User Engagement with Digital Health Technologies

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1 Introduction

Recently, there has been a digital revolution in healthcare [30]. Over the last two decades, billions of dollars' worth of investments have been directed into ICT (information and communications technologies) solutions for healthcare. "Knowledge is the enemy of disease, the application of what we know will have a bigger impact than any drug or technology likely to be introduced in the next decade", famously predicted Sir Muir Gray, Director of the United Kingdom (UK) National Health System (NHS) National Knowledge Service and NHS Chief Knowledge Officer over 10 years ago [25] when he established the National Electronic Library for Health in the UK [26].

New evidence-based digital libraries and web portals designed to keep busy clinicians up to date with the latest evidence were created in the UK and USA [34]. Digital libraries have formed a subset of online health portals [8, 10, 44] and have been increasingly providing key information about clinical care, up-to-date policies and guidelines and essential underlying evidence-based knowledge [60]. Further, serious (educational) games are new arrivals that have established themselves firmly in the spectrum of health online resources contributing to health knowledge, awareness and subsequently health outcomes. One of the key challenges is how to methodologically assess their educational impact without decreasing user enjoyment and engagement. Online virtual communities of practice (VCoP) in the health domain have enabled collaborative work over geographical distances and barriers; however, keeping them sustainable remains a challenge.

How have digital health technologies actually been assessed? The typical methods for assessing them (and the core method of engagement) have been to investigate

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their effectiveness in providing information through searching and browsing. User preferences for information access and navigation behaviour on medical portals have been widely researched to improve usability and access to information [44]. While it is known that user perceived behaviour differs from actual online behaviour [47, 61] combined methods are required to gain a realistic picture.

However, how do we define, assess and ultimately improve engagement with these resources? With more research being undertaken, the focus of health resources evaluation has started to shift towards impact evaluation [9] and assessment of knowledge, attitude and behaviour change; this development has been mirrored in traditional library domains [49].

Overall, in this chapter, we focus on health online resources delivering evidence and improving knowledge, their impact in clinical settings at the point of care, the role of serious games for health and, finally, engagement of individuals and communities. We define user engagement from the perspective of these four themes:

1. Knowledge and attitude change
2. Impact at the point of care
3. Integrative digital storytelling
4. Professional communities of practice

In each section, we discuss one of these four core themes using the particular definition of engagement (above) and methodological framework for digital health technology; these are applied to a real case study from health domain. The structure of this chapter is illustrated in Table 1. For the purposes of this chapter, we do not investigate the evaluation of behaviour change.

Table 1 Four themes for user engagement, digital health technologies and case studies

Theme	Digital health technology	Case study project
Knowledge and attitude change	Internet portals	Bugs and Drugs
Impact at the point of care	Digital libraries	National Resource for Infection Control
Integrative digital storytelling	Serious games	Edugames4All
Professional communities of practice	Virtual Communities of Practice and collaborative Web 2.0 technology	FEMwiki

2 Knowledge and Attitude Change

2.1 Knowledge and Attitude

Disseminating "explicit knowledge" (i.e. knowledge that can be written down) [59] could be considered one of the fundamental aims of Internet health portals aiming to equip users with the knowledge necessary to carry out their work, whether that be appropriate clinical guidelines, relevant articles for an assignment or evidence to support decision-making.

There is general consensus on the definition of attitude, that it involves placing value or judgment on something or someone. Fishbein and Ajzen suggest that "Attitude refers to a person's favourable or unfavourable evaluation of an object, event or person" [22] or "the degree to which performance of the behaviour is positively or negatively valued" [2]. In the medical context, attitudes are important as the value or judgment a healthcare professional places on the information held within the portal may affect the impact this information has on their work [22]. This is of equal importance for patients and citizens who are looking after their own health and well-being.

There have been studies looking at users' ability to search and find specific information on the Internet [17], but there has not been enough consideration of whether the users of health information websites have actually remembered this information and whether it has had any impact on their knowledge or attitudes.

Assessing knowledge and attitude independently provides a valuable proxy of user engagement; however, for wider impact, understanding the relationship between knowledge and attitude change is important. Through administrating two identical sets of questions assessing knowledge and attitude before and after using an online health portal, we could:

- Test for changes in knowledge
- Test for changes in attitudes
- Evaluate the relationship between changes in knowledge and changes in attitude

2.2 Relationship Between Knowledge and Attitude Change

It is all very well to improve people's knowledge, but if this has no impact on their attitude and subsequent behaviour, then in this case, it would be a futile exercise. Therefore, the knowledge and attitude change evaluation was designed in a complementary way to show the correlation between these variables.

This approach has been piloted with a small digital library in the healthcare domain (Bugs and Drugs) where library users were asked a series of questions before using the library and then asked the same questions after using the library, showing positive changes in knowledge and attitude [42, 43].

2.3 Case Study: Bugs and Drugs

Bugs and Drugs (www.antibioticresistance.org.uk) is a website aimed at the general public about antimicrobial resistance [46]. It was funded by the UK Department of Health and provides an interface for the general public. Bugs and Drugs was developed under the umbrella of the health digital library (DL) called National electronic Library for Communicable Disease (NeLCD) [67, 69], which later became the National electronic Library of Infection (NeLI) in the UK (www.neli.org.uk) [35–37, 44]. NeLI further enhanced access to evidence by semantic navigation to infection resources [15, 16, 28]. Bugs and Drugs provided a small collection of information to help reduce the unnecessary prescribing of antibiotics, i.e. changing attitudes and eventual behaviour.

2.3.1 Changes in Knowledge and Attitude

To evaluate changes in knowledge about antibiotics and antibiotic resistance, the user was asked to decide whether seven statements about antibiotics were true or false. Some of the "answers" or correct versions of the statements were more obvious in the site than others, e.g. one question ("People become resistant to antibiotics": True or False?) was the subject of the current tip of the month present on every page of the site.

To evaluate changes in attitude, the user was asked to rank their agreement with six statements on a Likert scale of 1 (strongly disagree) to 5 (strongly agree). Four of these statements were about the user's attitude to information on the site, e.g. "Antibiotics help to reduce the duration of pain in AOM (acute otitis media—a common childhood ear infection)". How the user evaluates that information will be seen in their attitude to the statement after using the site, i.e. to what extent they agree or disagree with it. Other Likert scale statements were about the user's attitudes to prescribing antibiotics for AOM, "Doctors should prescribe antibiotics for AOM" and "I would expect an antibiotic for me/my child if I/they had AOM". Answers to these statements will indicate clearly the user's attitude with respect to the use of antibiotics in AOM in general and in their own situation.

2.3.2 Relationship Between Knowledge Change and Attitude Change

The knowledge questions on antibiotics were reflected in the attitude questions on AOM and a question on user learning self-assessment to indicate further correlations. To evaluate our AR test bed, these results are essential as the ultimate aim of the antimicrobial resistance website is to contribute to reducing inappropriate prescription of antibiotics. If people know that antibiotics are not an effective treatment for certain infections as a result of using the site but would still expect one from their doctor for those infections, then the site has only half done its job.

2.3.3 Results

The antimicrobial resistance site was tested in the Science Museum, London, as part of their "live science" programme. Over a period of 7 days during UK February school holidays, 227 people took part in the study. Of these, 177 completed both questionnaires. A paired t-test was performed to test the statistical significance of changes between pairs of questionnaires. The detailed results for each question are illustrated in Table 2.

There was a significant change in the mean score for the true/false statements (1 for correct answer, 0 for incorrect or "don't know") of users before (mean = 4.33) and after using the site (mean = 4.90 $p < 0.001$). With respect to individual statements, there were significant changes in the answers to four of the seven statements. The largest change was from 9.6 % of users getting the answer right to statement 1b ("People can become resistant to antibiotics") before using the site to 45.76 % getting this answer correct after using the site ($p < 0.001$). This reflects the visual impact of the answer to this question in the site, as it was the focus of the tip of the month on the home page.

With respect to changes in attitudes, the most significant change (mean from 3.44 to 2.74, $p < 0.001$) was for the statement about the duration of antibiotic course in the ear infection indicating that after using the site, people were tending to neither disagree nor agree with the statement, rather than agree. For the two statements examining attitudes to prescribing, there were significant decreases in the mean scores (i.e. levels of agreement) for both "I would expect an antibiotic for me or my child if I/they had AOM" and "Doctors should usually prescribe antibiotics for AOM", indicating that maybe this "new" information the users had learned could have an impact on their potential behaviour.

Comparing the actual changes in knowledge and attitude for individual users, Fig. 1 shows the relationship between users' change in knowledge score and their

Table 2 Agreement before and after using the site with changes in mean scores, p values from a paired t-test and associated confidence intervals (CI) for statements testing attitude to information on the site

	% (n) agree before	% (n) agree after	Change in mean	p	95% CI
Antibiotics are effective in acute otitis media	64% (113)	38% (67)	-0.52	0.0003	-0.79 to -0.25
10-day courses are more effective than 3-day courses of antibiotics in AOM	42% (74)	21% (38)	-0.70	0.000007	-0.99 to -0.42
Antibiotics help reduce the duration of pain in AOM	46% (82)	32% (57)	-0.23	0.09271	-0.49 to 0.03
You are more likely to have a complication from AOM if you do not have antibiotics	44% (78)	23% (41)	-0.49	0.00041	-0.76 to -0.23

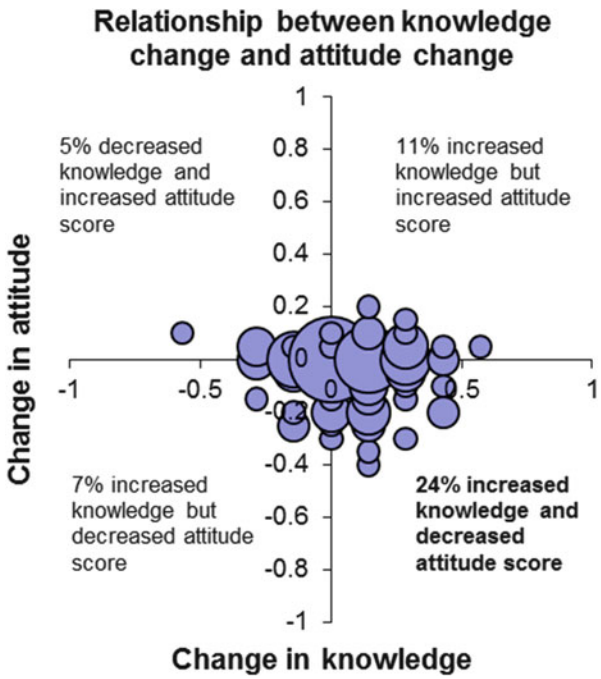

Fig. 1 Relationship between change in knowledge and change in attitude to prescribing of antibiotics in AOM for individual users. The size of the bubbles indicates the number of users at that point

change in attitude towards prescribing. 24.24 % of users increased their knowledge score and decreased their attitude score (i.e. they were less likely to expect antibiotics for AOM). 10.10 % of users did not change their knowledge score but decreased their attitude score. Changes in knowledge do not always equal changes in attitude, particularly when knowledge is applied to a personal situation such as the prescribing of antibiotics for AOM, so using these figures we can suggest that 34.34 % of users increased their knowledge about antibiotics and resistance and allowed that knowledge to change their attitude to the prescribing of antibiotics in AOM.

The mean, mode and median scores for "I have learnt something new after using this site" indicated that users did generally feel they had learned from the site. This is supported by the fact that for 45.19 % of users, increases in knowledge scores matched the perception that they had learned from the site. In contrast, 17.31 % of users thought they had learned but actually decreased their knowledge score.

3 Impact at Point of Care

3.1 Definition of Impact in the Context of Digital Library

In addition to knowledge and attitude change, health digital libraries aimed at professionals need to deliver more impact at the point of care. "Impact concerns long-term and sustainable changes introduced by a given intervention in the lives of beneficiaries. Impact can be related either to the specific objectives of an intervention or to unanticipated changes caused by an intervention; such unanticipated changes may also occur in the lives of people not belonging to the beneficiary group. Impact can be either positive or negative, the latter being equally important to be aware of" [7].

Users were asked if the library has ever had an impact on their professional knowledge or whether they applied the knowledge or attitude in their work [41]. Various research findings in psychology suggest that knowledge and attitude can be indicators of behaviour [1, 3], and therefore, this research used them as proxy measures for digital library impact [22]. To assess behaviour, we drew from Dervin's model that is defined as "a model of methodology, rather than a model of a set of activities or a situation" [70]. Dervin's sense-making model [14] is considered to be a model of the "how to" of information seeking. The holistic approach we propose in the next section investigates the knowledge provided by the DL in the decision-making context of the individual user and directly at the point of care.

3.2 The Impact-ED Model

In order to address the impact of digital libraries at the point of care, we developed the Impact-ED evaluation framework measuring impact on four dimensions of digital libraries—content, community, services and technology, as defined in [45]. Data collected by qualitative and quantitative methods were triangulated to analyse pre- and post-visit questionnaires to assess the clinical query or aim of the visit and subsequent satisfaction with each visit to the site, mapped against weblog analysis for each session, and data from semi-structured interviews.

The Impact-ED (Impact Evaluation for Digital Libraries) model on which the methods for evaluation were developed is shown in Fig. 2. It was developed to meet a set of impact evaluation criteria developed in a systematic review of digital library evaluations [41], and the full details can be found in [32, 41, 45]. The model is based around previously published digital library dimensions [24] and enables development of an impact score if evaluations are consistently based around one model [31].

The Impact-ED provides a set of criteria around which questionnaires and interviews are designed to collect appropriate data. The four dimensions are assessed to answer key questions about the DL impact from the point of community,

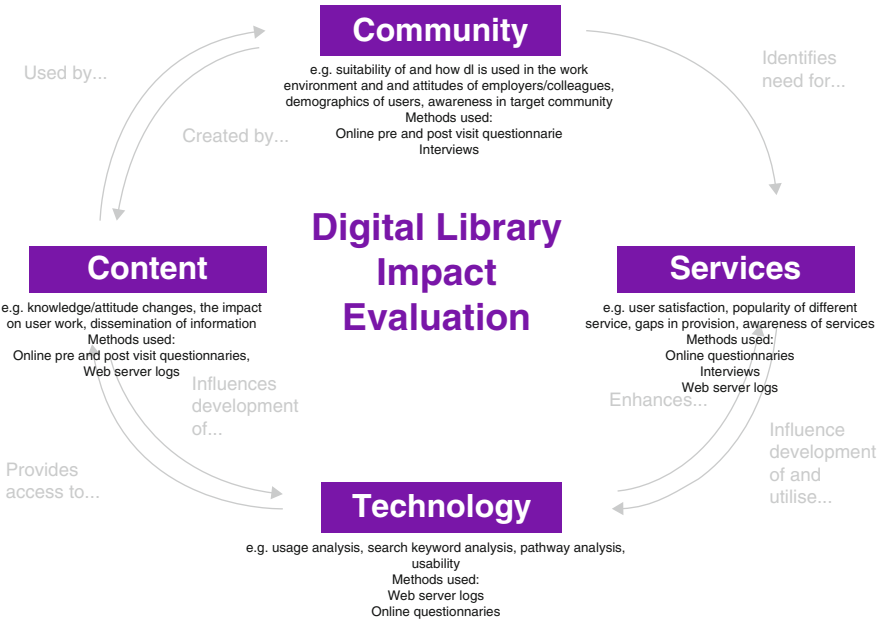

Fig. 2 Impact-ED impact evaluation framework

services, technology and content (see [32] for full details). The methods used in the model to collect data included online questionnaires (investigating use of the DL/web portal within the work environment); online pre- and post-visit (sense-making) questionnaires (investigating real-time, real-world use and how knowledge and attitudes change); online tasks (investigating how users complete tasks to find information within the library and how this changes knowledge and attitudes); weblog analysis (showing what users actually did within the DL); and semi-structured interviews (complimenting these other methods by providing more in-depth qualitative data that expands on issues identified in the questionnaires and weblogs).

In Fig. 2, it is illustrated how the DL evaluation methods are used together in a study flow diagram (Fig. 3).

3.2.1 The Impact Score

The framework defines a method for triangulating the data sets collected from the questionnaires, weblogs and interviews. Weblogs were statistically analysed to calculate length and time of visits, while statistical tests, such as Fisher's exact test, independent t-test and analysis of variance (ANOVA), were used to evaluate the pre- and post-questionnaire data. Qualitative analysis was applied to semi-structured interview results to determine the outcome for each criterion from all three data sets.

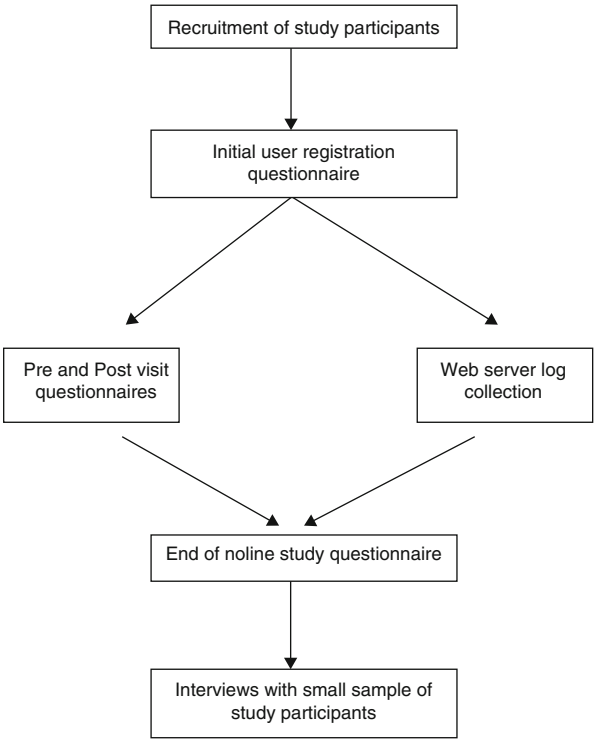

Fig. 3 Framework for digital library impact evaluation methods

The *impact score* is defined as follows: data obtained from the pre- and post-visit questionnaires coded to show where there was a strengthening of knowledge or change in knowledge or gain in knowledge as a result of a visit to the library. For each visit where this occurred, the library scored 1. A running total is kept until all visits have been scored, and this is then divided by the total number of visits analysed. The formula is shown below:

$$\text{Impact score } I = K/V_t$$

where V_t = total number of visits analysed and K = knowledge score (where K = sum of number of visits where either a change/strengthening or gain in knowledge is recorded).

In order to gain a comparative figure, we look at the reasons for "no impact" by recording reasons given by users. Where the digital library had no impact on user knowledge, it is possible to establish a known maximum achievable score based on the areas in which the library design is in control, i.e. if a reason for no impact is that the user could not find any information related to their query, then the impact score could have been improved by either adding information where it was lacking or by

improving the navigation or organisation of the library so the available information is more easily found. The calculation is as follows:

Reason for no impact 1 (R_1) = e.g. No relevant information found
Reason for no impact 2 (R'_2) = e.g. Couldn't access document
R_3 etc.
V_{R_x} = total number of visits with no impact coded R_x
Known maximum achievable impact score $I_{\max} = (\sum_x V_{R_x})/V_t + I$

Therefore, the actual impact score I_A can be calculated as a ratio with the $I_{\max}$ as follows:

$$I_A = \frac{I}{I_{\max}}$$

Using the definition, the I_A can also be calculated for all outputs or services rather than just an overall figure, e.g. personal education, training/education of other staff, etc.

3.3 Case Study: NRIC

Since May 2015, the UK-based online portal National Resource for Infection Control (NRIC: www.nric.org.uk) has been disseminating the latest evidence in infection prevention and control for professionals in healthcare settings and social care in the UK as well as internationally [39, 72], stressing the need to share evidence-based resources with professionals at the point of care [71, 73] in particular around major outbreaks [74]. But what difference is NRIC making to those who use it?

In order to use the Impact-ED model on NRIC, the framework needs to be mapped onto the specific situation of this digital library. Based on the generic model, Fig. 2, an NRIC specific mapping in accordance with the four dimensions was undertaken and can be found in Fig. 4.

The four dimensions of the Impact-ED model were applied to NRIC. The NRIC community has been involved in identifying the need for services and, in some cases, involved in creating and reviewing content for the library. The Internet technology, based on IBM Lotus Domino web server with a Dublin Core (DC) metadata tagged documents, was designed in order to provide the services required and to ensure consistent access to content throughout the library. The content is freely accessible to the community although a minority of external documents have restricted access. The aim of Impact-ED is to see the infection control content evaluated to allow improvement of the technology to increase the impact of the content on the user community.

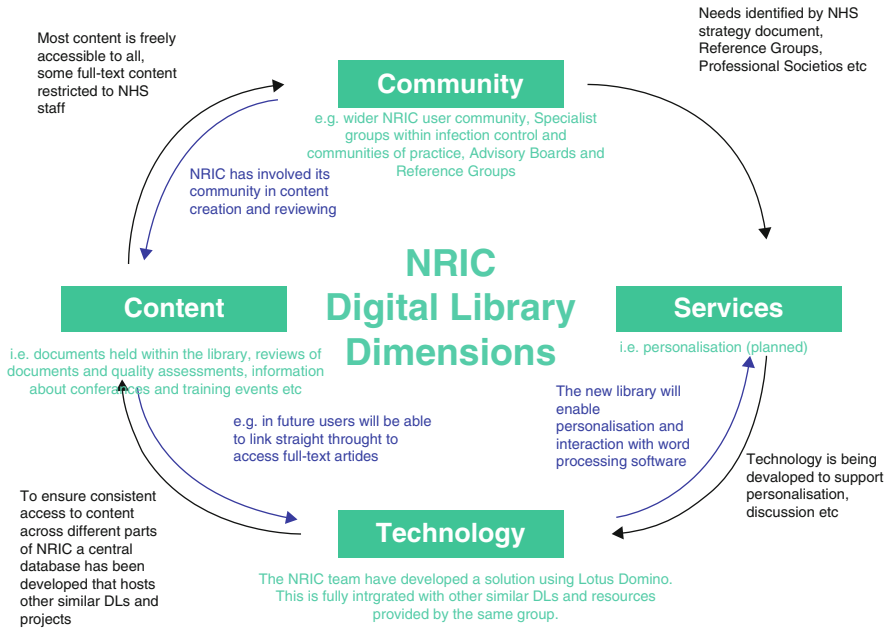

Fig. 4 Mapping the NRIC library onto the Impact-ED model

3.3.1 Results

The very positive outcome of this study demonstrated that NRIC had an impact on user knowledge in 52.8 % of visits (n = 38). The main reasons for no impact were that not enough information was found (n = 16) and the user couldn't access the document (n = 4). NRIC has a positive impact in many areas of user work including policy development, training and education, implementing changes in practice and business case or proposal preparation.

Calculating impact scores for these different groups resulted in the hypotheses shown in Table 3. Statistical tests were performed to validate the data. The Kolmogorov-Smirnov test determined that the data was normally distributed.

Table 3 shows that if people find related information in NRIC, then this does have an impact on their knowledge. However, there was no statistical significance for any of the other hypotheses despite the differences in impact scores. This is possibly due to the small sample numbers involved and a larger evaluation may provide more significant results.

Table 3 Statistical significance of the impact of NRIC services and features

Hypothesis	Impact scores (I_A) (no. of visits)	Test	p
When information is found in NRIC it has an impact on user knowledge	Information found (47) = 0.74 Information not found (24) = 0.13	Fisher's exact	< 0.001
NRIC has a greater impact on its newsletter readers than on non-subscribers	Subscribers (24) = 0.55 Non-subscribers (10) = 0.48	t-test	> 0.5
NRIC has a greater impact on visitors who browse rather than search or do both	Browsing only (24) = 0.63 Search only (17) = 0.47 Browse and search (27) = 0.52	ANOVA	> 0.5
NRIC has a greater impact on visitors who view reviewer's assessments than those who don't	Viewed (5) = 0.6 Didn't view (29) = 0.52	t-test	> 0.5

4 Interactive Digital Storytelling

While user engagement with a health portal could be assessed in terms of knowledge change or impact on clinical care after using the site, serious (educational) games require users to engage during the interaction to maximise their educational opportunity. This is of particular importance for serious health games [19] that use storytelling as the paradigm [56].

Interactive digital storytelling (IDS) games [29], using story and narrative as the educational intervention in games, are particularly popular game mechanics increasing user engagement through interaction with the story while delivering both entertainment and health educational content [54]. Serious health games are typically aimed at teaching a particular set of learning objectives (LOs) assessed using pre- and post-tests to provide information regarding the efficiency of the game, as well as feedback for the player about his/her knowledge, further enhancing the educational value of the game and contributing to player's knowledge. It has been shown that feedback is vital for learning, as it is necessary to encourage "deep" learning and engage students with the subject [27].

However, assessments using tests and questionnaires are known to be disengaging for students and bring additional inconsistencies and bias to the tested knowledge. Thus, seamlessly integrating tested LO into the story narrative prior to and after playing the game provides an engaging instrument for knowledge assessment without losing players' attention, immersion and engagement.

4.1 IDS Seamless Evaluation (SE) Framework

This section will first introduce the structure of an IDS framework and present the extensions to the framework required for evaluation to be seamlessly integrated

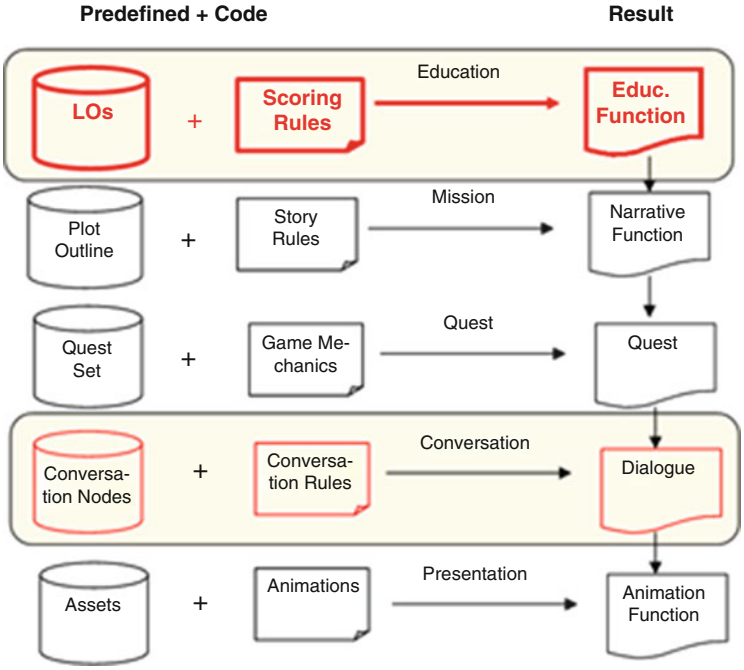

Fig. 5 User-centered seamless evaluation framework

into the game. The IDS game framework (see Fig. 5) is based on four conceptual layers for authoring that we enhanced by incorporating the Education Layer. The five layers are: Presentation Layer, Conversation Layer, Quest Layer, Mission Layer and Education Layer. A detailed description of the first four layers can be found in [63]. Here, we briefly introduce the layers, by focusing on the methodological enhancement necessary for an integration of the seamless evaluation and on the Education Layer, the enhancement necessary for the Conversation Layer.

For reasons of clarity, a brief definition of the four layers is discussed to set the scene—full details can be found in [51, 52].

Presentation Layer contains the assets/animations needed to deliver the IDS. It consists of animation for characters, rooms, items, etc., in the game and the motion models that are used to describe how the virtual characters move or behave. Together they form the game animation function.

Conversation Layer is the main means of interaction and content presentation [15]. This layer consists of conversation nodes and conversation rules. A conversation node (CN) is a line of text/or a sentence recited by a player character. The conversation rules show which player is saying what and in which context they are saying it. For example, a rule could be a virtual character that greets the player at the beginning of the game. Another rule states that the virtual character greets the player only if the player does it first.

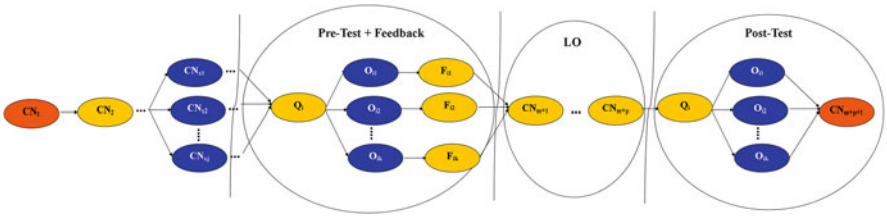

Fig. 6 A section of game which highlights how pre-test, feedback, LO and post-test are integrated in the game. *CN* conversation node, *Q* question, *F* feedback, *O* option. The *colours* represent different characters; in this case, *blue* is the player, who has to select among the different options, while the other *colours* are different characters

Quest Layer contains the quest set and the game mechanics. Quest in the context of this research refers to any "story element" of the game that requires activation when certain conditions are met, a series of states visited according to transition function and finished at quest end state, based on a set of conditions met. It contains the game mechanics that determine the operations of the game world and deals with the player interactions with the game.

Mission Layer contains the "overall dramatic outline" [15]. Story Mission is an ultimate quest starting with the game initialisation state and finished when then the IDS story is finished by reaching the finish state. It has the highest level of abstraction as the IDS.

Education Layer is the new layer added to the framework. It consists of LOs and scoring rules. The LOs contain a high-level description of the LO delivered through the game. For example, an LO could be: "One should only use antibiotics with a doctor's permission". The scoring rules consists of rules describing how the LO evaluation contributes to the player's score. For example, how many points the player gets for answering correctly one of the questions in the game (Fig. 6).

4.2 Case Study: Edugames4all

Seamless evaluation integrated into a role-playing game utilises problem-based learning (PBL) [18]: the GHD (Global Handwashing Day) Game [56] builds on the European e-Bug project that teaches children about hygiene [12, 20, 21, 38]. The game is an educational IDS game that relies heavily on the narrative. It aims to reinforce the importance of hygiene, focusing on handwashing, and enforces the learning through a game tutorial [53].

4.2.1 Game Narrative

The player is placed in the e-Bug agency and she/he is introduced to her/his boss, Big C. Also here, the player meets Alyx who is the player's partner and helps him/her during the investigation. After the introductions are made, Big C introduces the problem that Hugh Gaego, a famous actor, is supposedly poisoned, and the player has to decipher the mystery: whether it was a case of an alleged poisoning or not and who the guilty party is, if any, for poisoning Hugh. The state space of the game allows the player to explore different parts of the game, by making it non-linear and allowing different options during the investigation. Not all the paths lead to an answer, and they are not all mandatory for solving the mystery. Although totally integrated into the game flow, the questions assess the educational content presented (Fig. 7). The questions are spread throughout the game but asked before the player is exposed to game mechanics through which she/he can learn about the objectives being asked. The questions are asked in an abstract manner, in order to see whether the player understands the scientific concept and if what she/he learns is generalised. However, the LOs are delivered both in an abstract manner and through the game mechanics. If the player gets an answer wrong, the correct answer is given to the player, in order to correct misconceptions and allow the player to improve his/her knowledge and engagement during the game play.

Following the SE evaluation framework, the post-questions that assess the knowledge after the LO was delivered were asked towards the end of the game when the investigation was over, and the player returned to the headquarters for debriefing Big C—who asked the player the same set of questions as when the questions were asked for the first time (Fig. 8).

Fig. 7 Example of an evaluation question integrated in the game

Fig. 8 Example of a question at the end of the game, during the debriefing

4.2.2 Results

The key to understanding the impact of the seamless evaluation is the first assessment; however, the seamless evaluation can only demonstrate useful results if the positive education impact is not affected. The participants played the game either in a controlled environment (in a school with a teacher present with 50 min to finish the game) or online at their convenience. The schools at which the evaluation took place were located in London and Glasgow, UK.

The seamless evaluation was assessed through a mixed method, combining a survey (performed at the end of the game playing session) with observations during the playing sessions. The effectiveness of the game in conveying the LOs was assessed through the experimental studies in which participants had to play the game from beginning to end. For measuring the statistical significance of the effectiveness of the game in conveying the educational content, we used a paired t-test.

One hundred and forty-five participants were considered for the evaluation, selected based on whether they finished the game or not. The main reason for this decision is the fact that the evaluation is integrated in the game and the post-evaluation is towards the end of the game; therefore, for a player who did not finish the game, the results of the evaluation were not available. The end survey was completed by 21 participants (incomplete surveys were not considered).

Ninety-five percent of the players realised that they had to choose one of the options presented. The players who realised that they have to select one of the presented options were asked to rate how these affected their game experience on

Table 4 The results for how people perceived that the seamless evaluation affected their experience

#	Option	%
1	They obstructed my game experience	6
2	It wasn't too bad, they didn't discourage me but I would prefer not to have them	12
3	They did not affect me in any way	24
4	It was good having them, they had made the game more interesting	44
5	They enriched my game experience, they engage me more into the game	12

a five-point Likert scale, presented in Table 4. As can be seen, half of the players consider the questions to be a good addition to the game: 12 % stated that they enriched their game experience, while 44 % said that they made the game more interesting. Among the rest, 24 % were not affected in any way by the integrated questions, and the rest were affected in a negative manner. This can lead to the conclusion that, for most of the players, the integrated evaluation does not only facilitate the assessment but can also improve the game experience and enhance engagement.

To summarise, the results of the seamless evaluation assessment indicate players' strong preference of this method. Moreover, most players considered the questions as an enhancement to the game. The effectiveness of the game at conveying the educational content was performed using a paired t-test on the number of correct answers the players had on the pre- and post-questionnaire. The results show that the difference between the players pre- and post-questionnaire questions is statistically significant ($p = 0.01, \sigma = 2.20$).

5 Professional Communities of Practice

We have focused so far on engagement of a single user with health websites, portals, digital libraries and serious games through knowledge and attitude changes, impact assessment at point of care and seamless evaluation of IDS games. However, humans are community beings—communities have always been the key to our communication, interaction and social and professional lives. Traditional communities of practice (CoP) have been the cornerstone of professional life [68]; however, with the recent rise in online social networks (OSN) dedicated to professional communities, professional VCoPs have enabled interactions over geographical and cultural boundaries [57]. These are of pivotal importance in the medical domain [48]. Recent research investigated community interaction at health events [64], but the underlying roles and dynamics of VCoPs are of key importance for engagement. They also underpin the relationship between roles in traditional CoP and VCoPs in online activities. Unlike many studies evaluating large networks a posteriori with no insight into the user base, through a collaboration with real CoPs, we could develop

a roles framework for engagement and experiment with a real community, enabling us to better understand actions on both sides of the digital divide.

Do leading experts in a real community naturally become moderators of online discussions, or does the influence change the pattern of interaction? What factors play a role in keeping an ongoing and long-term interest in VCoP engagement? These are some of the aims of our research conducted with users of the FEMwiki portal and the CoPs of epidemiologists.

5.1 Communities of Practice and Their Virtual Counterparts (VCoP)

Unlike ad hoc online social networks, professional CoP has a long history in the organisation of traditional societies, as defined by Wenger [68]:

> Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly.

According to Wenger, CoPs are characterised by the domain, the community and the practice. Professional communities in the medical domain have a history spanning centuries (such as the Royal Societies); however, new digital social networks and collaborative activities have transformed traditional human ties to virtual interaction [62]. The evolution of online communities has been studied for a long time, from a user or community perspective [4–6]; however, our focus is engagement through the synergy and dynamics between VCoP and CoP roles.

In the virtual world, online discussions (e.g. "ask the expert" forums) in fact "crowdsource" scientific contributions, but sustainable active engagement remains sparse. There are a number of ways to define the roles of CoPs—these include champion, moderator, practice leader, sponsor, member and facilitator [57]. In VCoP context, Dale [11] differentiates these roles according to their increasing level of engagement, anonymous reader and anonymous commentator, and after registration, commentator with attribution, "ask a question" with attribution, blog writer, mentor and expert. In the health domain, we define the roles this way in the framework below, in Table 5, drawing from our initial work establishing roles on a wiki portal [33, 40].

Please note that if it is not stated "anonymous" in Table 5, then "registered" users were assumed.

Definitions for the wiki section (non-self-explanatory terms) are as follows:

- Original author: recognising the author of the resource prior to being turned into online project
- Author: creator of a new wiki page
- Contributor(s): any user who made a contribution to an existing wiki page
- Editor: responsible for quality control and has the right to authorise the page as "approved", enabling a specific dual versioning for each page of user-generated edits while maintaining editorial control over the quality of the resource (one editor per page)

Table 5 Taxonomy of roles in VCoP

Role	VCoP	Wiki project	Discussion forum project
Level 1	No friend	Anonymous reader	Anonymous reader
Level 2	Follower	Reader	Reader
Level 3	Mutual followers	Contributor	Initiator of a thread
Level 4	Friends	Author/ Original Author	neither (replies 2nd or later)
Level 5	Editor	1st reply	
Level 6		Both 1st poster and 1st replier, (these are naturally the most active members of the community)	

5.2 Case Study: FEMwiki

In the next section, we will apply our framework on the Field Epidemiology Manual Wiki (FEMwiki, www.femwiki.com) online community (VCoP). FEM Wiki is an online wiki training resource consisting of growing online wiki training resource consisting of wiki pages defining key terms and procedures in field epidemiologists and active discussion forum.

FEMwiki was developed to support the European training programme "European Programme for Intervention Epidemiology Training" (EPIET, ecdc.europa.eu/en/epiet/). Investigating the real CoP, EPIET, together with its online FEM Wiki counterpart, we could better understand the roles, their dynamics and the relationships and implications for engagement. In the final set of results, we provide a comparison between FEMwiki and another medical community, Medicines Support Unit for Optometrists (MSU).

5.2.1 Discussion Forum: Dynamics of the Roles

We analysed the longitudinal data from user forum discussion. Figure 9 is an illustrative snapshot giving an idea of an evolution of the network taken by a moving week-long window in the period 2010–2012.

As seen in Fig. 9, the majority of nodes are red (only active nodes are depicted), indicating 1st replies, while blue nodes (indicating both activities, 1st posts and 1st replies) are on a similar level. Green nodes, 1st posters (typically, those asking questions in discussions), are in the minority on this snapshot. However, as we used a week-wide sliding window analysis approach, this was the only way to generate a longitudinal changing data.

Figure 10 is illustrating the growth in users contributing to the forum discussion with respect to the roles: the increasing number of 1st poster indicates a widening community, while the main success in terms of engagement is increase of 1st responders and "both". Although a step in the right direction, analysing the user base indicates these are still centered around the European Centre for Disease Prevention and Control (ECDC) and EPIET CoP. The dynamics in forum discussions is strongly

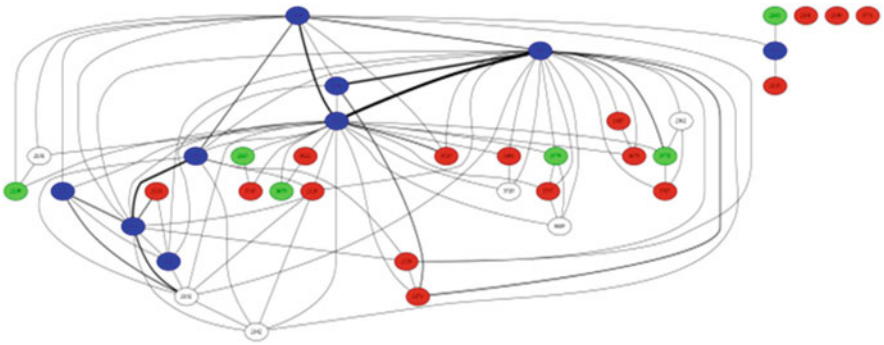

Fig. 9 Forum dynamics with illustrative snapshot of activities

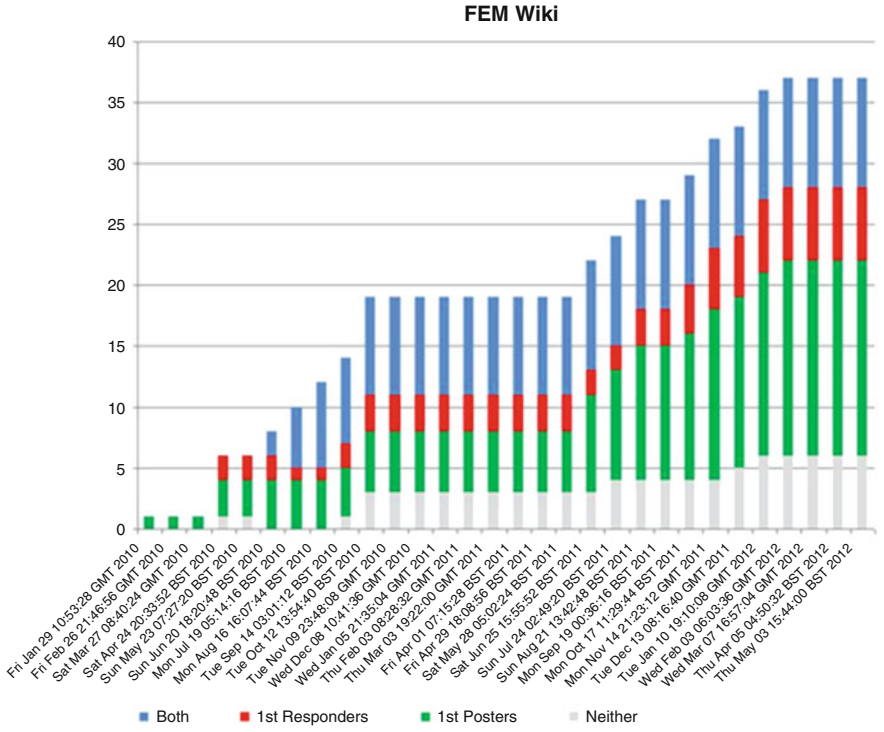

Fig. 10 Week-wide sliding window illustrating 1st and 2nd posts and both types of users in forums

reflecting the CoP roles; however, the growing number of users who started posting as well as sending 1st posts in the forum has tripled since the launch of the project (15 members up from 5). This indicates engagement of new users asking questions (including those from outside of Europe). However, for sustainability of the portal,

the pool of "blue" (8) and "red" (5) users willing to respond needs to be adequately expanded or a dedicated moderator engaged.

5.2.2 Relationship Between Discussion Forum and Wiki

We also investigated the relationship between the forum and wiki activity—this includes any contributions regardless of roles. As discussed above, 483 wiki pages have been subject to over 3000 edits made by a total of 33 different registered users. On the forums for discussing pages, there are 95 forum discussions since January 2010, with over 200 posts. Thirty-seven distinct users have made comments.

However, the overlap between these groups (wiki contributors/authors and forum posts) is 20 users out of 33 and 37. Figure 11 shows the monthly number of page edits and forum posts on FEMwiki.

Naturally, users in the intersection of activities are those senior members of the EPIET community and core staff from the European Centre for Disease Prevention and Control (ECDC)—an agency that is responsible for running EPIET and FEM Wiki.

5.2.3 FEM Wiki Semantic Navigation Model

FEMwiki framework is structured using a domain taxonomy editable by users in the same way as the actual content. The taxonomy browser on the front page

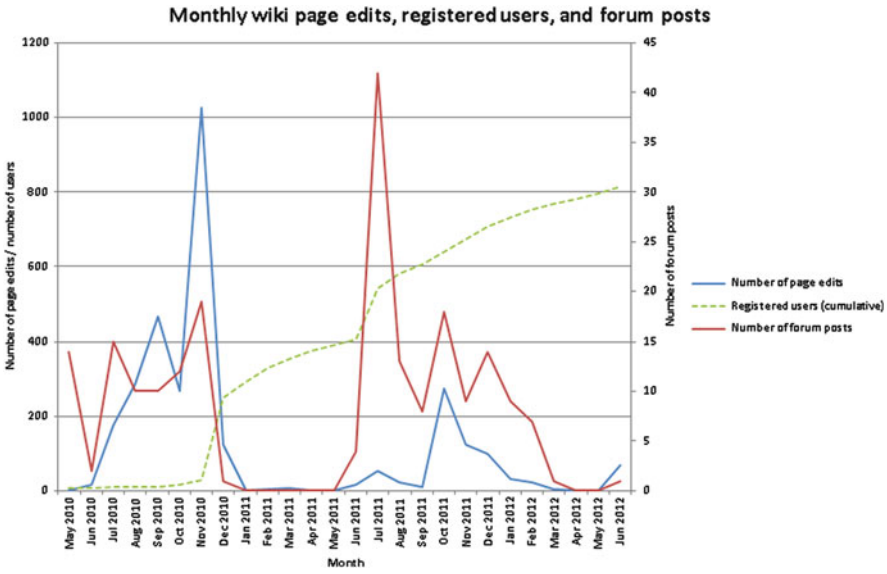

Fig. 11 Signups, forum discussion

of the wiki allows users to immediately see and navigate the organisation of the repository. User-friendliness of ontology editors is another challenge. In the FEM Wiki framework, we utilised the wiki user interface users have been using for collaborative editing of the medical content for an entirely different purpose: the wiki page also serves as a user-friendly taxonomy editor, thus, offering a seamless experience to users and increasing engagement with the VCoP.

In order to elicit more edits from users, the entire field epidemiology taxonomy is displayed on the navigation page (rather than just pages with existing content). A colour coding is used to draw user attending to empty pages ("stubs") and to distinguish between various types of content; see Fig. 12. The taxonomy editor supports colour-coding for the dual versioning of pages: (A) Yellow is the link to the latest version of the page. (B) Green is the link to the expert-reviewed (and approved) page—clicking on the text "approved version" will lead to the reviewed version. Further, (C) question mark is for pages that do not have an expert-reviewed version (indicated by the question mark icon)—the link will lead to the latest version. (D) Green only indicates pages where the latest version is also the expert-reviewed version—the link leads to this common version. Any edits to the page will cause a new latest version to be created. Finally, (E) red illustrates (and visually draws attention to) pages tagged as "stubs" where content has not been developed yet. By simply looking at the colour-coded taxonomy browser, users can see which pages have expert-reviewed versions and can either choose to see that version or a later unapproved version if one exists (Fig. 12). The user can also see "stub" pages

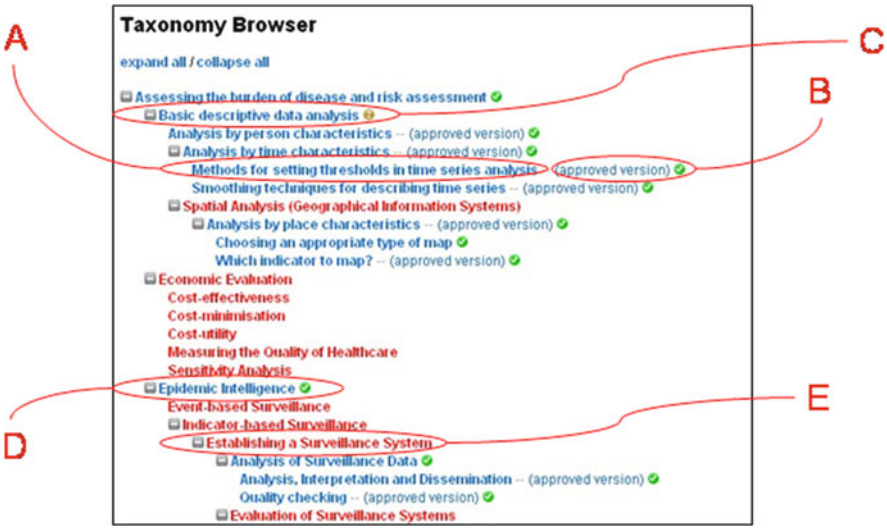

Fig. 12 The FEMwiki taxonomy browser: (A) latest version; (B) expert-reviewed page; (C) no expert version exists, only latest version; (D) latest version is also the expert-reviewed version; and (E) empty "stubs" marked in *red*

marked in red—this feature is specifically designed to highlight parts of the wiki content that need to be filled in and to encourage users to start this process.

The user-friendly semantic taxonomy with the same interface to modify the parent-child tree structure as the pages themselves further engages users in contribution and resulted in 12 new nodes in taxonomy (not possible to add without editable taxonomy) and 15 filled stubs which otherwise would not be created. Four percent of registered users contribute new content, and those who contribute to editing pages are also active in discussion forums.

5.2.4 Comparison of Two Health Communities: FEMwiki and MSU

In the final section, we examine two independent CoPs and a theory of engagement developed around medical scientific Internet portals: FEMwiki (www.femwiki.com), dealing with field epidemiology, and Medicines Support Unit for Optometrists (MSU, www.med-support.org.uk), supporting therapeutic prescribing by optometrists. The user bases are geographically dispersed (mainly throughout the UK for MSU and throughout Europe for FEMwiki). Both sites provide centrally authored information to specialists and have means for user discussion. Each was created to order, but FEMwiki is more highly structured than MSU. In FEM Wiki, users can directly edit the content, but to guarantee quality, changes must be approved before the changes are made official. In MSU, changes can be suggested informally via the forum [23].

We collected the messages that were posted on the discussion forums of the communities and extracted networks of users. Each node corresponds to a user, with arcs linking the nodes of users who were involved in the same discussion (see Fig. 13).

While it is clear from Fig. 13 that each community has a moderator or a set of very engaged users, Figure 14 shows more details—the number of connections for each node in the networks—and Table 6 summarises some key statistics. Each network has a number of users who are involved in many discussions; these seem to be mainly senior project leaders or administrators. There is an almost linear decline to users who were only involved in one or two discussions (possibly they only had a specific question that was answered to their satisfaction). Users with many connections are involved in many discussions and therefore may have more knowledge and experience to share.

Further, ongoing research is required to expand our understanding of engagement strategies in relation to actions taken to engage the actual CoP members.

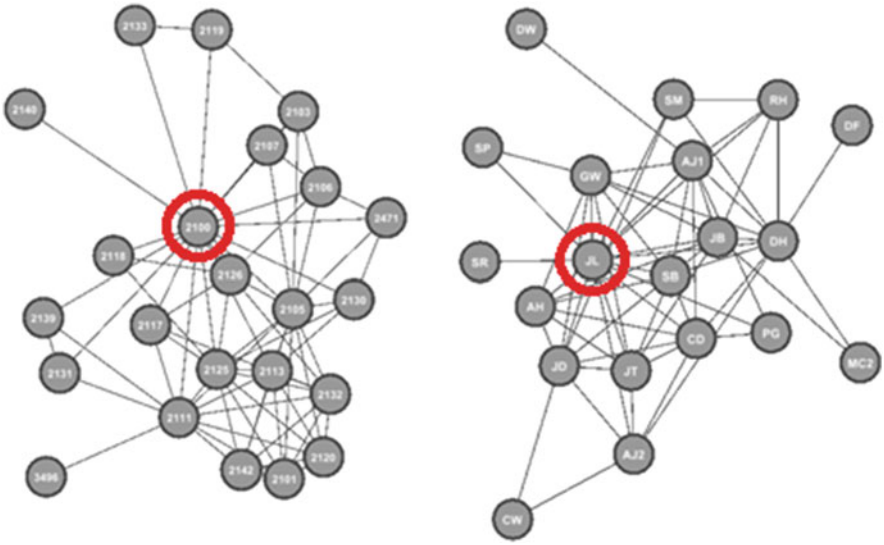

Fig. 13 The user networks extracted from FEM Wiki (*left*) and MSU (*right*). The nodes with most connections are *highlighted*

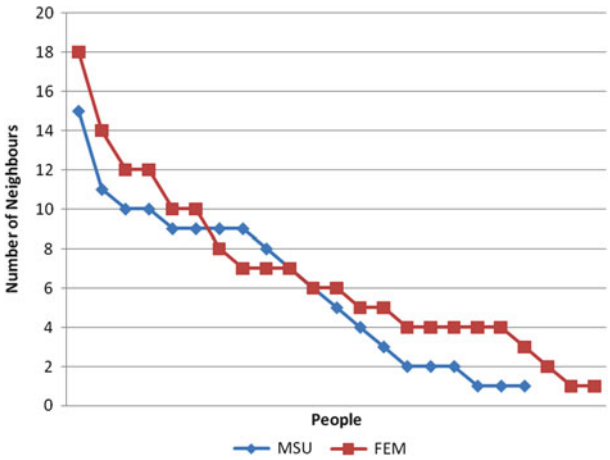

Fig. 14 The numbers of neighbours for each node in Fig. 13

6 Conclusions

In this chapter, we discussed the role of user engagement with health technologies. We specifically focused on health Internet portals, digital libraries, serious games and collaborative online spaces for development of VCoP underpinned by real CoPs.

Table 6 Summary statistics for the two communities

	FEMwiki	MSU
Nodes	23	20
Edges	73	62
Average Degree	6.35	6.20
Diameter	3	4
Average Path Length	1.80	1.82
Graph Density	0.289	0.326

In particular, we focused on the role of user engagement with health technologies aimed at knowledge and attitude change, the impact in clinical settings at the point of care, seamless assessment of serious IDS games and, finally, roles enabling engagement of professional CoP.

Firstly, with regard to knowledge and attitude change, we defined a correlation method highlighting the relationship between these two measures and illustrated this approach using the case study: the "Bugs and Drugs" project.

Secondly, Impact-ED is a framework defining the impact of a health digital library at the point of care along four DH dimensions: community, services, technology and content. We illustrated the Impact-ED and calculated the impact score on assessment of the National Resource for Infection Control.

Thirdly, IDS games are increasingly important platforms delivering health educational messages while entertaining users. The seamless evaluation (SE) framework enhancing the IDS layers was developed to enable assessment of users' knowledge against learning objectives (LOs) while keeping players entertained. SE was implemented on edugames4all games and GHD and demonstrated users' preferences for this method.

Finally, engagement measures for VCoP were defined in terms of user roles in the VCoP and their relationships to the real CoP. Engagement dynamics in the online wiki, discussion forums and collaborative editing of the navigation taxonomy was analysed through the FEMwiki project.

However, there are still a number of challenges and barriers: frequent changes of technology platforms and subsequent usability issues might jeopardise user engagement with health portals [58]. New methods are required to analyse cross-platform engagement with growing segments of users using mobile phones and tablets as their primary devices, who are typically very interactive and on the go, thus creating porting challenges [55]. Designing for children's engagement is particularly challenging [50], as are the multilingual aspects and localisation of health technologies [66]. Rapidly expanding use of wearable and tracking devices creates a new need for understanding user engagement with technology for monitoring health and well-being with the primary goal to achieve behaviour change. Finally, increasingly virtual professional CoPs resembling social networks rather than mirroring more traditionally structured CoPs bring new opportunities and challenges for community engagement.

In this chapter, we outlined four major themes for user engagement with health technologies, presented four methodological frameworks and illustrated their use with case studies representing real-world medical communities and resources.

To summarise, user engagement with health technologies is essential for their success, but more fine-grained definition of their purpose, ranging from education to online community interaction to the impact at the point of care, is essential for choosing the appropriate methodological framework. Technological challenges, usability issues and technology access barriers within workplaces or learning environments (hospitals, schools) were identified as key obstacles that hinder user engagement. This is further enhanced by the fast speed of technological evolution and the need for co-authoring to reduce developmental costs [65]. However, when it comes to the ongoing investment in maintenance and improving existing health resources, the notoriously underfunded healthcare and educational sectors are often lagging behind. Finally, promotion of health technologies and resources, essential for users to actually be aware and find the portal or game, brings another set of challenges requiring right strategies and sufficient resources [13].

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