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iCBLS: An interactive case-based learning system for medical education

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ABSTRACT

Medical students should be able to actively apply clinical reasoning skills to further their interpretative, diagnostic, and treatment skills in a non-obtrusive and scalable way. *Case-Based Learning* (CBL) approach has been receiving attention in medical education as it is a student-centered teaching methodology that exposes students to real-world scenarios that need to be solved using their reasoning skills and existing theoretical knowledge. In this paper, we propose an interactive CBL System, called iCBLS, which supports the development of collaborative clinical reasoning skills for medical students in an online environment. The iCBLS consists of three modules: (i) *system administration* (SA), (ii) *clinical case creation* (CCC) with an innovative semi-automatic approach, and (iii) *case formulation* (CF) through intervention of medical students' and teachers' knowledge. Two evaluations under the umbrella of the context/input/process/product (CIPP) model have been performed with a *Glycemia* study. The first focused on the system satisfaction, evaluated by 54 students. The latter aimed to evaluate the system effectiveness, simulated by 155 students. The results show a high success rate of 70% for students' interaction, 76.4% for group learning, 72.8% for solo learning, and 74.6% for improved clinical skills.

1. Introduction

Medical education is an active area of research and has undergone significant revolution in the past few decades. In health education, the purpose of medical education programs is to: (1) develop educational leaders, (2) change the learners' knowledge, skills, or attitudes, and (3) improve educational structures [1]. Various teaching methodologies have been introduced in professional health education [2], where *Case-Based Learning* (CBL) is known to be an effective learning approach for small groups of medical students at undergraduate level education as well as for professional development [3–6].

In professional education for health and social care domains, the clinical case is a key component in learning activities, which includes basic, social, and clinical studies of the patient. Normally, in CBL practice non-real patient medical cases are developed in addition to unplanned clinical encounters, which totally relies on patient's goodwill [3]. Furthermore, students also feel that classroom CBL activities require a significant amount of time [7]. Sometimes, students feel uncomfortable while participating in group learning activities and they prefer to work alone [8]. Medical students tend to choose computer-based cases [3,9] and opt for web-based cases as compared to lectures for their learning [10,11]. Additionally, more attention is given to online/web-based learning environments [3] and real-life clinical case(s) are increasingly emphasised in medical students' practice [3,12,13]. Finally, less attention is given to the development mechanisms of real-world clinical cases and most of the stakeholders, including learners, teachers, administrators, and other health professionals, are interested in change [1].

Keeping in view all aforementioned facts, we focused on designing and developing an interactive computational e-learning platform by using CBL concepts so that medical students are provided the following learning activities: (1) practicing real-world case(s) before and outside the class to determine the treatment of patients in an easy to use manner, (2) identifying the components of a medical chart (such as demographics, chief complaint, medical history, etc.) from a given clinical case, and (3) constructing appropriate interpretations about a patient's problem to create a significant medical story using identified components within the context of his or her life. In order to achieve

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these goals and expectations, this study was undertaken with the following objectives: (1) create a real-world online and computer-based clinical case (see Sections 3.2 and 4.2); and (2) identify basic science information relevant to patient data for their practice (see Sections 3.3 and 4.3).

In this study, we have designed and developed an *interactive Case-Based Learning System* (iCBLS) based on the current CBL practices in the *School of Medicine, University of Tasmania, Australia*. This study is the extension of work mentioned in [14] that lacks the support of acquiring real-world patient cases, and is also detailed study of some parts of work [15]. The proposed iCBLS provides features such as: an online learning environment, interactiveness, flexibility, display of the entire collection of data at one place, a paging facility, and support for in-line reviewing to edit and delete the displayed data. The iCBLS consists of three modules: (i) *system administration* (SA), (ii) *clinical case creation* (CCC), and (iii) *case formulation* (CF). The SA module manages multiple types of users and it maintains the hierarchy of courses, their units, and clinical cases for each unit. Similarly, the CCC module is based on an innovative semi-automatic approach that consists of three steps. First, graphs are generated from a patient's vital signs with a single click. In the second step, a clinical case is generated automatically by integrating basic, history, and vital signs information. Finally, in the third step, the medical teacher refines the generated case in order to create the real-world clinical case. The CF module is based on identification of the medical-chart's components in order to formulate the summaries of CBL cases through the intervention of medical students' as well as teachers' knowledge and getting feedback from the concerned teacher. In addition, the CF module enables the students to practice the real-world case (s) before and outside the class.

The key contributions of this research are as follows:

1. This work focuses on developing an intelligent computational e-learning platform for CBL in medicine that enriches and enhances the learning experience for medical students.
2. The paper shows the design and development of an interactive CCC module that supports an innovative method to real-world clinical case creation using a semi-automatic approach.
3. The paper shows the design and development of an interactive CF module that provides a flexible case formulation environment.

The paper is organized as follows: Section 2 covers the related work; the methodology of the proposed iCBLS is discussed in Section 3. Section 4 discusses the iCBLS along with a case study scenario. Section 5 provides the details of evaluations performed along with results, while Section 6 discusses the significance, challenges and limitations of the proposed system. Section 7 concludes the paper with a summary of the research findings.

2. Related work

In the *Introduction* section, we discussed about the background information relating to medical education and *Case-Based Learning* (CBL). This section demonstrates more detailed pedagogical concepts, methodologies applied in CBL, and the related web-based learning systems in medical education. It is further classified as: (1) background subsection, which describes the basics of CBL with respect to background, features, and its comparisons with *Problem-Based Learning* (PBL); and (2) review subsection, which overviews the existing web-based learning systems, compares with well-established CBL systems, and finally presents the overall limitations of existing learning systems.

2.1. Background for case-based learning

CBL was introduced by pedagogy experts to improve knowledge exploration, emphasize critical thinking, achieve better collaboration, and increase opportunities for receiving feedback [4]. Research literature provides multiple features of CBL, such as: (i) it assists students to examine fact-based data, employ analytical tools, articulate their concerns, and draw conclusions for relating to new situations [16,17], (ii) offers an opportunity to realize theory in practice [17], and (iii) develops students' clinical skills in independent and group learning, as well as in communication and critical thinking to acquire meaningful knowledge for improving students' attitude towards medical education [6,17–23].

CBL is a teaching methodology that utilizes PBL principles. Scavarda et al. [24] and Thistlethwaite et al. [3] described CBL as more structured than PBL as it uses authentic cases for clinical practice. Similarly, Grauer et al. [25] noted that CBL methods require less time and are more efficient in providing large amounts of material compared to PBL. Moreover, Umbrin [26] differentiated PBL from CBL and defined the steps for learning in both PBL as well as CBL. In PBL, the steps are: Problem → Explore problem → Self-learning → Group discussion, while in CBL, the steps are: Prior reading → Problem → Seeking out extra information → Interview with a knowledge expert. Furthermore, the researcher of [26] mentioned that in PBL, students improved their problem solving skills; while in CBL, students learned clinical skills. In addition, in PBL, the role of a facilitator is passive as opposed to CBL, where a facilitator's role is active. Finally, the researcher of [26] concluded that CBL is a preferred methodology over PBL.

2.2. Review of existing web-based learning systems

In order to support the learning outcomes of students, a plethora of web-based learning systems have been developed [14,27–35]. A review of the literature shows that learning systems, *Design A Case* (DAC) [27] and *Extension for Community Healthcare Outcomes* (ECHO) [28] are well established CBL projects. The ECHO platform was developed for case-based learning in which primary and specialty care providers working together to provide care for patients using video conferencing and sharing electronic records. Similarly, the DAC provided an online educational tool, which is designed to supplement the traditional teaching and allows to develop health related virtual cases for medical students. Both ECHO and DAC projects support the postgraduate medical students; however, they do not allow the medical teacher to visualize vital signs, which is an important feature while developing clinical cases.

Ali et al. [14] developed an online CBL tool, called *Interactive Case-Based Flip Learning Tool* (ICBFLT), which formulates the CBL case summaries (e.g., further history, examination, and investigations) of virtual patient through intervention of student as well as medical experts' knowledge. This tool also provides learning services to medical students before attending the actual class. Boubouka [34] designed a case-based learning environment, called *CASes for Teaching and LEarning* (CASTLE) for supporting teaching as well as learning through cases. In CASTLE, a teacher can author the cases for their students and also monitors the elaboration of scenarios interpreted by their students. As conclusion, ICBFLT and CASTLE lack the support of acquiring real-world patient cases. For medical training purposes, Dilullo et al. [31] created online predefined case-based tutorials to provide clinical exposure to the medical students without the support of acquiring real-world patient cases and do not provide feedback to students.

Cheng et al. [30] adopted a web-based prototype system called *Health Information Network Teaching-case System* (HINTS) in practical training of medical students for clinical medicine. They also explained the development mechanism of teaching cases but with no support of providing feedback to students. Shyu et al. [29] established a platform, called *Virtual Medical School* (VMS) for problem-based learning. They utilized their online authoring tools to capture the patient cases from *Hospital Information System* database. Suebnukarn and Haddawy [32] developed a problem-based learning system, called *Collaborative Medical Tutor* (COMET) for medical students to provide intelligent tutoring during problem solving tasks. The COMET generates tutorial hints to

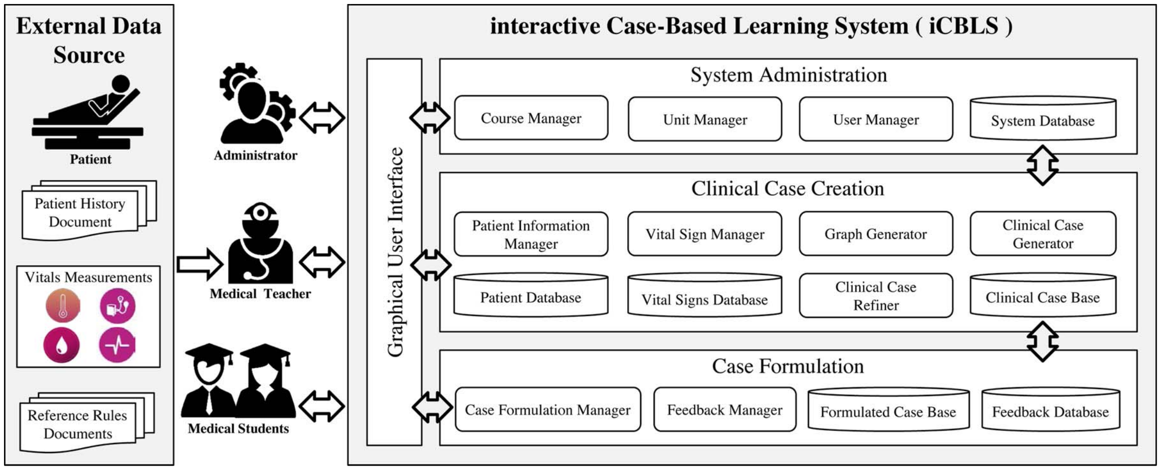

Fig. 1. Functional architecture of the iCBLS.

guide the medical students for problem solving. Both VMS and COMET have been used for problem-based learning; however they lacked tutors' feedback support. Sharples et al. [33] described a case-based training system called *MR Tutor* for learning purposes. This system provided computer-assisted training in radiology, where it also provides feedback to user without considering tutors' feedback for solved clinical cases. Chen et al. [35] developed a web-based learning system that followed the development of the real clinical situation; however their system also lacked the support of feedback.

We have responded to these deficiencies by adopting an online learning concept in case-based learning with the support of the proposed system called iCBLS. In order to refine real-world clinical case(s), graphical trends are also incorporated to assist medical teachers with analysis. Moreover, our proposed system enables students to practice real-world case(s) before and outside the classroom environment.

3. Material and methods

To develop an interactive CBL system which prepares students for their real-world clinical practice before and outside the class, this section describes the architecture of the proposed system and detailed methodologies used for *Clinical Case Creation* and *Case Formulation* modules. The conducted study have an ethics approval from the *University of Tasmania, Australia*, and that it was developed in 2016.

3.1. Proposed system architecture

The functional architecture of the proposed system is described as shown in Fig. 1, which consists of four modules, namely *Graphical User Interface*, *System Administration*, *Clinical Case Creation*, and *Case Formulation*. Three types of users – *administrator*, *medical teacher*, and *medical students*, interact with the iCBLS through the *Graphical User Interface* module. The detailed role description of each user is shown pictorially in Section 4 and Fig. 5.

The functionality of each module is described as follows.

3.1.1. The functionality of the Graphical User Interface module

The *Graphical User Interface* module provides an interface to all users to interact with the other three aforementioned modules. This module provides a flexible environment by facilitating: (1) an easy and user-friendly paging facility, (2) a display of the entire collection of data, and (3) support for inline editing to edit and delete the displayed data.

3.1.2. The functionality of the System Administration module

The iCBLS provides support for managing numerous courses, where each course consists of multiple units e.g. *'CBL Cases'* is one course that includes two units, namely *'Fundamentals of Clinical Science'* and *'Functional Clinical Practice'*. Multiple students are able to enroll in each unit. The *administrator* is assumed to be the coordinator that manages the CBL administration and interacts with *System Administration* module, as shown in Fig. 1. The administrator manages the hierarchy of courses, their units, and users' relations with units by using the *Course Manager*, *Unit Manager*, and *User Manager* components to store the information into the *System Database*. Moreover, the administrator manages two types of users, namely *medical teacher* and *medical student*. In addition to this, the administrator assigns the courses' units to the individual medical teacher and enrolls the medical students to each unit. All aforementioned information is stored and managed in *System Database*. The detailed flow diagram of *System Administration* module is described and shown in Fig. 2.

3.1.3. The functionality of the Clinical Case Creation module

The *Clinical Case Creation* module is used to create real-world clinical cases. The *medical teacher* who interacts with this module is assumed to be a medical expert that interacts with patients either at the private clinic or at hospitals. This module consists of five components as follows: *Patient Information Manager* for managing patient's basics and history information, *Vital Sign Manager* for managing the categories and measurement information of patient's vital signs, *Graph Generator* for generating and visualizing vital sign's, both individual and average values, *Clinical Case Generator* for auto-generating a clinical case by integrating basic information, patient history, vitals' (a.k.a. vital signs) information and finally, *Clinical Case Refiner* for refining the auto integrated case. This module also requires real-world patients' and vital signs reference rules' information (see Table 1 in Section 3.2) that is obtained from *External Data Source*, which includes *Patient*, *Patient History Document*, *Vitals' Measurements*, and *Reference Rules' Documents* as data sources.

3.1.4. The functionality of the Case Formulation module

The *Case Formulation* module is intended for (1) identifying the components of a medical chart (such as demographics, chief complaint, medical history, etc.) from a given clinical case, (2) allowing the medical students to write their observations for each component and finally, (3) receiving feedback from the medical teacher. This module helps medical students to understand the causes of patient behaviours and symptoms, to formulate summaries of CBL cases and to get feedback about self-formulated cases from their medical teacher. The *medical students* as well as *medical teacher* interact with this module. This module is comprised of two components: *Case Formulation Manager* for

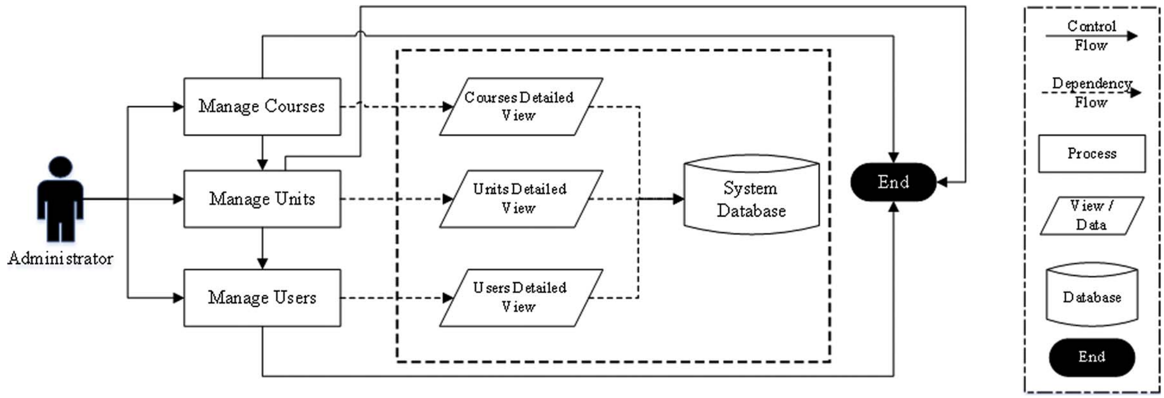

Fig. 2. Flow diagram of system administration module.

Table 1
Vital signs reference ranges with interpretations.

Vital sign	Categories	Reference range	Interpretation
Blood pressure (mmHg) [40]	Systolic blood pressure (SBP)	SBP ≤ 119	Normal
		120 ≤ SBP ≤ 139	Prehypertension
		140 ≤ SBP ≤ 159	Hypertension stage 1
		160 ≤ SBP ≤ 180	Hypertension stage 2
		SBP ≥ 181	Hypertensive crisis
	Diastolic blood pressure (DBP)	DBP ≤ 79	Normal
		80 ≤ DBP ≤ 89	Prehypertension
		90 ≤ DBP ≤ 99	Hypertension stage 1
		100 ≤ DBP ≤ 110	Hypertension stage 2
		DBP ≥ 111	Hypertensive crisis
Blood glucose (mg/dL) [40,41]	Fasting blood glucose (FBG)	FBG ≤ 69	Hypoglycemia
		70 ≤ FBG ≤ 99	Normal
		100 ≤ FBG ≤ 126	Pre-diabetic
		FBG ≥ 127	Diabetic
	Random blood glucose (RBG)	RBG ≤ 139	Normal
		140 ≤ RBG ≤ 199	Pre-diabetic
		RBG ≥ 200	Diabetic
Heart rate (bpm) [42,43]	Resting heart rate (RHR)	RHR ≤ 59	Bradycardia
		60 ≤ RHR ≤ 100	Normal
		RHR ≥ 101	Tachycardia
	Sleeping heart rate (SHR)	40 ≤ SHR ≤ 50	Normal
	Irregular heart rate (IHR)	IHR = true	Arrhythmia
Body temperature (°F) [43]	Body temperature (BT)	97.7 ≤ BT ≤ 99.5	Normal

managing formulated cases that are created by students as well as teachers, *Feedback Manager* for providing teachers' feedback to individual students.

3.2. Clinical case creation methodology

This section briefly describes the procedure for creating a real-world clinical case in the proposed system (iCBLS) using an innovative semi-automatic approach as shown in Fig. 3. As mentioned in some studies [30,36,37], a clinical case is generally written as a problem which includes basic personal information, reported complaints, history and physical examinations, imaging studies, vital signs, clinical signs and symptoms, laboratory results, findings, diagnoses, discussions, comments, and learning points. In this study, *patient basic information*, *patient history*, and *vital signs* information are considered as components of a real-world clinical case.

Five steps are involved for real-world clinical case creation, which are shown in Fig. 3. First, the medical teacher converses with the patient and records the patient's basic information such as the patient's name, gender and age. Following this, the patient's history is recorded, this covers medical history, family history, symptoms review and food habits etc. This information is stored in the *Patient Database*. In the second step, the patient's vital signs are recorded in the *Vital Signs Database*. In this study, body temperature, blood pressure, blood glucose, and heart rate vital signs categories are considered. These vital signs are measured by traditional devices such as thermometers for body temperature, sphygmomanometers for blood pressure, blood glucose meters for blood glucose, and stethoscopes for heart rate. However, this vital signs information can also be captured with the help of RFID technology and sensors through wearable devices [38,39]. Weekly graphs are generated from a patient's vital signs data in the third step. For visualization, line and bar graphs are used, and the weekly average value for each vital sign's category is computed and a separate graph is generated. In addition, reference ranges, as defined in Table 1, for each vital sign category, are shown on each graph in order to assist with interpretation. In the fourth step, the patient's basic information along-with history and vital signs' data are integrated to create the system generated clinical case. Finally, in the fifth step, the medical teacher visualizes the system generated case as well as all auto-generated graphs. After visualization and analysis, the medical teacher refines the auto-generated case and stores this in the *Clinical Case Base* for medical students' practice.

The aforementioned process of real-world clinical case creation for multiple patients is briefly described in Algorithm 1. This algorithm takes *basic information* (i.e., BI), *patient's history* (i.e., PH), and *vitals' information* (i.e., VI) as input and then sequentially passes through mandatory steps to create the multiple real-world clinical cases. The output of this algorithm is used as input for Algorithm 2, which is described in following subsection.

Algorithm 1. Creation of Real-World Clinical Case(D = BI, PH, VI)

Data: $D = BI, PH, VI$: Input dataset (basic information, patient history, vitals' information)
Result: $CC-$ Real-world clinical case

/* $D = p_1, p_2, p_3, ..., p_n$ where D represents data for n patients */;
for $\forall\ p_i \in D$ **do**
  /* Get the basic information e.g. gender, age; and patient's history e.g. medical history, family history, symptoms for each patient p_i */;
  $BI_i \leftarrow getBasicInformation(D.p_i)$;
  $PH_i \leftarrow getPatientHistory(D.p_i) : p_i = ph_1, ph_2, ph_3, ..., ph_n$;
  /* Vitals' information VI_i consists of vital's category and its measurements. Firstly, select the vital sign category e.g. systolic blood pressure for each patient p_i */;
  selectVitalSign(VS) : $VS = vs_1, vs_2, vs_3, ..., vs_n$;
  for $\forall\ vs_j \in VS$ **do**
    $M_k = m_1, m_2, m_3, ..., m_n$ // no. of measurements for vs_j ;
    for $\forall\ m_i \in M_k$ **do**
      /* Get vital sign measurements for each vital sign category vs_j */;
      $m_i \leftarrow getVSMeasurement(D.p_i, vs_j)$;
    end
    /* Compute the average values for each vital sign category vs_j */;
    $vsmAvg_i \leftarrow \sum_{i=1}^{size(M_k)} m_i / size(M_k)$;
    /* Plot the individual and average graph for each category vs_j */;
    $trendgraph \leftarrow plotVSMeasurementGraph(D.p_i, vs_j)$;
    $meangraph \leftarrow plotVSMeasurementAverageGraph(vsmAvg_i)$;
  end
  /* Generate the case by integrating BI_i, PH_i, and $vsmAvg_i$ for each patient p_i */;
  $SGC_i \leftarrow generateCase(BI_i, PH_i, vsmAvg_i)$;
  /* Analyze the patient auto generated graphs */;
  $AG_i \leftarrow analyseGraphs(meangraph, trendgraph)$;
  /* Refine the generated case based on the personal knowledge and graphical analytic */;
  $CC_i \leftarrow refineCase(SGC_i, AG_i)$;
  return CC_i : *clinical case*
end

3.3. Case formulation methodology

Case formulation is a commonly taught clinical skill and it is the foundation for balanced treatment planning that develops with practice and clinical experience [44–46]. In case formulation, clinicians determine the treatment of their patients and treatment of each particular patient is different from that of other patients [44]. Case formulation has a vital role in clinical decision-making [45] which is emphasized in many published documents [46]. It is frequently emphasized to practitioners to develop professional competency in case formulation for their professional training as well as continuing medical education. Case formulation has multiple definitions and contents in various approaches [44]. As described by Godoy and Haynes [46], "Case formulation is an individualized integration of multiple judgements about a patient's problems and goals, the casual variables that most strongly influence them, and additional variables that can affect the focus, strategies, and results of treatment with a patient". Formulating a clinical case involves constructing appropriate interpretations about a patient's problem to create a significant medical story within the context of his or her life [45].

As case formulation has multiple definitions, in this study, case formulation means identification of a medical-chart's components from a given clinical case and then writing personal observations for each component. As mentioned in some studies [30,47], demographics, chief complaint, medical history, habits, family history, medicines, allergies, physical exam, tests ordered, initial diagnosis, differential diagnosis, test results, final diagnosis, treatment, recommendations, and prognosis are considered as the components of medical-chart. As described in Fig. 4, the authorised medical student views the allotted courses. For case formulation, the student first selects the CBL case. After clinical assessment of the selected case, the student conceptualises the information and identifies the components of the medical chart. Following this, the student then records his/her personal observations. During the formulation process, the student can also get help from available formulated cases that are completed by other medical students. After case formulation, students get feedback from their teacher in order to improve their concepts and knowledge.

The process of case formulation briefly is described in Algorithm 2. This algorithm takes a clinical case (i.e., CC) as an input and sequentially passes this through mandatory steps to resolve the clinical case in terms of creating a medical-chart.

Algorithm 2. Case Formulation($D = CC$[*Ref*. **Algorithm 1**])

```
Data: D = CC: Input dataset (clinical case)
Result: CF– Case Formulation
if Verify(D) then
    /* For creating the medical charts, add the components of medical charts
    e.g. presenting complaints, previous medications for D cases */;
    MCC ← addMedicalChartComponent(D): D = mcc_1, mcc_2, mcc_3, ..., mcc_n ;
    for ∀ mcc_m ∈ D do
        /* Add observations e.g. felt fatigue, breathlessness of each chart
        component mcc_m */;
        Obs ← addObservations(mcc_m) ;
    end
    /* Case formulation includes information of medical charts component and
    observations */;
    CF ← caseFormulation(MCC, Obs) ;
    return CF : case formulation
else
    Error(message);
end
```

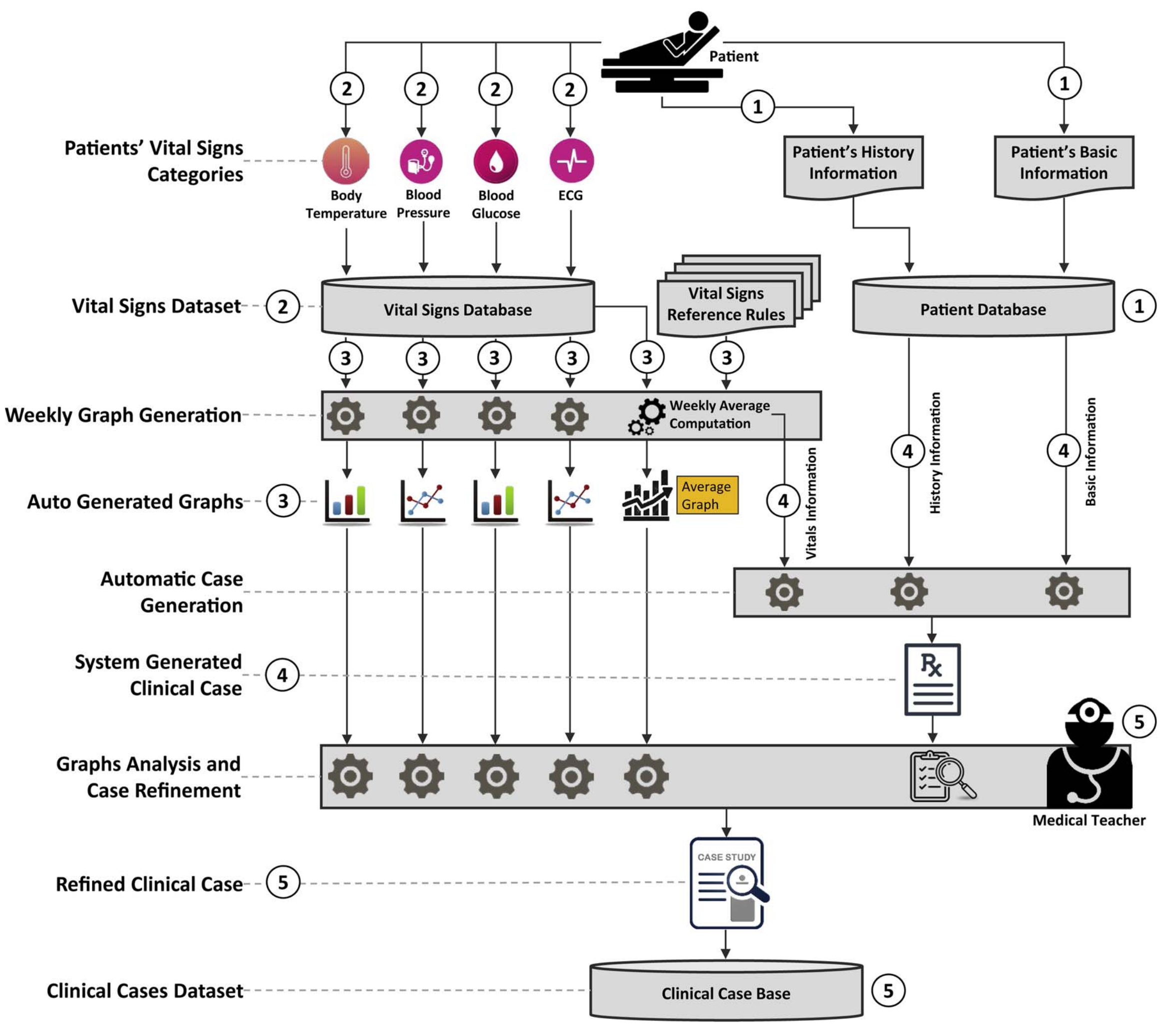

Fig. 3. Real-world clinical case creation steps.

4. Simulation of iCBLS

The design of the iCBLS is based on the current CBL practices whose working principle is explained with the help of a *Glycemia* case study. Using this system, the medical teacher can create cross-domain clinical case(s) and then students can formulate summaries of cases before attending the actual CBL class for practice. Moreover, the teacher can review the students' formulated summaries and can provide feedback on their solutions. The output of this system is the course's information, real-world cases, health records, formulated cases, and the teacher's feedback.

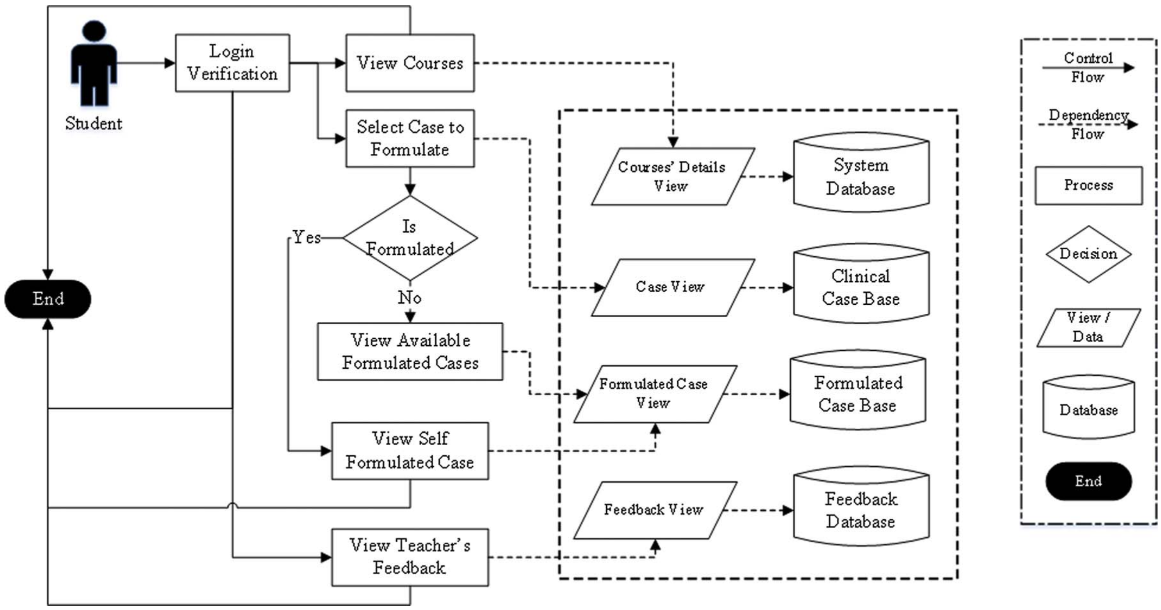

Fig. 4. Flow diagram of case formulation module.

The iCBLS is an interactive as well as flexible online software system, which manages multiple types of users according to their roles and privileges. It has been implemented in *C#* using *SQL Server 2008 R2* and *Bootstrap* as the front-end framework. In this system, nested *GridView* controls are used to manage the hierarchies of courses or cases. Similarly, *Stored Procedures* are created to decrease roundtrip response times and avoid code redundancy, as well as to simplify maintenance and enhancement. Both *GridView* and *Stored Procedure* techniques allow for increased system flexibility.

The role description of this system is shown in Fig. 5, it depicts types of system users, main options available in iCBLS for each user, and detailed functionalities of each main option.

4.1. Case study: glycemia case

For in-depth study or analysis of real-world or imagined scenarios, the case study is used as a training tool to explain development factors in the case. For case study purposes, we have considered a *Glycemia* patient who regularly visits a hospital for clinical check-ups. The medical teacher interacts directly with the patient to obtain his demographics, daily routine activities, medication history (if any), and family history information. The medical expert obtains the patient's basic information and initial history through dialogue and available patient records.

The medical teacher requires the log of vital signs to understand the severity of disease, therefore, it is advisable that the patient's vital signs

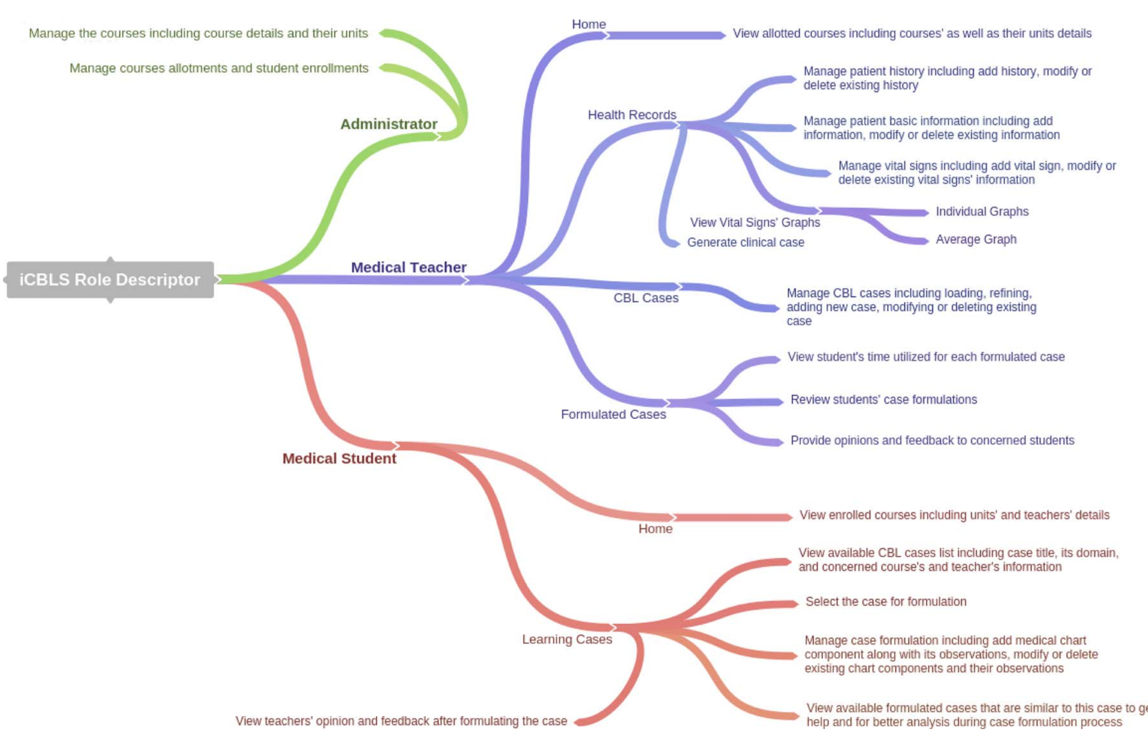

Fig. 5. iCBLS role descriptor.

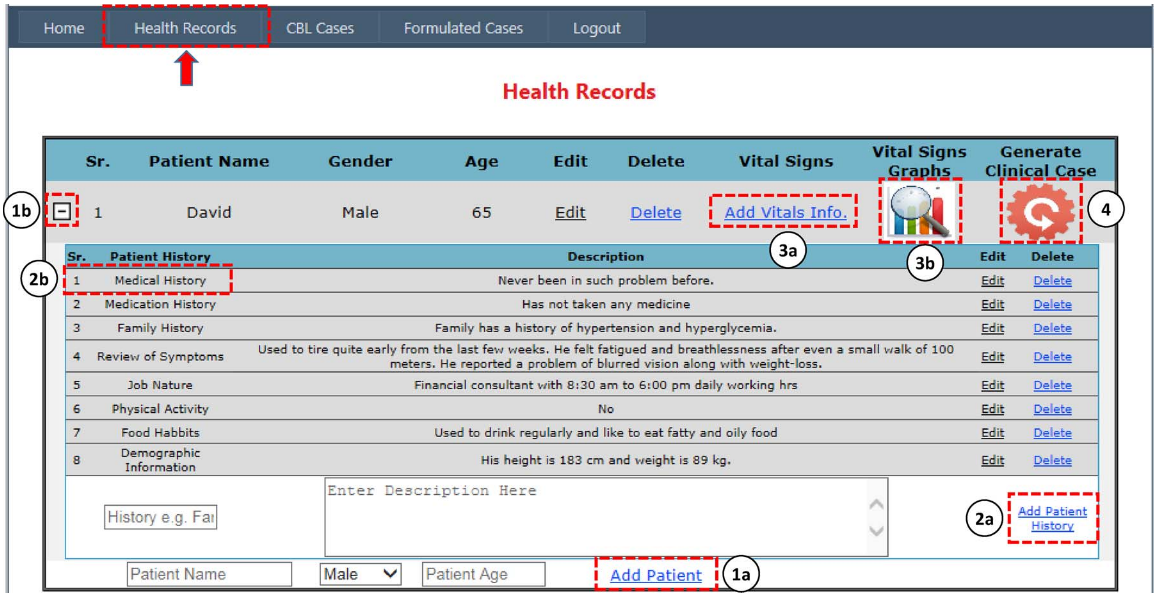

Fig. 6. Health record management interface.

such as *body temperature*, *blood pressure*, *glucose level*, and *heart rate* are recorded on a regular basis. The teacher also suggests that the patient's blood glucose level should be monitored in the morning with fasting as well as measured 2 h after lunch and dinner. The patient then records their vital signs information three times a day for one week, based on the teacher's instructions.

4.2. Clinical case creations

The process of real-world clinical case creation is described through the steps that are explained as follows.

4.2.1. Step-1: Record basic information and history information for the patient

In order to execute the scenario for creating a CBL case, the medical teacher uses the patient's basic information e.g. patient name, gender, age. This information is added into the system after clicking the *Add Patient* link as shown in Fig. 6(1a). After successful addition, the system refreshes the patient pane as shown in Fig. 6(1b). Similarly, after adding a patient record, the system displays the history pane to enable history details to be added, by clicking the *Add Patient History* link as shown in Fig. 6(2a). The system then refreshes the history pane as shown in Fig. 6(2b). Once patient information is added, the teacher can easily modify or delete the record at any time using the *Edit* or *Delete* links as shown in Fig. 6.

4.2.2. Step-2: Record patient's vital signs information

For inclusion of vital signs information, the medical teacher uses the *Add Vital Sign Info.* link shown in Fig. 6(3a). After doing this, the system displays the list of vital signs as shown in Fig. 7(a). The teacher clicks the '+' icon to see a child grid that provides options for adding a vital sign measurement as shown in Fig. 7(a). In the expanded grid view, the '+' icon is changed to '–' icon. For a better view, a paging concept is also implemented as shown in Fig. 7(a). The teacher enters the vital signs data into iCBLS. To enter date and time information, the system provides a calendar to the teacher for user-friendliness as shown in Fig. 7(b). When modifying existing measured values, the teacher clicks the *Edit* link. The system then shows the relevant data in an editable form as shown in Fig. 7(c). After modification, the teacher clicks the *Update* link. The system then updates the existing data and refreshes the grid.

4.2.3. Step-3: Generate and visualize the vital signs graphs

Visualization is the presentation of data in a format which is easily understandable. It is a key feature used to analyse and interpret the measured data. Once the *Vital Signs Graph* link icon, as shown in Fig. 6(3b), is clicked, the system generates auto-scaled trend charts for each vital sign category using their measured values and then visualizes them as shown in Fig. 8. Moreover, charts are also auto divided into different areas based on the previously mentioned reference ranges. In Fig. 8, each vital sign graph is divided into different areas depending on

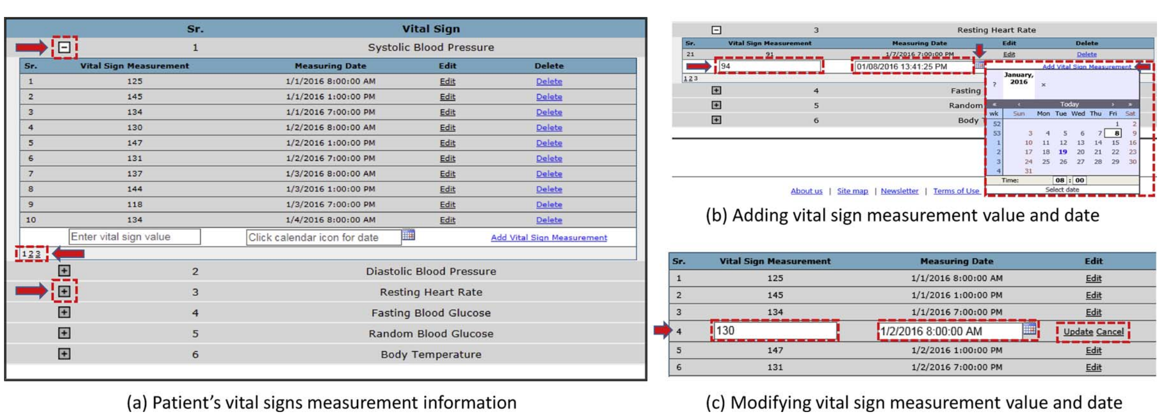

Fig. 7. Managing vital signs information view.

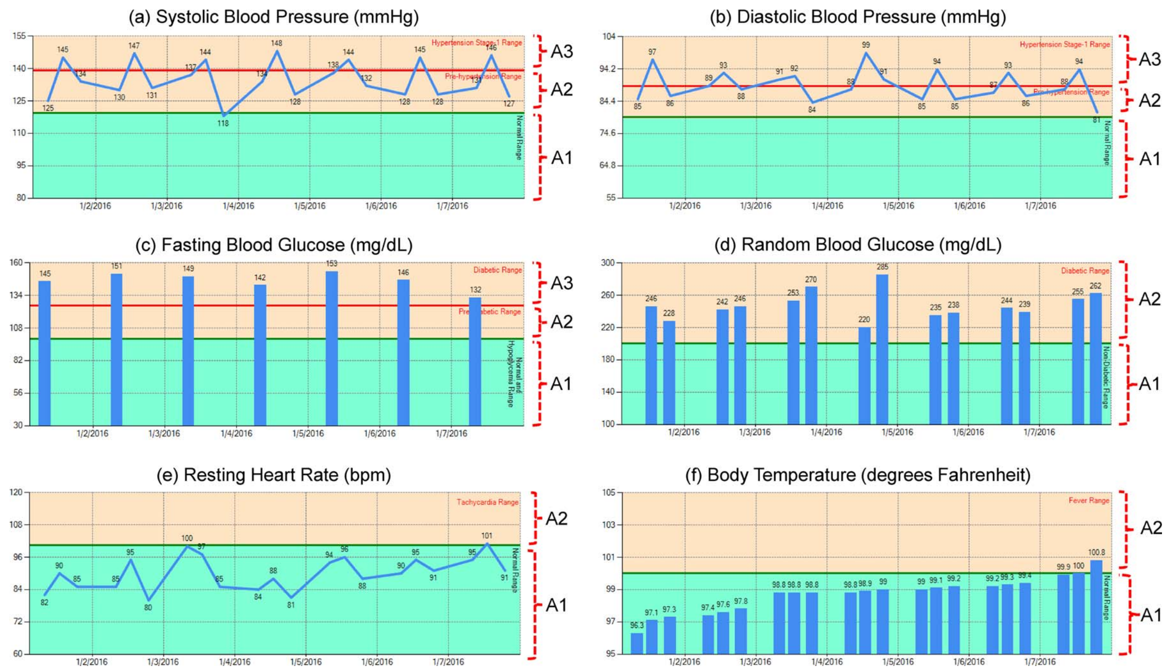

Fig. 8. Weekly trends of patient's vital signs information.

their reference ranges. Each range has its own interpretation in each vital sign category. For example, in Fig. 8(a), the *Systolic Blood Pressure* (SBP) graph has shown three areas such as A1, A2, and A3 having ranges ≤119 (Normal Range), 120–139 (Pre-hypertension), and 140–159 (Hypertension Stage-1) respectively as defined in Table 1. These ranges help medical teachers to analyse and interpret any vital signs trends easily. The system computes the average of each vital sign and generates the average trend chart for each vital sign category as shown in Fig. 9.

4.2.4. Step-4: Generate clinical case

Once the basic information, patient history, and vital signs information are recorded into iCBLS, the system generates the clinical case when the *Generate Clinical Case* link icon is selected as shown in Fig. 6(4). The system integrates all this information as described in Step-1 and Step-3 to generate the new clinical case labelled (2) that is shown in Fig. 10.

4.2.5. Step-5: Refine clinical case

After generating a new clinical case, the medical teacher interacts with the iCBLS and loads the system generated case, as shown in Fig. 10(2), by clicking the *Load Case* link as shown in Fig. 10(1). Once the case is loaded, the medical teacher enters *Case Title* and selects *Case Domain*, *Unit Title*, and *Difficulty Level* of the case as shown in Fig. 10(3)-(6). Following this, the teacher enriches the system generated case, as shown in Fig. 10(7), based on the personal knowledge and graphical trends' information shown in Figs. 8 and 9. In Fig. 10, labels 2 and 7 show the comparison between the system generated and teacher-enriched case. After enriching the clinical case description, the teacher clicks the *Add Case* link, as shown in Fig. 10(8), in order to store newly created CBL case into *Case Base*.

4.3. Case formulation

After the medical teacher creates the CBL case, the system automatically updates the list of cases available to students for their practice along with related information. In order to start the case formulation, the student loads the interface, which is shown in Fig. 11. A timer starts at the back-end of this interface until the submission of this formulation. The timer helps the teacher to assess the future difficulty level of a case for that particular group of students. As depicted in Fig. 11, the interface is divided into three sections. The first section provides the

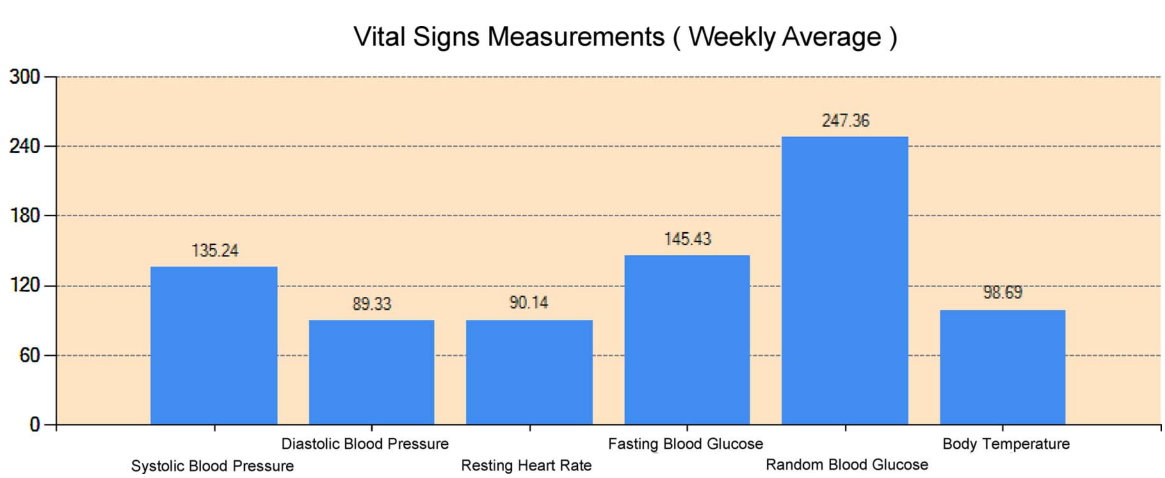

Fig. 9. Weekly average chart of measured patient's vital signs.

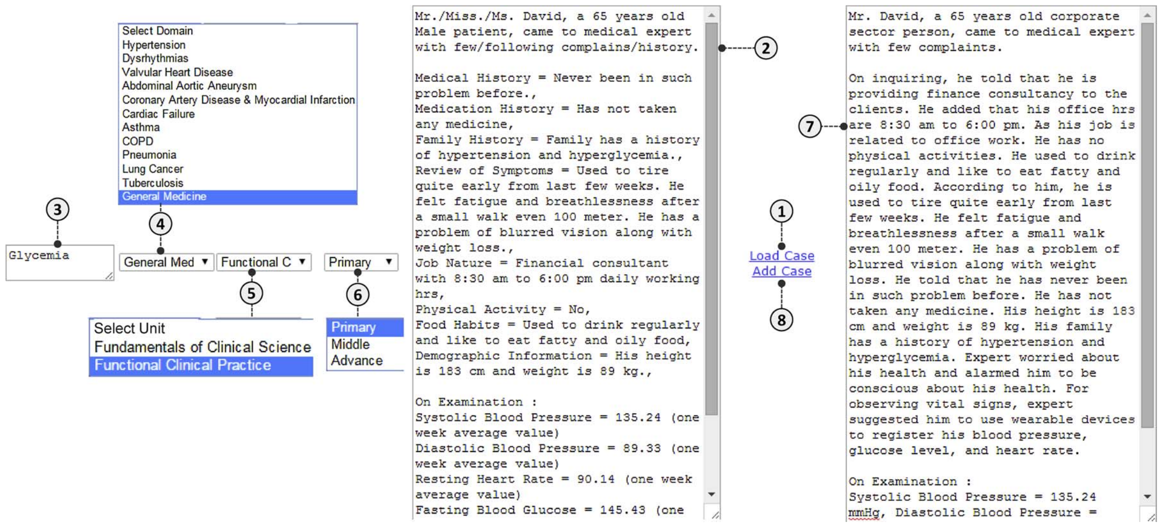

Fig. 10. Real-world clinical case creation steps.

case description, while the second section shows the medical chart that includes students' entered chart-components such as *Previous Medication* and their observations such as *No medicine mention*. Initially this section is blank. As students add chart components, this section updates and expands dynamically. Finally, the third section shows the list of students who submitted their formulation and solutions for that particular case. After completing the formulation of a CBL case, students submit their data. During the submission process, the system records the total time taken by each student.

Once students have submitted their solutions, the teacher reviews the medical chart and analyses student capabilities by considering their submitted solution along with the time taken to construct it. After reviewing the submitted formulation, the teacher enters their opinions and feedback for each student in each case through the feedback interface. This feedback provides help to students to improve their learning conceptualisation and increase their understanding, which contributes to their evolution of knowledge [48]. The CBL case selection and feedback simulations are not included here due to limited space.

5. System evaluation

In specialised literature, medical education programs are considered to be complex due to their diverse interactions amongst participants

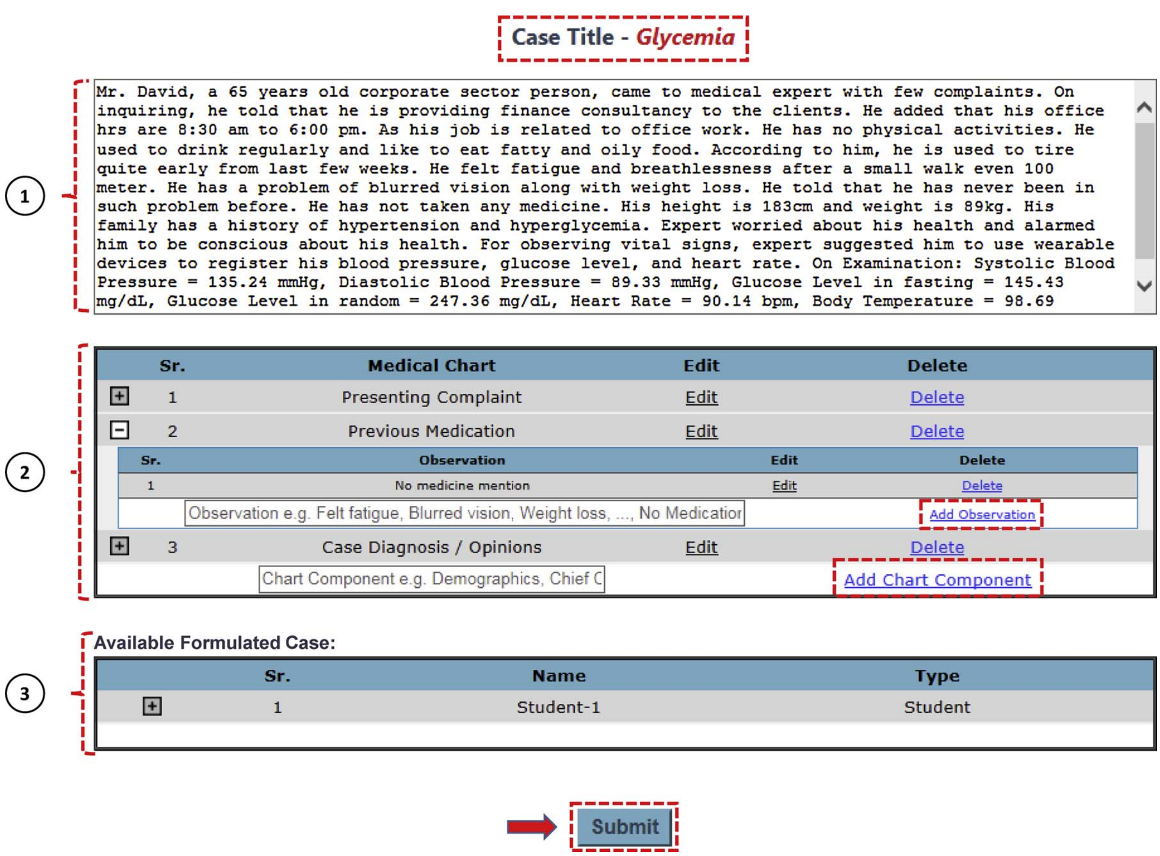

Fig. 11. Student view for case formulation.

Table 2
CIPP elements and tasks performed in iCBLS [1].

Context	Input	Process	Product
• Heterogeneous environments • Surveys • Interview • Focus groups	• Literature review • Visiting standard learning programs • Consulting expert	• Establish the evaluation questions • Collect the data • Participant interviews	• Judgements of the system • Assessment of achieved targets • Interviews about system's outcomes • Surveys

and environment [1]. Discussion-based learning in a small-group, like CBL, is considered to be a complex system [49]. In small-groups, multiple medical students are interacting and exchanging information with each other, where each student is also a complex system [50]. For evaluation of complex systems, the CIPP (context/input/process/product) model is most widely used in literature [51–55] and is considered as a powerful approach [1]. This model is used for evaluating as well as improving ongoing medical education programs; it is also consistent with system theory, and to some degree, with complexity theory [1,55]. For holistic understanding, the proposed system is evaluated under the umbrella of the CIPP model.

The evaluation phase of any system involves studying, investigating and judging the importance of the information for making a decision about the worth of an education program [1,56]. In the health profession education field, new developments in system evaluation are evolving, which are not yet ready for the mainstream approach [57]. Developments are still based on outcome-based evaluation, which is considered not to be sufficient for evaluating the health profession [57]. Furthermore, predicting the outcome of an education program is limited if we have an incomplete view of a program [1]. For evaluation of health professionalism, the program's context, and process elements of the CIPP model are widely used factors for assessing health professionalism using surveys and informal interviews [54,57].

For holistic understanding, the proposed system is evaluated in heterogeneous environments by involving multiple stakeholders and using multiple methods such as quantitative methods (e.g. surveys) and qualitative methods (e.g. interviews and focus groups) under the umbrella of the CIPP model. The functional mapping of the evaluation approach used in iCBLS's evaluation, with each element of CIPP model are illustrated in Table 2. In the first element of the CIPP model, heterogeneous environments, surveys, interviews, and focus groups are considered for *context* study, while for *input* study, literature review, other learning projects visitation, and expert consultation are performed in the second element. In the third element, the establishment of evaluation questions, data collection as well as participant interviews are covered for analysis purposes as to whether iCBLS is delivered in the manner in which we intended. Finally, the last element is used for assessing the outcome of the proposed system through positive or negative feedback and it also inspects the degree to which the target is achieved.

In this study, the *product* element of the CIPP model is responsible for investigating the impact of the proposed CBL system usability in terms of students' interaction and the system effectiveness for students' learning, which is explained in the following subsections. For both environments, survey-based as well as interview-based system evaluations are selected after performing beta testing on a given scenario with control information. In each survey, multiple evaluation questions are selected and prepared. The questions are considered as important factors for system evaluation, to help understand the success or shortcomings of the system [1]. A CBL case is created through iCBLS and made available to all users to assess the impact of the developed system. Moreover, in each environment, the system is first introduced and demonstrated before the survey and interview are completed. The evaluation setup for both environments is illustrated in Table 3.

5.1. Users interaction evaluation

This subsection describes the system evaluation in terms of interaction [58]. We compiled the feedback provided by the users to draw the holistic picture of the system, which is illustrated in Table 4. Overall, we found that *interaction* of the system through the interface was generally valued by the users, whereas, *load on the users' memory* was criticized. The results, as illustrated in Table 4, clearly show that users were quite satisfied with the *system capabilities*, *operating learning*, *screen flow*, and *interface interaction*, which were greater than 70%. The area of *consistency* and *load on user memory* due to surplus steps needs improvement as the system's interface was not able to satisfy the users. It was also inferred that the display of error and support message windows has further room for improvement.

We classify our users into 3 groups on the basis of their responses which are; those who evaluated the system as poor; those who evaluated it as average and above average; and those who evaluated it as good and excellent. In order to assess an evaluation criteria of the system, the comparison of evaluation for various categories is depicted in Fig. 12. The details of these results are given in Appendix A.

As represented in Fig. 12, the confidence on *system capabilities* and *interface interaction* was measured as about 70% from all users. Approximately 50% of users considered the *interface consistency*, *screen flow* and *operation learning* aspect as an appealing factor. Moreover, less than 40% of users were satisfied with the factors like *load on human memory* and with the *number of actions performed*, in order to achieve a particular task. Finally, for the evaluation of the system, on average, 42% of users responded with their level of satisfaction as medium level.

5.2. Learning effectiveness evaluation

This evaluation captures educational viewpoints and highlights the aspects that are technically inclined. We compiled the feedback from users as shown in Fig. 13 and found that *system appropriateness* with

Table 3
Evaluations setup for the iCBLS.

Evaluation criteria	Environment-I (users interaction evaluation)	Environment-II (learning effectiveness evaluation)
• Primary hypothesis • Secondary hypothesis • Variables • Options and weightages set for each question • Survey method • Number of users	• Flexible and easy to learn • Minimum memory load and efficiency (minimum actions required) • System capability, operation learning, screen flow, interface consistency, interface interaction, minimal action, memorization • Excellent (10), Good (8), Above Average (6), Average (4), Poor (2) • Google docs (Online), 1-on-1 • 209 (different years students and professionals)	• System appropriateness with respect to students' learning • System suitability with respect to students' level and user friendly system • Appropriate for group learning, appropriate for solo learning, useful for improving clinical skills, performing tasks straightforward • Five options from 1 to 5 representing poor to excellent and quantified in multiple of 20 • Google docs (Online), 1-on-1, small groups at the hospital

Table 4
Summarized response with respect to categories results.

Evaluation criteria		Sub-categories response	Categories response	
Categories	Sub-categories	(Out of 10)	(Average)	(%)
System capability	System reliability	7.5555	7.8148	78.15
	Designed for all levels of users	8.0740		
Operation learning	Learning to operate the system	7.2963	7.2037	72.04
	Reasonable data grouping for easy learning	7.1111		
Screen flow	Reading characters on the screen	6.9629	7.0555	70.56
	Organization of information	7.1481		
Interface consistency	Consistency across the label format and location	7.1111	6.6851	66.85
	Consistent symbols for graphic data standard	6.2592		
Interface interaction	Flexible data entry design	8.0000	8.1481	81.48
	Zooming for display expansion	8.2962		
Minimal action	Wizard-based information management	6.7407	6.0185	60.19
	Provision of default values	5.2962		
Memorization	Highlighted selected information	4.8148	4.8148	48.15

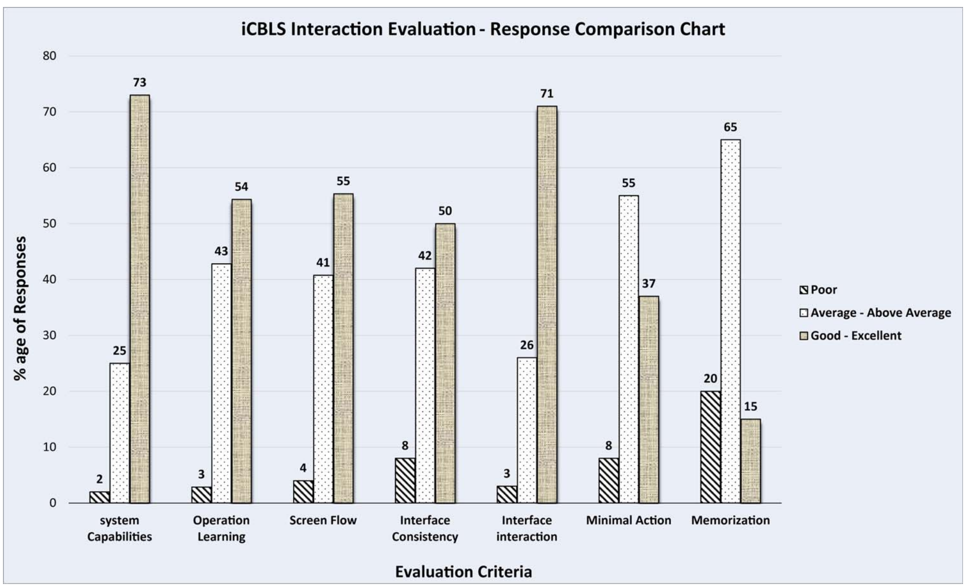

Fig. 12. iCBLS interaction evaluation – response comparison chart.

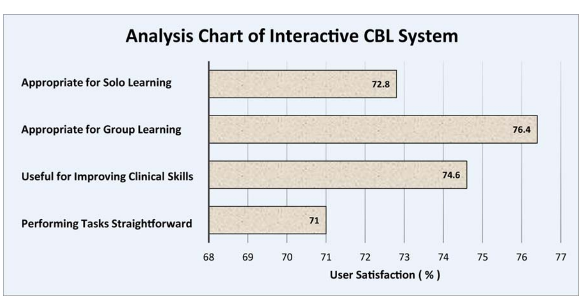

Fig. 13. System effectiveness summary chart.

respect to *group learning* was mostly appreciated by the users.

Fig. 13 clearly represents that users were quite satisfied with the *system appropriateness* for group as well as solo learning, *system usefulness* with respect to enhancing clinical skills, and *user friendliness* of the system, which were greater than 70%. We also evaluated our system to check *suitability* and *appropriateness* for different course-year levels of medical students. The system achieved votes for year-levels 2 or 3 that showed confidence on system suitability for these students, which is the stage where students begin to do placements at hospitals.

We also conducted an open-ended survey evaluation in order to analyse whether the proposed online interactive CBL system contributed to effective medical knowledge and skill learning. All 155 first-year medical students in the *University of Tasmania* used the system for one semester and were asked to provide information on their learning experiences and perceptions through an open-ended survey with 3 different questions. Open-ended questions normally aim to collect more detailed information and actionable insights since they allow the freedom and space to answer in as much detail as the respondents would like to give. The aim of the conducted survey was to encourage students to share their medical skill learning experience by using the proposed CBL system. Table 5 shows the open-ended survey questions for learning efficiency evaluation.

Responses to our survey evaluation with 155 students, can be summarized as follows:

- Key phrases from answers to the first question were 'self-learning', 'independent thinking', 'gaining more professional knowledge' and 'distance learning'. The majority of students felt that CBL encouraged them to be active learners, and to use logic to think and learn with real-world cases. The system also allowed students to access the learning materials (real-world problems observation, problem-solving skill learning, and teachers' feedback) in rural settings, and students felt this sort of online system could help support this lack of resources.
- The key phrase from answers to the second question was 'senior

Table 5
Open-ended survey question for learning efficiency evaluation.

#	Open-ended survey questions
1	What did you like most about the computer-based tutorial preparation module?
2	What did you like least about the computer-based tutorial preparation module?
3	Are there any areas where you think the Case-Based Learning tutorial program can improve?

level education'. Further to that, some students felt this is not suitable for very junior students (i.e. first-years) as they have not had the exposure to clinical environments to understand what sort of content they were given in such a system format without some guidance. However, other students thought that it was great opportunity to review their learned knowledge and skills as first-year students.

- Key phrases from answers to the third question were 'time consuming work', 'tutor engagement', 'improvement of feedback interface'. Some students mentioned that it would be better to have more tutor support or feedback on their answers through the system interface in real time.

The evaluation of any medical education program can be affected by participants' characteristics, the domain knowledge, and the environment in which the system operates [59]. As it is an initial concept, we do believe that with increased usage of the system this efficiency may increase for complicated scenarios and it will help students to understand the real world's patient-medical scenario in an efficient and accurate manner [36].

6. Discussion about significance, challenges and limitations of the work

This study addresses an issue of great interest to many readers who have an interest in teaching and learning in medicine with regard to how to foster medical trainees' collaborative learning skills as a lifelong learning endeavour, using advanced technology. The main aim of every medical student is to interact with patients and to experience a variety of cases during their clinical practice period. The proposed system, iCBLS, provides the facilities for creating a real-life situation clinical case, practising that case before and outside the class, and finally getting feedback from experts to evolve their knowledge. This system supports distance learning and provides maximum (24/7) time management flexibility to each student. In addition, this system has the capability to generate useful information as well as knowledge which is then stored in a continuous manner that can be helpful in future for computerized feedback, intensive learning, better clinical competence, and transferring the expertise among experts and students. Based on the aforementioned system's characteristics, we do believe that the iCBLS will be effective in professional learning.

During the real-time implementation of our proposed system, we encountered several challenges. Some of the key challenges we attempted to resolve were the hierarchical management of data, abstraction of logic, avoidance of code redundancy, and analysis of the vital signs data. To manage the addition, modification, deletion, paging and nested hierarchy of data, we have used data grids. Similarly, for abstraction or obscuration of logic and to avoid code redundancy, we have used the stored procedures. Moreover, for analyses of vital signs data, we have generated individual as well as average graphs based on reference ranges.

Limitations of the proposed approach include lack of real-time integration systems due to the.NET framework; no user interface was created for the administrator to manage course allotments and enrolments; no connection with IoT devices to collect vital signs data was developed, nor did the system perform data validation for invalid values. Finally, the real-world clinical case creation process currently does not include image support.

7. Conclusions

This study describes how to foster medical trainees' collaborative learning skills as a lifelong learning endeavour using advanced technology with the support of online learning and real-world clinical cases. Practising real-world clinical cases before and outside the class can promote learning capabilities; save class time for effective discussion; and enhance the academic experience of medical students. For this purpose, we have developed a CBL system, iCBLS, which creates real-world clinical cases with a semi-automatic approach, formulates the summaries of CBL cases and provides feedback for formulated cases. This system manages multiple types of users according to their roles and privileges. In addition, this system also supports a number of features such as displaying the entire collection of data at one place, a paging facility, and support for in-line reviewing to edit and delete the displayed data. The working principle of the iCBLS is explained with the help of a *Glycemia* case study. Two types of evaluations under the umbrella of the CIPP model have been performed in heterogeneous environments. The iCBLS achieves a success rate of more than 70% for students' *interaction*, *group learning*, *solo learning*, and *improving clinical skills*. This success rate indicates that iCBLS effectively supports the learning of medical students.

Conflict of interest

None declared.

Disclosure statement

No conflict.

Notes on contributor(s)

Maqbool Ali proposed and implemented the idea, conceived and designed the experiments and wrote the paper; Soyeon Caren Han provided advisory comments and modified representations; Hafiz Syed Muhammad Bilal and Matthew Jee Yun Kang contributed in system evaluation; Sungyoung Lee and Byeong Ho Kang provided advisory comments, remarks and financial support for the paper; Byeong Ho Kang also arranged and took an student evaluation; Muhammad Asif Razzaq and Muhammad Bilal Amin involved in revision and improved the quality of paper.

Summary points

- Designed and developed an *interactive Case-Based Learning System* (iCBLS).
- The iCBLS consists of three modules: (i) *system administration* (SA), (ii) *clinical case creation* (CCC) with an innovative semi-automatic approach, and (iii) *case formulation* (CF) through intervention of medical students' and teachers' knowledge.
- Two evaluations under the umbrella of the context/input/process/product (CIPP) model have been performed with a *Glycemia* study. The results show a high success rate of 70% for students' interaction, 76.4% for group learning, 72.8% for solo learning, and 74.6% for improved clinical skills.

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Appendix A. Evaluation results of the iCBLS's interaction

In Table A.6, we present the detailed results of the proposed system's interaction, where results with bold size is depicted in Fig. 12.

Table A.6
Interaction evaluations results.

Categories	Evaluation Criteria Sub-categories	Poor (%)	Average (%)	Above Average (%)	Good (%)	Excellent (%)
System Capability	System reliability	2	14	14	45	25
	Designed for all levels of users	2	7	15	35	41
	Average	**2**	**10.5**	**14.5**	**40**	**33**
	Range Average	**2**		**25**		**73**
Operation Learning	Learning to operate the system	4	12	23	36	25
	Reasonable Data grouping for easy learning	2	8	43	34	13
	Average	**3**	**10**	**33**	**35**	**19**
	Range Average	**3**		**43**		**54**
Screen Flow	Reading characters on the screen	4	15	27	38	16
	Organization of information	4	8	32	32	24
	Average	**4**	**11.5**	**29.5**	**35**	**20**
	Range Average	**4**		**41**		**55**
Interface Consistency	Consistency across the label format and location	4	15	23	38	20
	Consistent symbols for graphic data standard	12	19	27	33	9
	Average	**8**	**17**	**25**	**35.5**	**14.5**
	Range Average	**8**		**42**		**50**
Interface Interaction	Flexible data entry design	5	6	23	37	29
	Zooming for display expansion	1	3	20	25	51
	Average	**3**	**4.5**	**21.5**	**31**	**40**
	Range Average	**3**		**26**		**71**
Minimal Action	Wizard-based information management	0	14	35	45	6
	Provision of default values	16	32	29	23	0
	Average	**8**	**23**	**32**	**34**	**3**
	Range Average	**8**		**55**		**37**
Memorization	Highlighted selected information	20	41	24	12	3
	Average	**20**	**41**	**24**	**12**	**3**
	Range Average	**20**		**65**		**15**

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