Highlights

Towards a Component-Based Framework for mHealth Apps: bridging the gap between the Nursing Domain Language and the Computation Domain

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- Discusses the gap between no-code platforms and the needs of healthcare applications.
- Uses a nursing taxonomy as a base for developing core software components.
- Identifies common elements and behaviors across healthcare interventions.
- Aligns clinical workflows with technical aspects of software development.

Towards a Component-Based Framework for mHealth Apps: bridging the gap between the Nursing Domain Language and the Computation Domain

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Abstract

Building an effective mobile health solution is challenging, requiring a strong technical foundation, close collaboration between healthcare professionals and developers, special attention to user experience, and ongoing maintenance. This paper explores the potential for a Component-Based Software Engineering solution tailored to mobile healthcare applications, aiming to reduce development costs and complexity. We first investigate the existence of shared elements and behaviors across different healthcare intervention strategies. Then we evaluate the possibility of creating a set of core, reusable elements based on the NANDA-NIC-NOC taxonomy, a standardized framework for nursing diagnoses, interventions, and outcomes. Our findings confirm that it is feasible to define core components derived from the nursing taxonomy. Additionally, we demonstrate that these components can effectively bridge the clinical-technical divide, thereby establishing a foundation for the development of customizable, patient-specific mHealth solutions with reduced technical effort.

Keywords: mHealth, NANDA-NIC-NOC, care plan, component-based software development, no-code, nursing process, reusable components

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1. INTRODUCTION

Component-Based Software Engineering (CBSE) is a software development technique built upon reusable and independent components [1]. CBSE reduces costs, complexity, and development time by enabling developers to assemble reliable, pre-tested components rather than building each feature from scratch. This modular approach promotes the separation of concerns and simplifies the management of complex systems, making it particularly valuable for large-scale software projects.

No-code (NC) platforms have emerged as a user-friendly, high-level manifestation of the principles underlying CBSE, where the modularity, reusability, and abstraction of components are key to simplifying and accelerating the development of software systems. By offering modular, reusable components accessible through visual, drag-and-drop interfaces, NC platforms empower non-programmers, or "citizen developers", to create applications without writing code [2, 3, 4]. This high-level abstraction makes NC platforms accessible to business specialists, who can develop digital solutions quickly and efficiently. However, despite these advantages, NC platforms targeting mobile app development often fall short in domains requiring specialized functionalities, such as healthcare, where more complex execution flows are needed.

Mobile Health (mHealth) apps have proven to be particularly valuable for improving access, efficiency, and quality of care. They allow patients to monitor their health, track symptoms, manage chronic conditions, and communicate with healthcare professionals (HCPs) directly from their smartphones [5, 6]. However, building an effective mHealth app is challenging and costly, requiring a strong technical foundation in both medical and programming fields. Close collaboration between HCPs and developers is essential to ensure that these apps meet clinical standards, regulatory requirements, and user expectations. Additionally, this interdisciplinary collaboration must be continuous to support the ongoing maintenance required to deliver an effective solution. Such constant cooperation can be difficult and costly to achieve and maintain [7].

Many NC platforms that claim suitability for healthcare solutions [8, 9, 10] target the US market and their key feature is the compliance with the Health Insurance Portability and Accountability Act (HIPAA), the US regulation to protect sensitive patient data. In theory, HCPs could use NC platforms to create mHealth apps tailored to the specific treatment needs of their patients, reducing reliance on IT teams and cutting costs [11]. In practice, however, NC platforms are limited to basic functionalities and struggle to meet the specialized requirements of healthcare applications. Indeed, there is a considerable gap between the language and reasoning used by HCPs and the technical components they must manage in an NC environment [12].

To bridge this gap, one needs elements that HCPs already use in their daily practice as the basic construction components for the logic of the digital solution. Furthermore, one must define the relationship between those basic components and the computational elements executing that logic. We believe CBSE can fill this gap. It has been applied in several fields (such as avionics [13, 14], robotics [15, 16], and product lines [17, 18, 19]), but it has been little investigated in the health domain.

We propose a CBSE approach for mobile healthcare, using nursing taxonomy as the basis for the definition of core components that can be later used in, for instance, NC platforms. We assume the hypothesis that by using familiar healthcare elements in the form of modular components, HCPs can design patient monitoring applications directly aligned with clinical workflows. Therefore, we want to represent the reasoning and language of care plans as computational elements. By focusing on healthcare-specific components, we aim to reduce the gap between clinical and technical domains and assist in developing flexible, patient-specific digital solutions without extensive technical expertise. To this end, we evaluate in this paper the following research questions (RQs):

> ***RQ1:*** *Are there common elements and behaviors across different healthcare intervention strategies?*
>
> ***RQ2:*** *Can common elements and behaviors identified in RQ1 be represented as reusable components for adaptable clinical workflows?*

The paper is structured as follows: Section 2 positions the proposed approach concerning the related work. Section 3 provides background on the nursing process and taxonomy as well as the main CBSE concepts used in this work. Section 4 presents the methodology we adopted to answer the research questions. Section 5 presents the development details and results while Section 6 discusses the main limitations and practical implications of the proposed approach. Section 7 concludes the paper.

2. RELATED WORK

In this section, we discuss works in the fields of CBSE, mobile health, and NC platforms for healthcare solutions to position our work.

CBSE has evolved significantly in response to the increasing complexity and modularity requirements of software systems. Service-Oriented Architectures [20], Microservices [21], Model-Driven Development [22], Serverless Architectures [23], DevOps practices [24], and CI/CD pipelines [25] are all examples of this evolution. Recent CBSE advancements in tailored applications were made mostly in the fields of avionics and robotics or embedded systems [26].

Liu et al. [27] developed an open-source software adaptable to component reuse. The authors propose a new level of granularity for decomposing the Computer Numerical Control (CNC) domain into specific components following a specific component model. The results showed that the developed components effectively balance usability and reusability. They also instantiate concrete CNC components based on specific configurations to implement targeted CNC functionalities and can encapsulate the execution logic of other CNC sub-domains at an abstract level. Wang et al. [28] examine the use of CBSE in Industrial Control Systems. The study highlights the inadequacy of existing solutions in supporting advanced functions and modern technologies, with many being overly specific to particular manufacturers. The authors propose an open-source architecture for the industry, centered on component reuse. They also define a component model and apply the proposed approach in a real case, evaluating the system performance. Although not related to the healthcare field, those works show the benefits of defining domain-specific component models also with respect to usability.

Research on mHealth apps shows growing interest in using smartphones to promote health. Numerous mHealth solutions have been proposed in recent years with a wide variety of functions such as self-monitoring of chronic health conditions [29, 30], medication adherence reminders [31], self-care improvement [32], and direct interactions with the health care system [33]. Despite this growth, there are important challenges involved in the development, dissemination, and maintenance of mHealth apps [7, 34]. Such challenges are deeply related to the natural complexity of software development, and also to the inherent information asymmetry between the developer's and healthcare professional's expertise, points of view, and languages. Notably, although a large number of mHealth solutions tailored to distinct diagnoses and groups of patients are being developed and tested, only a few advance to health services, mainly due to the above-mentioned development challenges. Siegler et al. [34] argues that health researchers need structural support to propose, rigorously evaluate, and disseminate interventions that use mobile technologies.

Brandon et al. [35] propose a methodology to build low-code artificial intelligence (AI) development platforms for health informatics using model-driven development and component reuse concepts. The authors illustrate the platform development methodology using two case studies (health information and computational analysis of tissue images). The proposed solution requires an AI expert to train or refine a model from scratch. After that, the user connects the data flow to components, and the desired workflow can be executed. This is a low-code approach as it abstracts away many coding details, but still requires an educated user to program the target application.

Liu et al. [8] describe the process of building a no-code platform for creating mHealth applications. Based on the literature review and using a collaborative approach, 13 mHealth researchers with various levels of research experience and 4 software developers identified key software features for the proposed platform. Those features focus on behavior change techniques that present good intervention effectiveness. The main goal of the platform is to offer researchers the flexibility to design mHealth interventions with several techniques that vary with the underlying behavior theory or mechanisms of action considered in the research. The platform was validated by 5 people with experience in mHealth research and received good evaluation scores for its usefulness. The users highlighted two most helpful features: the easy navigation for both the research portal and participant app, and the ability to download app usage and survey data. These results are promising, but additional validation campaigns would be necessary to assess the performance of the platform with a larger range of logic flows. Moreover, the core components of the proposed platform are more related to the app domain and a specific research logic flow (screens, media, surveys) than to the health domain in general. This level of abstraction can be challenging for HCPs to manage without any third-party assistance.

Our work aims to further bridge the gap between the healthcare and technology domains by using the principles of CBSE. We investigate the definition of core component models in the language of the HCP to understand if they can be leveraged to address the complexity of implementing mHealth solutions.

3. BACKGROUND

This section presents the concepts of the nursing process and nursing taxonomy, which represent the reasoning we want to model in the proposed CBSE approach. We also review the concept of the component model that will be used during the modeling phase.

3.1. HCP routine and reasoning

Nurses play a critical role in providing close care and monitoring for patients, even after discharge from the hospital. They are often responsible for the follow-up care that ensures continuity in health management and prevents complications. Studies have shown that nurses frequently coordinate and deliver post-discharge care, especially in high-risk patients [36]. This includes both in-person and remote interactions, such as telehealth, to maintain communication with patients and ensure their health is monitored closely during recovery at home.

The nursing process is a structured, patient-centered approach that guides nurses in providing effective and efficient care. Its cyclical and adaptable nature supports clinical reasoning and judgment, allowing nurses to meet patient needs in a constantly evolving healthcare environment (see Figure 1). Based on the American Nurses Association (ANA) Standards of Professional Nursing Practice, this process defines the core actions and competencies expected of all registered nurses, regardless of their role, specialty, or setting [37].

The nursing process involves five essential steps as described below [38]:

1. **Assessment** This is the initial stage where nurses gather comprehensive information about the patient's physical, emotional, and psychological health. This data is collected through patient interviews, observations, physical examinations, and reviewing medical histories. The assessment provides a baseline for further care planning.

2. **Diagnosis** After assessment, nurses analyze the data to identify the patient's problems or potential health risks. These diagnoses are not medical diagnoses but nursing diagnoses, which describe the patient's response to health conditions. Examples include "ineffective airway clearance" or "risk for infection."

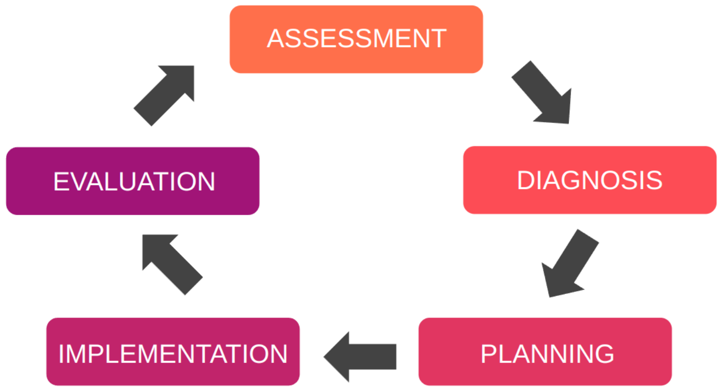

Figure 1: The Nursing Process. Adapted from [38].

3. **Planning** In this stage, nurses set measurable and achievable short- and long-term goals for the patient's care. Based on the diagnosis, nurses develop a personalized care plan with interventions designed to address the patient's needs. This plan involves setting priorities and determining the expected outcomes.

4. **Implementation** The nurse puts the care plan into action by performing interventions designed to address the patient's problems. This could include administering medication, providing education, or assisting with activities of daily living. Nurses continuously assess and modify interventions based on the patient's response.

5. **Evaluation** The final step involves evaluating the effectiveness of the care plan. Nurses assess whether the goals were met and determine if any modifications are necessary. If the outcomes are not achieved, the nurse revisits the process, adjusting the plan to meet the patient's needs better.

A care plan can be structured using a standardized language, called NANDA-NIC-NOC (NNN) [39, 40]. The NNN taxonomy enables nurses to create a clear, standardized, and evidence-based care plan that links diagnosis (NANDA), interventions (NIC), and outcomes (NOC).

North American Nursing Diagnosis Association International (NANDA-I, previously called NANDA) is a global nursing association that standardizes nursing diagnoses [41]. A diagnosis is a clinical judgment about individual, family, or community experiences and responses to actual or potential health problems and life processes [42]. NANDA-I focuses on defining standardized nursing diagnoses—statements that describe a patient's response to health conditions or life processes. In practice, it defines a standard and controlled vocabulary that can be used in different health settings. In a nursing care plan, the assessment phase leads to identifying a NANDA-I diagnosis. For instance, a nurse might identify "Impaired physical mobility" or "Risk for infection" as the diagnosis.

The Nursing Interventions Classification (NIC) standardizes nursing interventions. Once a diagnosis is made, the NIC taxonomy provides a list of standardized nursing interventions that are evidence-based actions to address the diagnosis. Interventions can be independent or collaborative, direct or indirect, and individual or group oriented [43]. In the planning and implementation phases of the nursing care plan, nurses select appropriate interventions from NIC. In our example, for "Impaired physical mobility," the nurse may choose interventions like "Exercise therapy" or "Fall prevention".

Finally, the Nursing Outcomes Classification (NOC) taxonomy offers standardized outcomes used to evaluate the success of nursing interventions. Nurses set measurable goals that are directly linked to these outcomes, which are assessed during the evaluation phase of the nursing care plan. Following our example, for "Impaired physical mobility," the expected outcome might be "Improved walking ability" or "Reduced fall risk".

The implementation phase of a care plan is critical for translating planned interventions into actions to achieve the desired health outcomes. During this phase, effective communication between the nurse and the patient is essential to ensure the patient understands their illness, treatment, and the specific interventions being carried out. Good communication fosters patient engagement, promotes treatment adherence, and helps reduce anxiety by clarifying any uncertainties [44]. A thorough understanding of their condition empowers patients to take an active role in their care, improving compliance and overall outcomes [45]. The NIC taxonomy plays a significant role in this phase by providing a standardized set of interventions that nurses can explain clearly to patients. By using the precise, evidence-based language of NIC, nurses can ensure that patients grasp the rationale behind each action, fostering transparency and trust. Moreover, the taxonomy allows for personalized care while maintaining consistency across different healthcare providers, ensuring the patient receives a well-coordinated and understand-able care experience.

An mHealth app can significantly enhance the implementation of a care plan by providing a platform for ongoing communication, monitoring, and support between healthcare providers and patients. For this reason, we assume the care plan as the main line of reasoning and the NIC taxonomy as the domain language used by HCPs.

3.2. NIC structure

The NIC taxonomy was first published in 1992 and is hierarchically organized into 7 domains, 30 classes, more than 500 interventions, and 12.000 actions or activities (hereafter, called activities). Figure 2 presents the current domains and classes of the NIC taxonomy, and Figure 3 shows an example of one intervention and its breakdown into activities.

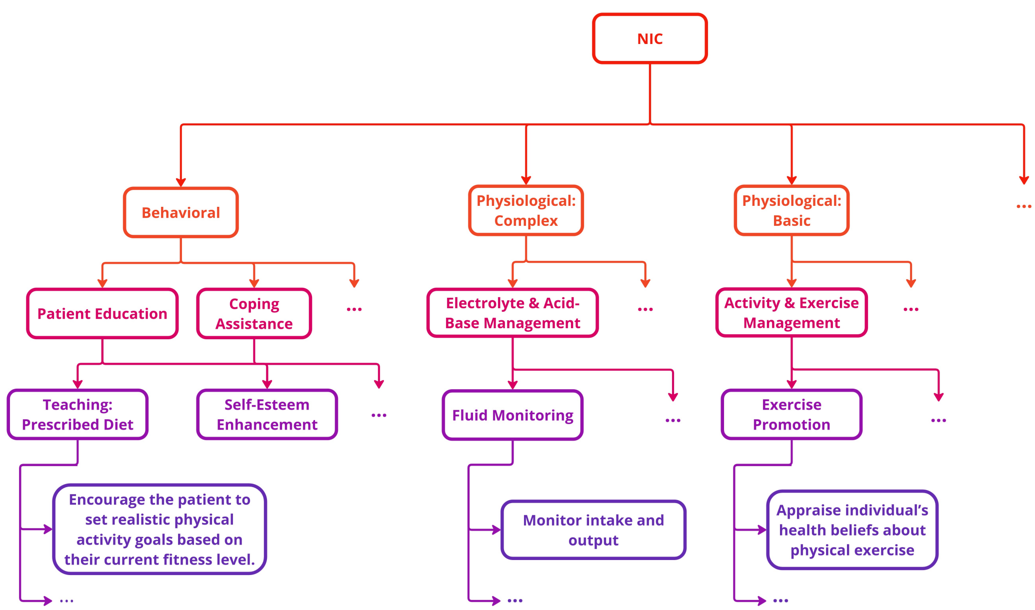

Figure 2: NIC taxonomy composed by domains (1st level), classes (2nd level), interventions (3rd level), and actions (4th level). Adapted from [46].

Nurses often need to tailor interventions to align with specific patient conditions, preferences, and cultural factors, which makes a standardized approach challenging. Therefore, activities associated with each intervention are not standardized because every patient has unique needs, health statuses,

NIC - Intervention "Fluid monitoring" - Actions

- Determine history of amount and type of fluid intake and elimination habits
- Determine possible risk factors for fluid imbalance (e.g., albumin loss state, burns, malnutrition, sepsis, nephrotic syndrome, hyperthermia, diuretic therapy, renal pathologies, cardiac failure, diaphoresis, liver dysfunction, strenuous exercise, heat exposure, infection, postoperative state, polyuria, vomiting, and diarrhea)
- Determine whether patient is experiencing thirst or symptoms of fluid changes (e.g., dizziness, change of mentation, lightheadedness, apprehension, irritability, nausea, twitching)
- Monitor weight
- Monitor intake and output
- Record incontinence episodes in patients requiring accurate intake and output
- Note presence or absence of vertigo on rising
- Administer fluids, as appropriate
- Restrict and allocate fluid intake, as appropriate
- Consult physician for urine output less than 0.5 mL/kg/hr or adult fluid intake less than 2000 in 24 hours, as appropriate
- Administer pharmacological agents to increase urinary output, as appropriate
- Audit intake and output graphs periodically to ensure good practice patterns

Figure 3: Example of activities associated to the “fluid monitoring” intervention (adapted from [46]).

and personal circumstances. In this work, we refer to activities as defined in the NIC reference book [46]. One can classify the activities into two groups: nurse-dependent and nurse-independent. The first one includes actions that require nurse participation (for example, catheter replacement). The second group contains actions that the patient can do on their own (for example “drinking water every 2 hours”). In this work, we focus on the second group.

3.3. Running example

Let us consider one example to illustrate the nursing process using NNN taxonomy. We have John, a 55-year-old male patient diagnosed with urolithiasis (kidney stones). The nursing process is applied using the NNN framework as follows:

1. **Assessment** John presents with symptoms of flank pain, nausea, and hematuria (blood in urine). He has a history of recurring kidney stones, often linked to inadequate hydration and dietary habits. The nurse gathers data about his fluid intake, dietary choices, and his understanding of urolithiasis prevention. The following data is collected:

    - Blood glucose logs

- Dietary assessment
- Pain level reports
- Urine characteristics

2. **Diagnosis** Using the NANDA-I framework, the nurse identifies the primary nursing diagnosis: *Risk for Imbalanced Fluid Volume related to insufficient knowledge of fluid intake requirements, as evidenced by frequent episodes of kidney stones.*

3. **Planning** The nurse collaborates with John to set achievable goals for managing his urolithiasis. The plan focuses on adequate hydration and adherence to a prescribed diet low in oxalates. The following NOCs (outcomes) are selected:

   - Adequate fluid balance
   - Improved knowledge of fluid intake requirements
   - Adherence to dietary modifications

4. **Implementation** The interventions focus on activities that John can perform independently. The following NICs are selected:

   - **Health Education**
     - Develop educational materials written at a readability level appropriate to the target audience;
     - Formulate objectives for a health education program;
     - Emphasize the importance of healthy patterns of eating, sleeping, exercising, etc. to individuals, families, and groups who model these values and behaviors to others, particularly children.
   - **Fluid Monitoring**
     - Monitor weight;
     - Determine if the patient is experiencing thirst or symptoms of fluid changes (e.g., dizziness, change of mentation, lightheadedness, apprehension, irritability, nausea, twitching).
   - **Teaching: Prescribed Diet**

- Include the family, as appropriate;
- Inform the patient of possible drug and food interactions, as appropriate;
- Appraise the patient's current level of knowledge about the prescribed diet.

For each selected NIC, the nurse needs to tailor the interventions to John's lifestyle and communicate possible daily actions that can help him overcome his health problem. This includes, for instance, advising John to log his meals and water intake volume, administering specific medication for pain, or recommending a particular podcast about weight control, considering John's preference for this type of media.

At this point, an mHealth app can be useful to document the nurse's instructions to John and help him implement them throughout his day during the treatment period.

5. **Evaluation** A return appointment is scheduled for six weeks from now so the nurse can evaluate John's progress. The goal is for him to increase his daily water intake and follow the recommended dietary guidelines. As a result, the nurse expects a decrease in symptoms, and his urine characteristics indicate better hydration.

3.4. CBSE: Basic components

In CBSE, a basic component is a self-contained unit of functionality that encapsulates both data and behavior. It is reusable, has well-defined interfaces, and can be independently deployed and replaced [47]. Components communicate through these interfaces rather than through direct code access.

Interfaces define how components interact with each other by specifying the services they provide and require. They ensure that components can communicate correctly without exposing their internal details. By setting clear parameters and communication patterns, interfaces determine how components are connected and how data flows between them. In essence, they define the "contract" that governs component interactions, allowing for modular and independent development while maintaining system integrity.

When developing a new component model, it is essential to define key characteristics such as the component's purpose, functionality, dependencies, and interfaces. This ensures that the model provides a clear and structured approach for creating reusable and interoperable components within a system. By establishing these elements, the model defines how components communicate and integrate, promoting efficient system design and development. In this paper, we aim to define healthcare component models based on the nursing process and the NNN taxonomy.

4. PROPOSED APPROACH

We propose a set of core components based on the nursing domain language that can be further used to generate computational elements. Our goal is to reduce the gap between the nursing domain and digital solutions, such as NC platforms and mobile applications.

As explained in Section 3, we want to address the implementation phase of the nursing process, where mHealth apps are mostly used. In this phase, the NIC taxonomy is the domain language used by HCPs, especially the activities associated with each mapped intervention. Thus, our ultimate goal is to model activities of the NIC taxonomy as basic components. To do this, we first need to respond the RQs defined in Section 1. That is, we need to group activities from the NIC taxonomy by semantic similarity, and then we need to define a component model for each identified group.

4.1. Methodology

Figure 4 depicts the methodology we use to answer RQ1. As there are more than 500 interventions and 30.000 actions mapped in the NIC taxonomy, we propose to select a subset of NICs to be analyzed in this first study. The process used to determine this subset is explained in Section 5. Once the subset of interest is defined, we manually sort out all activities that are nurse-independent. Then, for each nurse-independent action associated with an intervention, we analyze and classify its semantics and purpose. If this classification corresponds to an existing semantic group already mapped, the action under analysis is added to that group. Otherwise, a new semantic group is created. After all activities of all interventions of the subset of interest are analyzed, we name each semantic group according to its purpose, and we can evaluate the cohesion and representativity of each group.

If RQ1 is validated, we can proceed to RQ2 using the methodology depicted in Figure 5. The goal in RQ2 is to create a component model for each semantic group identified in RQ1. In this paper, we are only interested in the interface aspect of the component model, that is, whether we can

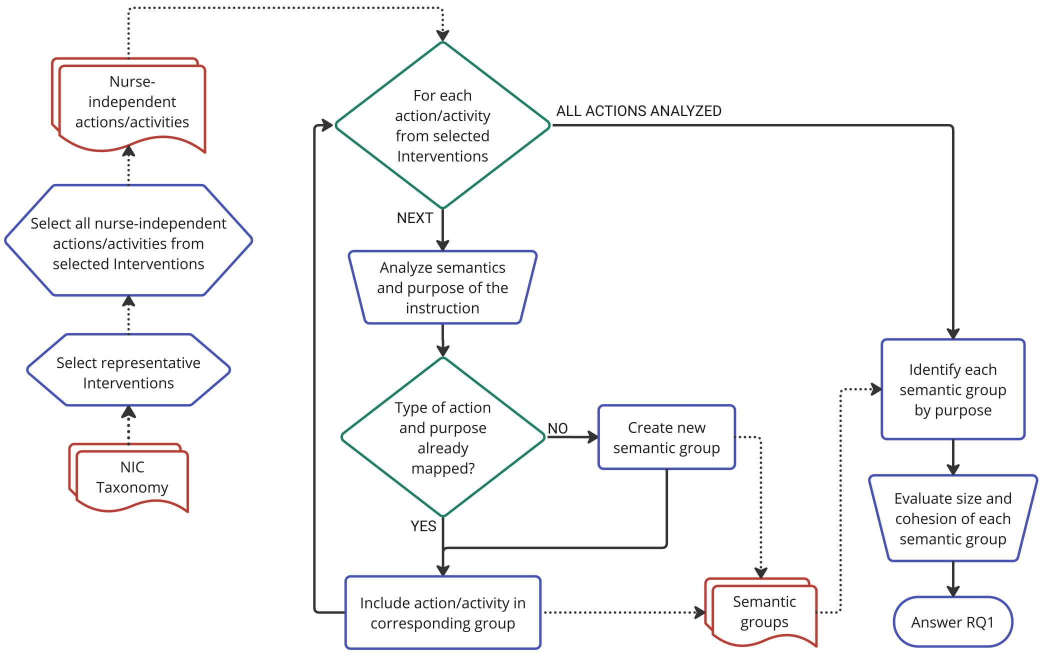

Figure 4: Validation methodology for RQ1

define the "contract" that governs the component interactions as explained in Section 3.4. Thus, we must identify all parameters involved in each action/activity in a given semantic group and, during this process, compose a suitable interface for the component model corresponding to that group. After all the activities of all semantic groups have been analyzed, we can evaluate the abstraction and composition characteristics of the generated component models.

5. DEVELOPMENT

In this section, we detail the development phase of this work following the strategy described above.

5.1. Analyzing RQ1

Following the proposed methodology (Figure 4), the first step to validate RQ1 is to select a subset of interventions to be analyzed. This step is described next.

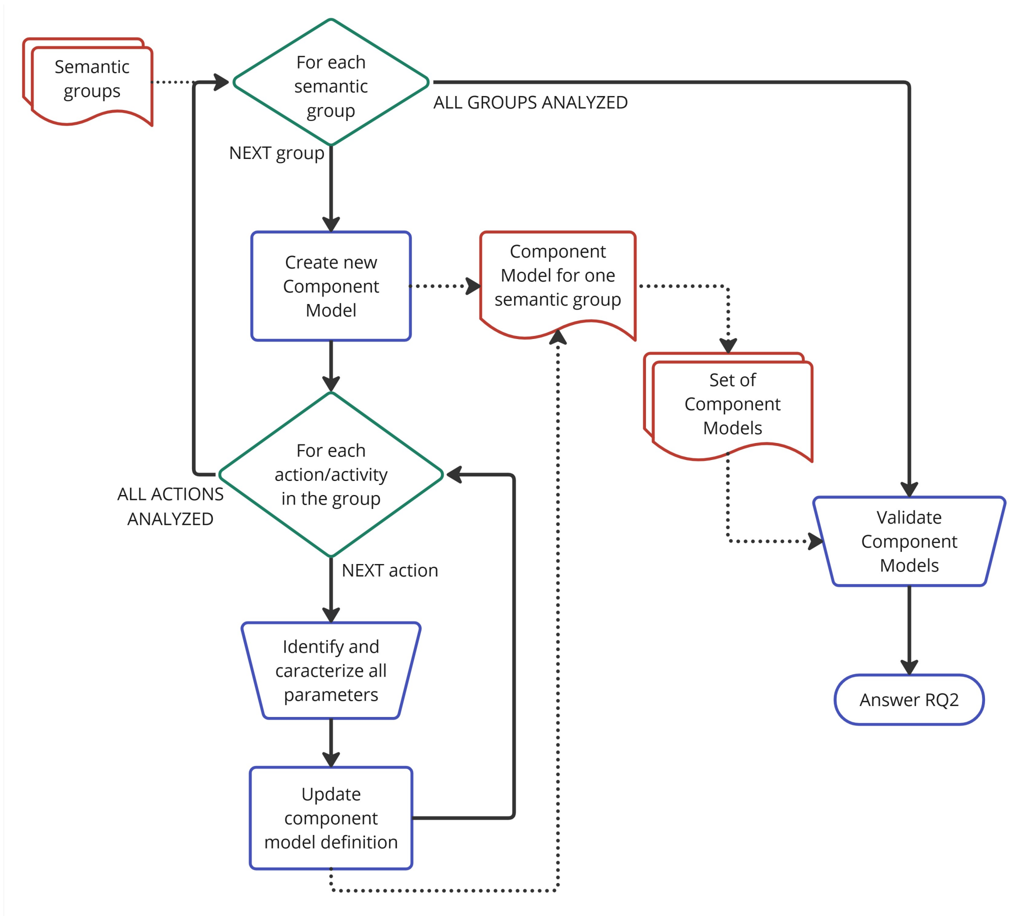

Figure 5: Validation Methodology for RQ2

5.1.1. Selection of representative interventions

As part of our research, we contacted nurses through personal and social networks to better understand their routine and care plan implementations. We were able to interview 14 nurses (out of 50 contacted) from different areas (pediatrics, cardiology, nephrology, oncology, and elderly care), who work in the metropolitan area of Porto Alegre (Brazil). Ten of the nurses we interviewed mentioned two diseases among their patients: cancer and urolithiasis. As a consequence, we were able to collect more information about care plans related to these infirmaries and decided to start our analysis with them.

For each disease, we looked for the commonly indicated interventions described in the literature. To do this, we performed a literature review on scientific work produced in the last twenty years that addresses cancer and urolithiasis interventions. We started with some references indicated by the nurses and expanded our search following the protocol shown in Table 1. We note that our goal with this search is not to produce a complete review of possible interventions for those diseases, but rather to identify typical actions or care plans that we can use as a basis for our initial analysis.

Repositories	Pubmed, ScienceDirect, Springer
Search terms	prostate cancer NIC
	urolithiasis NIC
Inclusion criteria	the paper addresses cancer or urolithiasis disease;
	the paper proposes one or more interventions using NNN taxonomy
	the paper has been published in the last five years
Exclusion criteria	the complete version of the paper is not available
	the paper proposes interventions that depend on HCPs

Table 1: Protocol for literature review

With this search, we obtained 671 papers. After reading their title, abstract, and conclusion, we applied the inclusion and exclusion criteria, leaving 134 works: 77 related to cancer and 57 to urolithiasis. All selected papers were read in full, so we identified the two most recommended interventions for each disease. Thus, we selected four NICs: two for each disease. For each NIC, we considered all nurse-independent actions described in [46]. Table 2 shows the selected interventions for each target disease (column 2) and the number of actions that must be analyzed in the next step (column 3).

5.1.2. Semantic Analysis of Activities

We analyzed all nurse-independent actions related to each selected NIC (Table 2) and grouped them by semantic similarity.

Disease	NIC	# of actions
Cancer	Exercise promotion	21
	Self-esteem enhancement	25
Urolithiasis	Fluid monitoring	12
	Teaching: Prescribed diet	17

Table 2: Selected NICs for RQ1 analysis

One way to do this grouping could be by analyzing action verbs in each statement. For example, the activities "Encourage eye contact in communicating with others" and "Encourage verbalization of feelings about exercise or need for exercise" have both the verb "encourage", which could lead to a semantic group related to behavioral change. However, this analysis may not be sufficient. In the given example, the first action is more related to a general advisement, and the other one implies the need for a concrete response from the patient (the nurse needs that information to adjust the care plan, for instance).

Hence, we consider an action semantically similar to another if they have the same purpose but with different information. For example, consider two actions selected from NICs of our running example (Section 3.3): one is to monitor the patient's weight, and another is to check if the patient is dizzy. These actions are similar because they are actions in which the patient should provide some information as input for the HCP (in this case, their weight and whether they are dizzy or not).

Tables 3 and 4 present the semantic groups identified for cancer and urolithiasis, respectively. The first column shows the name we defined for each group according to its purpose. Column 2 indicates the number of activities included in that group, and Column 3 shows an example of an action included in each group.

The purpose of each semantic group identified in our analysis is as follows:

- Ask: aims to receive some input from the patient;
- Explain: aims to instruct the patient about something using rich text;
- Medicate: helps patients to handle the medications they need to use;
- Orient: a short message for assisting or motivating the patient about something;

Semantic group	# of Actions	Example of Action
Ask	13	Determine individual's motivation to begin/continue exercise program
Explain	18	Instruct individual about desired frequency, duration, and intensity of the exercise program
Orient	12	Encourage individual to begin or continue exercise
Remind	3	Provide reinforcement schedule to enhance individual's motivation (e.g., increased endurance estimation; weekly weigh-in)

Table 3: Semantic groups identified for cancer

- Remind: a short message that is sent periodically.

Although each disease's diagnosis and expected outcomes differ, common behaviors can be found among the detailed nurse-independent actions present in different care plans. Even though only two diseases have been considered, we note they have very distinct characteristics and require very different interventions. Still, the resulting semantic groups identified for each one are quite similar. With this result, we believe the answer for RQ1 is yes, and we can proceed with our analysis of RQ2.

5.2. Analyzing RQ2

Having identified semantic groups from NIC's actions, we now evaluate whether component models can be defined for each group according to the methodology presented in Figure 5.

5.2.1. Generating the core components

We start by defining a basic component model, hereafter called Nursing Basic Component (NBC), with a given identification and purpose, as defined in Section 5.1. This basic component model has a standard interface consisting of a name, a description, and whether it is periodic or not. Each basic component will have its own detailed input/output interface parameters. Table 5 summarizes the NBC definition.

For each semantic group identified in Section 5.1 we first create a new instance of the NBC. As the main purpose of using components is reusability,

Semantic group	**Total actions**	**Action example**
Ask	10	Monitor intake and output
Explain	10	Instruct the patient on the proper name of the prescribed diet
Medicate	2	Administer pharmacological agents to increase urinary output, as appropriate
Orient	6	Audit intake and output graphs periodically to ensure good practice patterns
Remind	1	Consult a physician for urine output less than 0.5 mL/kg/hr or adult fluid intake less than 2000 in 24 hours, as appropriate

Table 4: Semantic groups identified for urolithiasis

Name	Component identification.
Description	Summarize what the component does.
Type	Indicates if it is a periodic or non-periodic behavior.
Input	List of parameters that the component receives.
Output	Information that is obtained at the end of the component execution.

Table 5: Nursing Basic Component (NBC) interface

we need to identify the inputs and outputs of these groups. Then, for each action in that semantic group, we identify the information and parameters required to perform that action, and that will define the inputs and outputs of the new NBC. This may include information the HCP needs to provide or receive from the patient, as well as information related to the intervention, the disease, or any other data relevant to the purpose of that action within the care plan. If the parameters of all actions in a given semantic group can be extracted and subsumed into a unique coherent (reusable) component, then we can define the component model that represents the semantic group.

In the following, we detail this process for each semantic group defined in RQ1.

Semantic group Explain: The NBC corresponding to the semantic group "explain" was named "Explanation". This element aims to educate the user. It is a non-periodic component with the following description:

"Guide/e-book for patient education and information". The input parameters for this component are: a name for the guide (its title), a description of its contents, and a list of pages, where each page is a rich text. It processes these inputs to compile and format the content into an electronic book (e-book), which is then generated and delivered as the output.

- **Preconditions:** The title and description must be a non-empty string. The list of pages must contain at least one page, and each must be a valid rich text.
- **Postconditions:** The output is a non-empty rich text.
- **Dependencies:** None

Semantic group Medicate: The NBC corresponding to the semantic group "medicate" was named "Medication control". It is a periodic component with the following description: "Details a specific drug prescription and provides periodic instructions on how to use it correctly". This NBC receives a name, a description, the reason for using the medication, notes, and dosage as input. From these inputs, the component should manage the medication schedule and provide periodic instructions, notifying the patient when it is time to take their medication.

- **Preconditions:** The name, description, and reason must be a non-empty string. The notes can be an optional string, while the dosage must be a valid dosage format.
- **Postconditions:** A notification is delivered to the user
- **Dependencies:** The user device must have compatibility with notifications.

Semantic group Orient: To represent the "orient" semantic group, we created an NBC called "Orientation". This component aims to provide specific instructions or messages to the user. It is a periodic component with the following description: "Specific instruction or message" and the following inputs: name, description, and content. It processes these inputs to create a short message, which should be sent to the user.

- **Preconditions:** The name, description, and content must be a non-empty string.

- **Postconditions:** A message is delivered to the user
- **Dependencies:** None

Semantic group Ask: The NBC named "Quiz" was created to assimilate the "ask" semantic group. Its objective is to collect information. Also, it is a periodic component with the following description: "Collects information from the patient". It has three inputs, including a name, a description, and a list of questions that need to be answered. From these inputs, the component should create a form, which is then generated and presented to the user for answering.

- **Preconditions:** The name and description must be a non-empty string. The list of questions must contain at least one question, and each question must be a non-empty string.
- **Postconditions:** A form is delivered to the user
- **Dependencies:** None

Semantic group Remind: For the "remind" group, the associated NBC was called "Reminder". It aims to remind the user about something. Also, it is a periodic component with the following description: "Prompts or alerts the patient with some information/required action about the treatment". It has four inputs: a name, description, content, and format. The format specifies how the reminder should be delivered (SMS message, alarm, push notification, and so on). The component processes these inputs to create a message, which is then generated and sent to the user in the specified format.

- **Preconditions:** The name, description, and content must be a non-empty string. The format must be a valid delivery method (e.g., SMS, alarm, push notification, and so on).
- **Postconditions:** A message is delivered to the user
- **Dependencies:** The user device must have compatibility with notifications.

Figure 6 summarizes the interfaces for the five defined NBCs.

Considering that we were able to generate component models corresponding to each semantic group and that each component covers the demands of

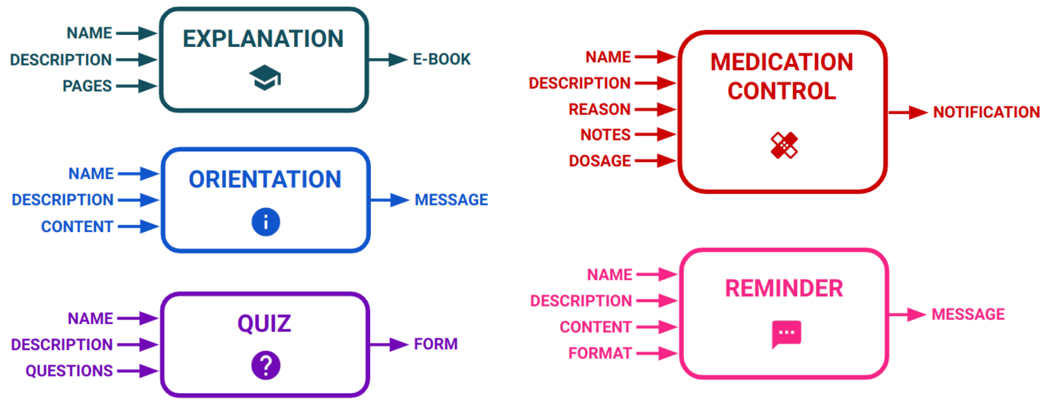

Figure 6: Input and outputs of NBCs

all activities contained in a given group, we can conclude that RQ2 is partially answered. Common elements and behaviors can be represented as reusable, adaptable components. It remains to be shown that these components can be combined to describe a care plan's implementation.

5.2.2. Composing NBCs into a care plan

We demonstrate how the devised NBCs can be composed into a care plan implementation by using the two case studies mentioned before: cancer and urolithiasis. For each one, we represent one intervention using the devised NBCs.

Figure 7 shows the representation of the "exercise promotion" intervention. In that, the care plan orients the patient on the importance of exercising, collects exercise history, and, depending on the patient's response, suggests sharing his/her exercises to improve engagement. Also, we explain the importance of exercising and, finally, we remind the patient about his/her daily exercises. This simple example already shows the need for a computational model to support the instantiation of the devised NBCs. Such a model is beyond the scope of this paper. We are currently assuming a composition based on a data-flow model, but this definition requires further research and validation with HPCs, as it will be clear in Section 5.3. For now, we aim to validate whether the information derived from the interventions and patient-tailored actions, which need to be communicated to the patient, can be represented by the defined NBCs.

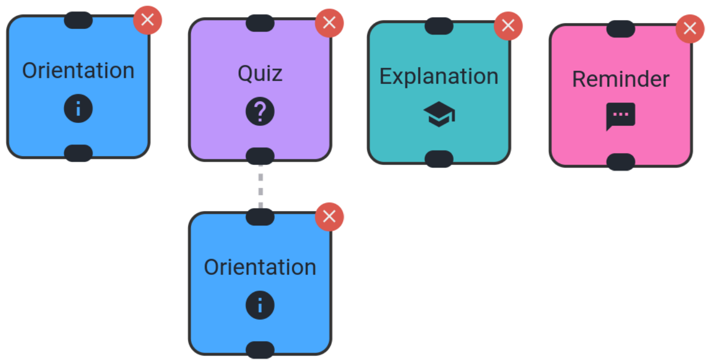

Figure 7: NBCs used for "exercise promotion" intervention. Note that connected nodes indicate a logic dependency flow between two nodes. Unconnected nodes can be executed independently.

Figure 8 represents the actions derived from the "fluid monitoring" intervention. We first recommend a medication to avoid ingesting more than the recommended fluid quantity (medication control element) and also remind the patient about the foods he/she should avoid (reminder element). When the medication is taken by the patient, we ask the patient about his/her intake and output in the last 24 hours (quiz element). Finally, when it is answered, we have two possible options: the answer indicates whether the patient's intake and output are as expected or not. If so, we send an orientation congratulating the patient and informing them of the benefits of his/her effort (orientation element). On the other hand, if the answer indicates the opposite, we orient the patient to talk to the responsible HCP (orientation element) along with taking a specific medication (medication element). Again, one notices the feasibility of describing the actions present in the care plan and the need to express the dependency between some actions.

Based on these results, we conclude that common behaviors present in distinct care plans can indeed be modeled as reusable NBCs. Furthermore, the NBCs can describe patient-tailored healthcare actions and be combined into adaptable clinical workflows, aiding the implementation phase of nursing care plans.

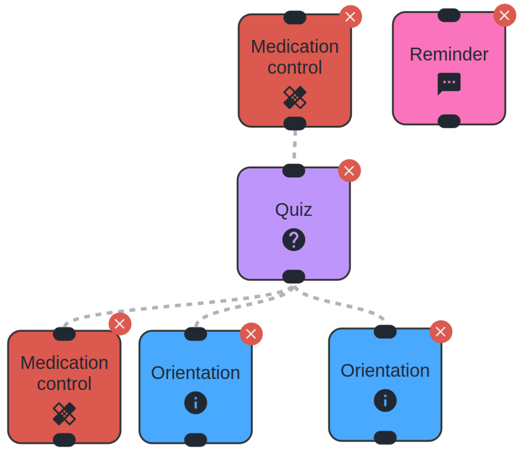

Figure 8: NBCs used for "fluid monitoring" intervention

5.3. Validation exercise

We have shown the composition of the proposed NBCs into a care plan implementation flow and assume that this approach can be later used by HCPs acting as citizen developers. A complete validation of this assumption requires the formalization of the computation model that supports the composition of the reusable components and the implementation of an NC platform based on the defined NBCs.

The assumption that HCPs will indeed find it easier to use the defined NBCs in their routine to generate mHealth apps supporting the implementation of individualized care plans is a strong one. Therefore, before investing in further development of the complete solution, we conducted a simpler validation exercise to test the acceptance and understanding of NBC-based care plan implementation by HCPs.

The exercise was carried out through a workshop with nurses and students from the UFRGS Nursing School. The attendees work in a public health setting that accompanies patients with ostomies and long-treatment wounds (such as diabetic foot wounds). In this workshop, we asked the attendees to devise care plans implementations using only the available NBCs (Figure 6).

We prepared the front-end prototype shown in Figure 9 to allow the HCPs to instantiate NBCs and combine them into a care plan. The prototype shows, on the right, the list of available NBCs, and, in the center, a canvas where the reusable components can be instantiated. To instantiate

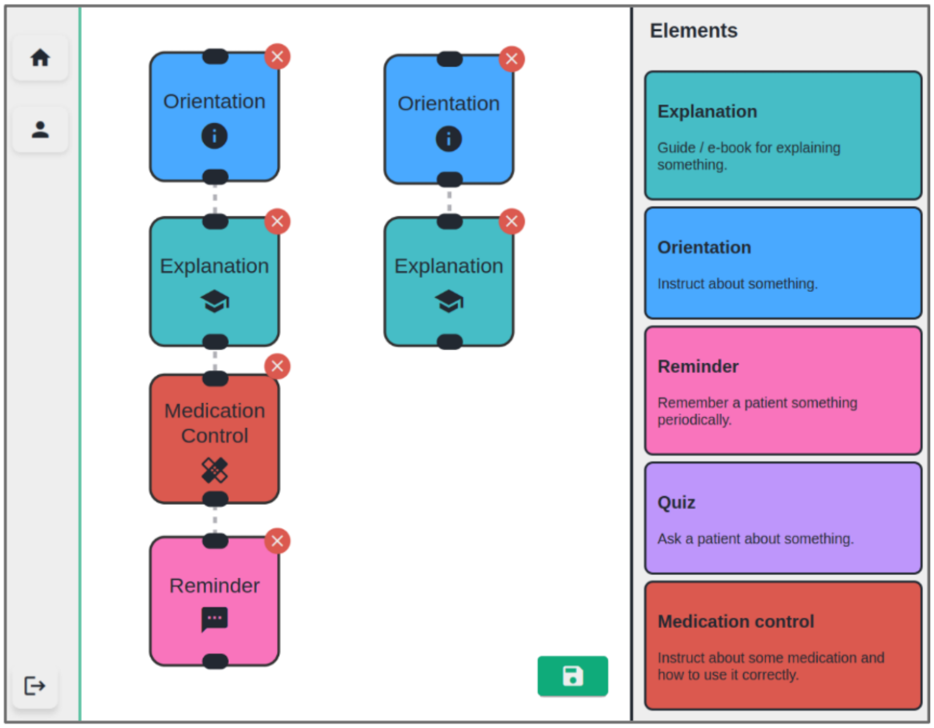

Figure 9: Front-end prototype for the validation exercise. The available NBCs are listed on the right menu "Elements" and can be instantiated by dragging and dropping them into the central area.

a component, the user simply drags it from the right to the center panel. A pop-up window then appears with fields corresponding to the parameters that need to be defined for that component. Those parameters can be modified at any time by just double-clicking on the component. The user can also indicate dependency between components by connecting them with a line.

Three nurses and nine mid-level students attended the workshop. During the exercise, we first divided the attendees into two groups: one with ostomized patients and another with wounded patients. We asked each group to think of a *persona* representing the typical patient with that diagnosis. Then, we asked each group to devise a care plan for their respective *personas*, focusing on the interventions and actions they would prescribe.

We then presented the interfaces, that is, the intended behavior, parameters, and pre and post conditions of each of the five defined NBCs, and how they could be instantiated and combined using the front-end prototype of Figure 9. Finally, we asked each group to document the care plan implementation for their patients using only the available NBCs and the front-end prototype.

During the exercise, we let the HCPs work autonomously and restricted ourselves to only observing and answering specific questions, without interfering in the implementation. In the end, we collected their feedback about the whole process.

We note the workshop was not meant to be a detailed user validation experiment. Hence, there was no additional setup regarding the number of attendees or testing protocols. Our main goal was to observe how the HCPs would use the proposed NBCs to document a given care plan. We also note that the care plans prepared during the exercise are different from the ones we have used to define the NBCs since they are related to other infirmities.

We observed the reactions of the HCPs during the process and their ability to construct a care plan using the proposed tool. Overall, the HCPs demonstrated positive feelings such as curiosity and enthusiasm during the exercise. We noticed the main questions during the exercise were related to the usability of the provided interface (how we chose to present the pre and post conditions) and to the identification of the scope of each NBC by their name (difference between Orientation, Explanation, and Reminder). Still, both groups were able to document the care plans without meaningful interventions from the IT team.

It is worth mentioning that Group 1 defined a more abstract care plan, mostly composed of unidirectional orientations, whereas Group 2 considered the possibility of this implementation to be translated to an mHealth app that would keep a communication flow with the patient, thus generating a more detailed plan. As a result, Group 2 was able to detect the limitations of the provided tool.

In order to better understand the needs of Group 2, we copied their plan to a visual collaboration platform and proposed a second discussion round with them to improve the model without the restrictions of the proposed tool. Then, they identified the need for a photo component and two control flow structures: a "conditional" and a loop control. Figures 10 and 11 present the resulting care plan implementation of each group at the end of the workshop. We note that, although the loop control was mentioned during the discussion, Group 2 decided to follow another flow in their final implementation.

Although informal, the validation exercise allows us to consider the pro-

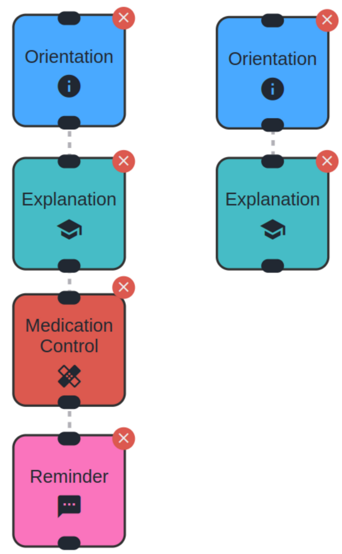

Figure 10: Care plans implemented by Group 1 (ostomies) during the validation exercise.

posed approach as a potentially viable method to bridge the gap between the medical and technical domains. The nurses were receptive to the idea and were able not only to identify and instantiate the reusable components with minimal support from the IT team but also to propose additional resources that could enhance the proposed solution.

6. DISCUSSION

This section aims to interpret our findings in light of the research questions and highlight the practical implications and potential for expansion.

6.1. Key Findings

The results presented in Section 5.1 show that the semantics of care plan actions can be grouped. We identified and characterized five core groups of actions (Ask, Explain, Medicate, Orient, and Remind) across distinct care plans. This represents one step towards representing the nursing domain language as basic components.

Our successful mapping of NIC interventions into NBCs, as shown in Section 5.2 validates the assumption that it is feasible to define core component

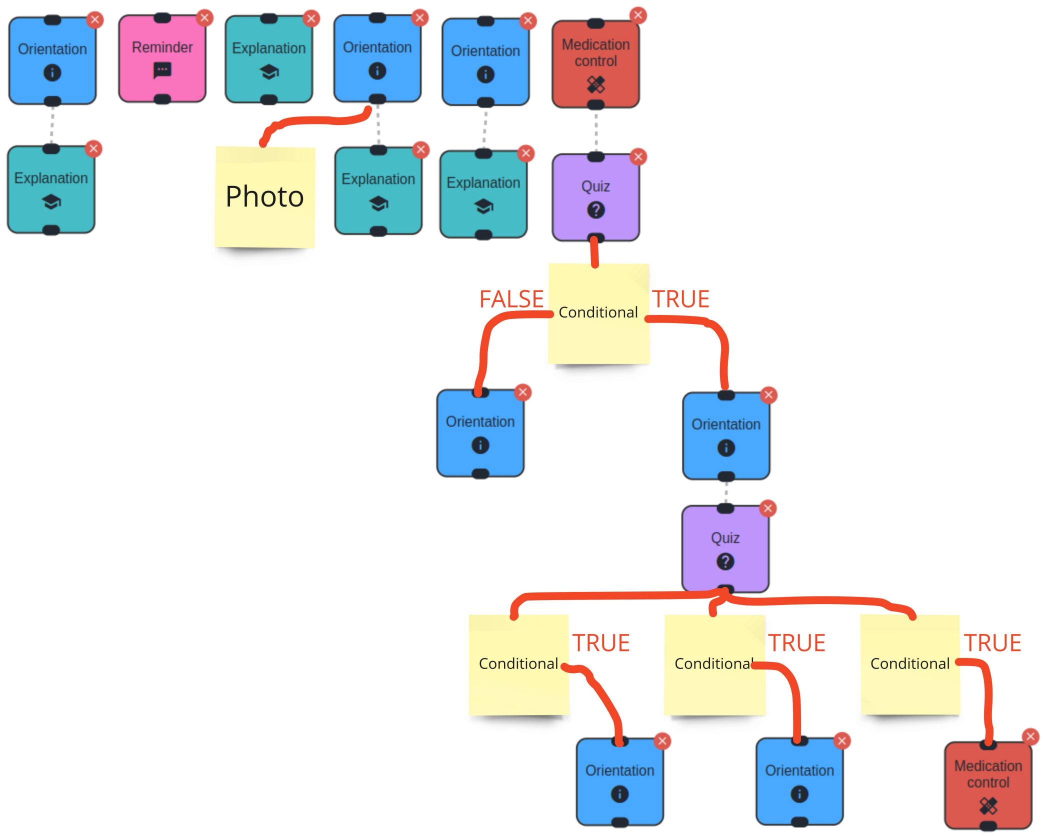

Figure 11: Care plans implemented by Group 2 (wounds) during the validation exercise. The post-its represent missing components identified by HCPs, and the red pen drawn by them represents the connections between these components.

models to represent nursing-independent actions of a care plan. Each component model is defined in terms of an interface, intended behavior, and pre and post-conditions. Finally, we showed how the components can be composed in a care plan implementation flow, demonstrating that NBCs may provide an intuitive way for HCPs to design and implement healthcare applications without extensive technical expertise. Moreover, we note that the resulting NBCs represent the semantics of the health interventions described in the NIC taxonomy, but are independent of the exact syntax used to describe that action and, ultimately, of the NIC itself. Therefore, the NBCs can not only be used together with any translation of the NIC taxonomy (it has been translated to more than 20 languages), but also in environments that adopt other standards or no standard at all. In the last case, the NBC approach additionally provides uniformization.

Finally, we note that even though we have considered the use of the NBCs by citizen developers, the devised component models can also be useful in other component-based solutions developed for the healthcare domain, speeding up and standardizing the communication among developers and users.

6.2. Limitations and Threats to validity

We identified three threats to the validity of our findings, which are discussed next.

Population validity: We interviewed 14 nurses from different specializations. Based on those interviews, we defined NNN taxonomy as the HCP domain language, although other standards or elements exist, such as ICNP[1]. We note that nursing standards vary in terms of scope and applicability, but can be very similar in terms of the mapped high-level interventions. NNN is more structured and detailed, while ICNP, for instance, offers broader categories of interventions. Less detailed interventions provide flexibility and can be adapted to various healthcare settings worldwide. On the other hand, it requires more effort from the HCP to translate the interventions into detailed actions and activities before prescribing them to each patient. Thus, for instance, the ICNP standard defines an intervention as "Promoting Self-esteem", but does not define specific actions to implement this intervention, which must be translated to the patient on their own terms. NNN suggests some specific actions for each intervention, promoting more structured and standard care. The methodology defined in Section 4.1 to identify semantic groups can be used for other standards as well. As for the basic components definition, our approach, in fact may help HCPs that use other standards by offering a set of possible actions that can be used across interventions.

[1]https://www.who.int/standards/classifications/other-classifications/international-classification-for-nursing-practice?form=MG0AV3

Sample size: We use a reduced set of NICs to answer the research questions. However, while this study focuses on two specific diseases and four interventions (Exercise Promotion, Self-esteem enhancement, Teaching: Prescribed diet, and Fluid Monitoring), the principles and findings from this research are not limited to those actions alone. The semantic grouping of actions shows a significant overlap between actions across different NICs. Furthermore, one can observe semantic similarities already among the NIC classes with many classes mentioning the words 'promotion', 'management', or 'education', for instance. As a result, the five basic components (Ask, Explain, Medicate, Orient, Remind) identified can be applied to a much broader range of NICs. This overlap suggests that the results from RQ2 (which demonstrate the ability to map nursing actions to NBCs) may be generalized to other NICs, enabling the representation of the reasoning and language of additional care plans, as we saw in the validation exercise.

Construct validity: We have shown the composition of the proposed NBCs into a care plan implementation flow and presented an informal validation exercise to show that the proposed approach can be later used by HCPs acting as citizen developers. The exercise highlighted the fact that, as expected, current results are still preliminary. Additionally, we noted that some new flow elements can be included in the future to ease the creation process. Based on these initial results and feedback, we can foresee a viable road map to tackle these challenges.

External validity - generalizability issue: The validation exercise was carried out with a small number of participants, thus limiting our ability to generalize the findings with respect to the acceptance of the NBCs as the input language for a care plan definition. Indeed, as mentioned, our goal with that exercise was not to draw a final conclusion, but to gather preliminary feedback on the proposed approach from the target audience. Still, the participants of the workshop were carefully chosen and did not receive any compensation. Two nurses are experienced professionals (20+ years in the service) in the public health service for patients with ostomies and long-treatment wounds, respectively. The third-year students had studied the nursing process and care plans in a previous semester and were working at the time on health service as part of their clinical rotation discipline under the responsibility of a professor (the third nurse who participated). During the workshop, each experienced nurse and the students were allocated to the group corresponding to the disease they routinely work on. Each group collectively devised the care plan as they do in their normal practice. Therefore, even though the results cannot be conclusive and require further investigation, we consider the feedback received as qualified as an indication of potential acceptance of the target audience.

6.3. Practical Implications

The implications of this work for clinical practice are substantial. By reducing the complexity of creating digital health solutions, NBCs facilitate greater engagement from HCPs in designing and developing mHealth applications. This could lead to more personalized mHealth applications, improve remote patient monitoring, and enhance the overall efficiency of healthcare services. Additionally, this approach can expand access to care, particularly in underserved regions, by enabling HCPs to create solutions tailored to their specific patient populations.

NBCs could be integrated into an NC platform, offering a new avenue for software development in healthcare. Different nursing taxonomies (including multilingual implementations of the NIC) or care plan standards can be mapped to NBCs. This adaptability enables the development of no-code healthcare applications that can be deployed across different linguistic and cultural contexts with minimal effort. By aligning NBCs with clinical workflows and structured intervention terminologies like NIC, this approach reduces dependency on IT teams. It lowers the cost of developing customized healthcare applications while ensuring semantic consistency across various healthcare systems.

7. CONCLUDING REMARKS

This paper explored the potential for a CBSE solution tailored to mobile healthcare applications, aiming to bridge the gap between the healthcare and the technical domains and establish a foundation for the development of customizable, patient-specific mHealth solutions with reduced technical effort.

We first investigated the existence of shared elements and behaviors across various healthcare intervention strategies described in the NNN taxonomy.

For a subset of standard interventions, we classified all nurse-independent activities associated with those interventions by semantics and purpose. With this, we identified and characterized five core groups of actions (Ask, Explain, Medicate, Orient, and Remind) across distinct care plans. This represents one step towards representing the nursing domain language as basic components.

We proceeded and evaluated the possibility of creating a set of core, reusable component models based on the NNN taxonomy. We were able to define five Nursing Basic Components. Each NBC is characterized by a standard interface, intended behavior, and pre and post conditions. Additionally, we have shown that these components can be combined into a care plan implementation flow and can be easily used by HCPs with little effort.

Although preliminary, our results show the potential of a CBSE-based solution to tackle important implementation challenges of mHealth apps. We are currently working towards the expansion of our analysis to all NIC domains and classes to complete the set of mapped NBCs. We are also working on the definition of the most suitable composition model, post-conditions, and the translation of each NBC into possible computational elements belonging to the scope of an app.

Future work includes the study of additional nursing taxonomies and the implementation of more robust validation experiments to validate the adaptability of the proposed approach across different healthcare systems. Another interesting avenue is the investigation of how Natural language processing (NLP) and machine learning approaches could assist in refining component identification, improving automation, and reducing manual effort in component-based software development. Also, testing the approach with software developers can be useful to evaluate the approach in the development process. Lastly, implementing the approach in real-world software and testing it in nursing practice can assess the effectiveness of NBCs.

CRediT authorship contribution statement

William Niemiec: Writing – review & editing, Writing – original draft, Software, Investigation, Methodology, Resources, Data curation, Conceptualization.

Erika Cota: Writing – review & editing, Writing – original draft, Investigation, Validation, Supervision, Methodology, Resources, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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