionnaire used in the qualitative research that led the evaluation of the model.

This work is divided into the following sections. Section 2 explains the GUI design challenge of mHealth in developing context-aware solutions. Section 3 explains the proposed model and an application example of it. Section 4 describes the evaluation process used to validate the model and shows its results. Section 5 presents a discussion of the results and analyses the model from the perspective of context-awareness. Finally, conclusions are reached in Sect. 6.

2 The Graphic User Interface Challenge of mHealth

The GUI design challenge of mHealth is linked to the smaller screens of mobile devices. It becomes more relevant when is analysed from the health perspective as it directly impacts on quality of health processes [1]. Furthermore, both the complex decision-making environment of health processes [6] and the fact that potential users of mHealth may have a limited technological background [10] make it important to design high-quality GUI of mHealth applications.

Despite this, GUI of mHealth applications are not properly evaluated and tested. The evaluation of GUI mHealth applications is less rigorous than the evaluation of web-based health applications [27]. Moreover, healthcare experts and target users are not included in the development process of these applications [7,8]. To counter this challenge, it is important to develop frameworks enhancing the design and evaluation processes of mHealth applications [18,27]. Besides, it is also critical to use potential users and communities of experts to assess the development of health applications [2,7,18].

Facing this challenge indirectly tackles other mHealth challenges. An appropriate GUI allows to spend less time using the application, which counters the less battery capacity of mobile devices. A proper GUI also decreases the cognitive overload that reduces decision-making capacity [23]. Data integration is another challenge [6] that is faced because a well-designed GUI can be used as a starting point to define the information flow required to develop a mHealth application. Finally, a usable GUI easing the users' adaptation process aids to cope with the IT literacy challenge that limits the number of potential users of mHealth [11].

2.1 Context-Awareness and GUI Design

The large amount of information available and the miniaturization of hardware components are both recognized in [28] as part of the advances that have allowed the emergence of the Intelligent Environment paradigm. Nevertheless, providing users with large amount of information is not always convenient given the fact that cognitive overload can reduce the quality of decision-making and the quality of healthcare services when it is evaluated from the mHealth perspective.

A simple example of cognitive overload is a mobile application tracking the temperature of a house. If this application sends notifications to the users (parents) every time there is a change in the temperature -even for variations of 0.1 °C-, it is highly probable that users will ignore these notifications because the temperature of the house may change several times during the day. This fact may reduce the quality of decision-making as the parents will not be aware of temperature as a consequence of ignoring the notifications. A better scenario is the same mobile application allowing users to set the temperature limits that will trigger the notifications. This approach would be better as the users will be notified only when the temperature changes are relevant for them.

From this point of view, context-awareness is important when is used to reduce the cognitive overload of users in mHealth [23]. In this research, its relevance is analysed from the GUI design perspective of mHealth applications. For this, it is important to highlight that the aim of using context-awareness in this field is to support humans and not to replace them in the decision-making process [23]. Hence, a proper context-aware GUI should provide the right distribution and formatting of the information to show in order to allow users to read the information easily and to make the decision-making process more efficient. In [6], this is explained by saying that the GUIs of mHealth applications should be able to adapt to the cognitive capacity of decision makers and to the necessities of the healthcare professionals involved in the health processes.

3 An Improved Model for GUI Design of mHealth Context-Aware Applications

3.1 Foundation of the Model

The proposed model improves the GUI design of mHealth applications. It is based on both the analytical model for improving decision-making in mHealth proposed by Varshney [23] and the Information Supply Chain (ISC) Framework proposed by Kandl and Khan [26].

Varshney proposes two enhancements for improving quality of decision-making in mHealth. The first one is related to data processing and its aim is to deliver more accurate alerts generated by context-aware solutions. The second enhancement improves GUI design by suggesting how to distribute information among the screens of a mHealth application. With the aim of enhancing decision-making, the author suggests that a mHealth application should show the most important information on the first screens and the least important on the last screens [23].

The ISC Framework of Kandl and Khan supports complex queries by using seven concepts related to integration in the ISC. One of these is the Information Completeness (IC) concept that measures how complete the information for decision-making is. The IC index can be calculated by using Formula 1.

$$IC = \frac{I_p}{I_r}, \quad (1)$$

which represents a comparison between the information instances present in the system and all the information instances required for decision-making [26].

I_p is the number of information instances that are present in the system and I_r represent the number of information instances required for decision-making. For example, to conclude an investigation, information about Sample, Drug, Clinical Issue and Hypothesis must be present. If all required information is indeed linked to the investigation then said information is 100% complete. On the other hand, if Hypothesis is missing the resulting IC is lowered to 75%.

Although the IC can be used to know how complete the information shown by a system is, it cannot be used to measure if the information shown by the system is properly distributed among its screens. This research integrates the IC concept with the enhancement proposed in [23] to show a more comprehensive view on GUI design for mHealth applications.

3.2 Explanation of the Model

The core of the model is Formula 2 that calculates the Information Distribution Index (IDI). This formula is the result of improving the IC for being capable of measuring the distribution of information among the screens of a mHealth application. The IDI is calculated by comparing how the information is distributed among the screens (dividend) and how the information should be distributed (divisor). The result is a real number between 0 and 1 whose interpretation is: the closer to one, the better the information is distributed among the screens of the mHealth application.

$$IDI = \frac{\sum(I_{pi}W_{pi})}{\sum(I_{ri}W_{ri})} \tag{2}$$

It is important to clarify the concept of Information Unit (IU) in order to understand Formula 2. An IU is a specific information that would be shown or not by the mHealth application. Examples of IUs are: weight, blood glucose level and beats per minute (bpm).

I_{pi} is an integer that becomes 0 when IU_i is not shown by the application, and 1 when IU_i is shown. W_{pi} is an adjusted weight representing the importance given to IU_i by the application. W_{pi} will be higher when IU_i is shown on an earlier screen of the application. I_{ri} is an integer that becomes 0 when IU_i is not required for decision-making, and 1 when it is required. W_{ri} is an adjusted weight representing the importance of IU_i in the decision-making process the mHealth application supports. The more important IU_i is in the decision-making process, the higher the value of W_{ri}.

The purpose of using W_{pi} and W_{ri} is making comparable the scale used to define the importance given to the IUs by the application and the scale used to assess the importance of the IUs in decision-making. For instance, an application using 5 screens to show IUs uses a scale of 5 to assess the IUs shown (1 is the value given to IUs shown on the fifth screen, and 5 to IUs shown on the first). If the importance of these IUs in decision-making is assessed by using a scale of 10 (0 to non-relevant IUs and 10 to the most relevant IUs), both scales will not be comparable.

W_{pi} is calculated by using Formula 3, where N is the number of screens the application uses to show IUs. Only screens dedicated to shown IUs must be included when calculating N (e.g. login or help screens are not included in this calculation). S_i is the screen number of the mHealth application in which IUi is shown. If IUi is shown on the first screen, then S_i will be 1.

$$W_{pi} = N - S_i + 1 \tag{3}$$

W_{ri} is calculated by using Formula 4, where E_i is the evaluation given to IUi regarding its relevance in the decision-making process the mHealth application supports, and E is the scale used to evaluate the relevance of the IUs in decision-making. An $Ei - value$ of 0 should be assigned to the non-relevant IUs, while the highest $Ei - value$ (E) should be assigned to the most relevant IUs.

$$W_{ri} = \left\lceil \frac{E_i N}{E} \right\rceil \tag{4}$$

It is important to consider that if W_{pi} is higher than W_{ri}, then W_{pi} must get the value of W_{ri}. By doing this, the formula penalizes when an important IU is not shown on an early screen, but it does not reward when a minor IU is shown on an early screen. Hence, the IDI does not benefit a mHealth application that compensates showing important IUs on later screens by showing minor IUs on earlier screens.

Other consideration to calculate the IDI is that if an application shows IUs that are not relevant for decision-making those IUs must not be included in the calculation. Otherwise, the IDI will not be valid. For instance, supposing an application that supports diabetes self-management shows patient's eyes colour. If this IU (eye colour) is included in the calculation, the IDI increases as the dividend is higher. This would be wrong as showing patient's eye colour does not improve the distribution of important information for decision-making among the screens of the mHealth application.

The proposed model can be used for two purposes: (a) as an evaluation tool to assess if the IUs are well distributed among the screens of a mHealth application, or (b) as a designing tool to provide a guideline on how to distribute IUs among the screens of a mHealth application that is being designed. Different processes should be followed depending on the purpose chosen to use the model.

When using the model as an evaluation tool, the process shown in Fig. 2 must be followed. The first two steps can be performed at the same time, but these must be completed before beginning the third. The first step aims to define the evaluation scale (E), the IUs required (I_{ri}) and its level of importance (E_i) in the decision-making process supported by the mHealth application that is being evaluated. The evaluation of the IUs must involve expert patients, healthcare givers and researchers. Including them is considered a good approach to face the GUI design challenge when creating IT health solutions [2,7,18].

The second step identifies the IUs shown by the mHealth application (I_{pi}), the number of screens dedicated to show IUs (N) and the screen in which each IU is shown (S_i). Finally, the third step is to calculate IDI by using Formula 2.

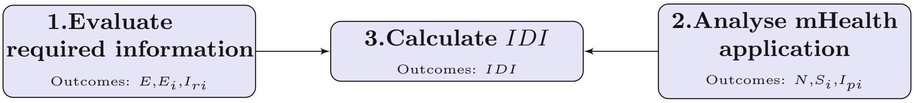

Fig. 2. Process to follow when using the model as an evaluation tool

Figure 3 shows the process to follow when using the model as a designing tool, which is made of three sequential steps. The first step is similar to the first step in Fig. 2. The only difference is that, when using the model as a designing tool, the IUs that will be shown by the mHealth application (I_{pi}) are defined in the first step. These I_{pi} are the same that the IUs required for decision-making (I_{ri}). When using the model as an evaluation tool (Fig. 2), the I_{pi} are defined in the second step.

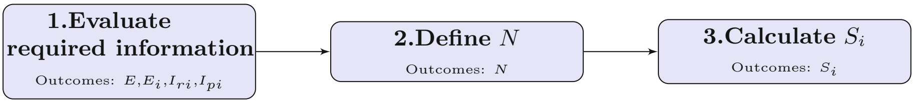

Fig. 3. Process to follow when using the model as a designing tool

The second step is defining some designing parameters to develop the mHealth application. These parameters will help to define the number of screens the mHealth application will use to show IUs (N). Some examples of these parameters are the fonts and formats that will be used to develop the application. It is recommended to complete Step 1 before beginning Step 2 as knowing the number of IUs the mHealth application will show helps to define N.

The third step is using the IDI to calculate the screen number in which each IU should be shown (S_i). As the objective of this case is to find the best possible distribution, the IDI should be equalized to 1 and, after substituting and clearing the equations related to calculate the IDI, the formula to calculate S_i is the following:

$$S_i = N + 1 - \left\lceil \frac{E_i N}{E} \right\rceil \tag{5}$$

The results of Formula 5 must be used as a guideline to distribute IUs among the screens of a mHealth application supporting decision-making. Other factors must also be considered in the distribution of the IUs among the screens. For example, in [23] it is recommended to show IUs correlated between them on the same screens.

Furthermore, it is also important to explain that the IDI penalizes when an IU is shown on a later screen than the one where it should be shown (S_i), but it does not reward when an IU is shown on an earlier screen than the one where it should be shown. Because of this, the IDI cannot differentiate between an application showing IUs on the screens suggested by the model and an application showing IUs on earlier screens than those suggested by the model.

3.3 Application Example of the Model

This section describes an example to clarify the use of model. The main goal is to show how to use the IDI to provide a guideline to distribute IUs among the screens of a mHealth application supporting diabetes self-management.

Table 2. Results of the application example

i	IU_i	E_i	S_i	i	IU_i	E_i	S_i
1	Blood glucose level	5	1	10	Blood pressure minimum	4	1
2	Urine glucose level	4	1	11	Total cholesterol level	2	3
3	Glucose target	5	1	12	Total cholesterol target	2	3
4	HbA1c level	3	2	13	Low Density Lipoprotein level	2	3
5	HbA1c target	3	2	14	Low Density Lipoprotein target	2	3
6	Fructosamine level	1	4	15	High Density Lipoprotein level	2	3
7	Fructosamine target	1	4	16	High Density Lipoprotein target	2	3
8	Blood pressure (hypertension)	4	1	17	Triglyceride level	2	3
9	Blood pressure maximum	4	1	18	Triglyceride target	2	3

The first step is to evaluate the IUs related to diabetes self-management. The IUs required (I_{ri}) were obtained from the Diabetes UK charity's website [29]. The scale used to evaluate the importance of the IUs in the diabetes decision-making process is 5 (0 to the non-important IUs and 5 to the most important). As the aim of this example is explaining the use of the formula, the evaluation process of the IUs required (I_{ri}) has been simplified. The evaluation of each IU (E_i) was done by interpreting the description provided in the website, without including expert patients, healthcare givers or researchers. The IUs to show in the application (I_{pi}) are the same IUs required for decision-making (I_{ri}).

The second step is to define the number of screens dedicated to show IUs (N). For this example, N is defined as 4. The third step is using Formula 5 to calculate in which specific screen each IU should be shown (S_i). Table 2 shows the results of this application example including the IUs (I_{pi}, I_{ri}), its evaluation (E_i) and the screens where they should be shown (S_i).

4 Evaluation and Results

The proposed model has been evaluated through a qualitative research based on the Health-ITUEM. This evaluation model assesses usability of health IT by evaluating how the technology affects nine concepts linked to usability [27]. These concepts are: Error prevention, Completeness, Memorability, Information needs, Flexibility/Customizability, Learnability, Performance speed, Competency and Other outcomes related to usability. The scenario mapping these concepts for GUI design is shown in Table 3.

Table 3. Scenario mapping Health-ITUEM for GUI design

Health-ITUEM concept	Description regarding GUI design
Error prevention	The GUI facilitates error management (e.g. showing error messages as feedback, supporting error correction and error prevention, etc.)
Completeness	The GUI assists users to successfully complete tasks
Memorability	The GUI aids to remember how to perform task through the system
Information needs	The GUI shows information improving or supporting basic task performance
Flexibility (or Customizability)	The GUI offers more than one way to perform tasks, allowing users to use the system as they wish
Learnability	The GUI makes it easier to learn how to use the system
Performance speed	The GUI allows to use the system efficiently
Competency	Users are confident in their ability when using the GUI of the system to perform tasks

A questionnaire was applied to two samples. The first sample (S_1) was made of 33 students from an Industrial and Systems Engineering undergraduate programme. They had taken and passed a module in which topics related to GUI design were taught and evaluated. The second sample (S_2) was made of 15 professionals that had completed undergraduate programmes related to Software Engineering. All respondents from S_2 had between 3 and 22 years of experiences in the subject and 13 of them had completed or were studying a post-graduate programme related to the subject.

The questionnaire was made of 10 closed questions. Two questions asked how using the model impacts usability and user-friendliness. The other eight questions asked how the model impacts the Health-ITUEM concepts. Hence, the results of the evaluation show if the proposed model improves, does not affect or decreases the Health-ITUEM concepts. Table 4, Figs. 4 and 5 summarize the results of the evaluation process.

All respondents state the model improves Usability, and most of them state the model improves User-Friendliness (S_1: 87.88%; S_2: 93.33%). At least 70% of the respondents of each sample affirm the model improves Error prevention (S_1:

Table 4. Results of the evaluation process

Concept	S_1(%)			S_2(%)		
	Improved	Unaffected	Decreased	Improved	Unaffected	Decreased
Usability	100.00	0.00	0.00	100	0.00	0.00
User-Friendliness	87.88	9.09	3.03	93.33	6.67	0.00
Error prevention	81.82	18.18	0.00	73.33	26.67	0.00
Completeness	87.88	9.09	3.03	93.33	6.67	0.00
Memorability	60.61	27.27	12.12	86.67	13.33	0.00
Information needs	87.88	12.12	0.00	86.67	13.33	0.00
Flexibility	36.36	45.46	18.18	33.33	40.00	26.67
Learnability	81.82	18.18	0.00	73.33	26.67	0.00
Performance speed	72.73	18.18	9.09	100.00	0.00	0.00
Competency	75.76	21.21	3.03	80.00	20.00	0.00

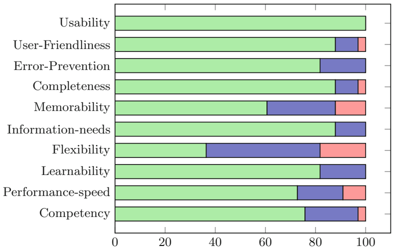

Fig. 4. Results (%) of Sample 1

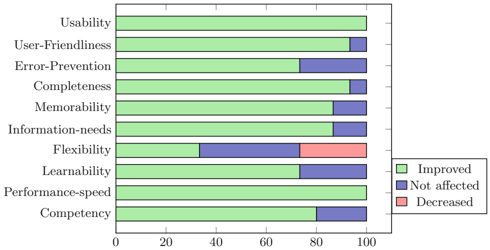

Fig. 5. Results (%) of Sample 2

81.82%; S_2: 73.33%), Completeness (S_1: 87.88%; S_2: 93.33%), Information needs (S_1: 87.88%; S_2: 86.67%), Learnability (S_1: 81.82%; S_2: 73.33%), Performance speed (S_1: 72.73%; S_2: 100%) and Competency (S_1: 75.76%; S_2: 80.00%).

The results also show that respondents do not coincide in confirming that the model improves, decreases or does not affect Flexibility. Moreover, 60.61% of S_1 and 86.67% of S_2 believe the model improves Memorability. All respondents of S_2 agree in affirming the model does not decrease any concept, except for Flexibility (26.67%). Nevertheless, some respondents of S_1 say that the model decreases User-Friendliness (3.03%), Completeness (3.03%), Memorability (12.12%), Flexibility (18.18%), Performance speed (9.09%) and Competency (3.03%).

5 Discussion

According to the respondents, although there is no majority, Flexibility (or Customizability) is the Health-ITUEM concept most negatively affected by the model. The reason why the respondents state this should be further investigated, but this result would be because of the fact that the model assesses the *IUs* for being on a specific screen of the mHealth application. Nevertheless, from this point of view, the model -as a designing tool- can be used to proposed an initial distribution of the *IUs* among the screens of the mHealth application. Then, this distribution can be altered by the users according to their specific requirements, using a GUI designing approach that allows them to personalise (or customize) the location of the *IUs* on the screens they want.

The proposed model can also be analysed from the perspective of context-awareness in order to show how it can aid the development of context-aware applications for mHealth. In [24,25], context is defined as "*any information that can be used to characterize the situation of an entity, where an entity can be a person, place, or physical or computational object*". It can be said that the *IU* concept is linked to this definition as context is made of *IUs that are relevant to the decision-making process of users*, who in this case are patients or people in charge of them. From this point of view, the model improves the distribution of the *IUs* that define the context supporting the decision-making of carers and patients regarding their disease. The model defines the *depth of screen* to reach an *IU* according to the importance the *IU* has in building the context of patients for a specific disease.

The evaluation of the model shows that it improves the GUI designing process of mHealth applications and it impacts positively on concepts related to usability and user-friendliness. Although the model is mainly targeted to assess the *IUs* framing the medical dimension of patients' context, the approach can be used to distribute the *IUs* defining other dimensions of the patients' context. Three main features of context-aware applications are shown in [24]: (1) the presentation of information an services to a user, (2) automatic execution of a service, and (3) tagging of context to information for later retrieval. The use of the model would impact on the first of these features. However, further research should be done to validate the use of the model to distribute *IUs* building multi-dimensional contexts among the screens of mHealth context-aware applications.

6 Conclusions

This research proposes and evaluates a model supporting GUI design of mHealth context-aware applications. The model directly faces the GUI design challenge and it indirectly faces others: IT literacy, decision-making, data integration and battery duration. It can be used to evaluate if the *IUs* are well distributed among the screens of an application and to provide a guideline to distribute *IUs* among the screens of an application that is being designed.

The evaluation of the model was based on the Health-ITUEM and its results show the model improves Usability, User-Friendliness, Error prevention, Completeness, Information needs, Learnability, Performance speed and Competency. Nevertheless, there is less evidence to confirm the model improves Memorability, and there is not enough evidence to know how the model affects Flexibility.

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