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# A Compositional Personalization Approach for Designing Personalized Patient Educational Interventions for Cardiovascular Risk Management

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**Abstract**

*Providing patients with personalized educational messages can improve self-management of Cardiovascular Disease (CVD) risk factors. We present our compositional personalization approach that generates personalized educational material by dynamically selecting fine-grained information snippets, as per the patient profile, and then synthesizing them in a educational template to yield personalized patient education interventions. We apply our personalization approach in the PULSE system—Personalization Using Linkages of SCORE and behavior change readiness to web-based Education—that generates personalized patient education for CVD risk management. The PULSE framework involves the calculation of CVD risk assessment using the Systematic COronary Risk Evaluation (SCORE) algorithm, the estimation of readiness to change using the Transtheoretical Model (TTM) of intentional behavior change. The educational interventions were derived from evidence-based staged lifestyle modification materials and Canadian guidelines for CVD risk management.*

***Keywords:***

Patient education, Self-management, Risk assessment, Cardiovascular, Information personalization

## Introduction

Patient education, especially for chronic health conditions, is an integral component of disease management, especially in a self-management context. Patient empowerment through education is geared towards encouraging patients to take increasingly responsibility for the management of their own health and wellness, whilst the role of the healthcare providers is the medical management of the disease [1]. Lately, there have been a number of programs that aim to empower individuals through educational programs to help them make informed choices about therapeutic options, risk assessments and lifestyle modification to ensure healthy lives. Such patient education programs offer evidence guided interventions, disease-specific care plans/maps and access to healthcare resources to improve patients' health status by influencing changes in patients' health behaviors and/or attitudes.

In general, patient education is practiced through the provision of 'generic' health educational material in the form of print materials (pamphlets or booklets) and/or Internet based health portals. Despite the benefits of patient education the rate of uptake of the educational material by patients is always a major factor in determining the impact of the educational program towards meeting the desired self-management targets. Typical educational material is designed to cover general issues pertinent to the needs a patient population, and from a patient's perspective they provide useful information but the information is not customized to the patient's specific needs. Lately, in an attempt to engage patients to self-manage their health and risk factors, patient education researchers have developed various approaches to personalize the rather generic patient education material towards the specific needs of individual patients [2, 3]. Personalized recommendations are more likely to be acted upon by patients since they can relate it to their own health targets. Lately, computer-based personalized patient education programs have made significant changes in the health and behavior of their targeted audience [4, 5].

Personalized patient educational programs can be made more impacting if we take into account the patient's underlying (a) perceptions and attitudes towards his/her health risks; and (b) behavioral disposition towards the uptake of any risk modification information [6]. If the patient is not fully prepared to accept the educational interventions to make lifestyle modifications, then even a personalized education program may be rendered ineffective in achieving the desired health outcomes. Therefore, we argue that the personalization of patient education material should be guided by patient's behavioral readiness to uptake educational interventions (in addition to the patient's health profile). Our strategy to personalize patient education is: (a) *determine* the patient's attitude towards his/her health condition and the associated risks and then establish their readiness level to make lifestyle changes; (b) *educate* the patient so that he/she contemplates lifestyle changes; and (c) *modify* the patient's lifestyle through personalized educational material that targets both the patient's behavior and health conditions.

In this paper we present a computer-based system to personalize patient education programs for the CVD risk management. The PULSE system—Personalization Using Linkages of SCORE and behaviour change readiness to web-based Education—personalizes educational material based on the patient's (a) ten-year CVD risk assessment calculated using the Systematic COronary Risk Evaluation (SCORE) algorithm [7]; and

(b) readiness to change risky behavior, which is determined using the Transtheoretical Model (TTM) of intentional behavior change [8]. We present a compositional information personalization method that involves the dynamic composition of a personalized educational package by (i) systematically selecting multiple, topic-specific, individual *snippets* of information based on the patient's behavioral and health profile; and (ii) synthesizing the selected snippets based on a patient-specific presentation template. The personalization logic was derived from Canadian clinical guidelines and behavior change literature, and was represented using Medical Logic Modules (MLM). The educational material covers both medical and psychosocial aspects of CVD risk management, derived from a combination of staged lifestyle modification and non-staged messages based on Canadian clinical guidelines. A web-based interface was developed for PULSE to interact with and to present a personalized educational package to the patient. We also report a small pilot user-study involving patients with CVD risks—the results highlight the efficacy of PULSE.

## Materials and Methods

The key aspect of the technical design of PULSE is our compositional information personalization method [9]. The entire educational material is decomposed into multiple individual educational messages, called *snippets*, where each snippet addresses a particular health issue, targets a specific set of patient parameters and is relevant to a specific stage of change. Our strategy is to dynamically construct a document by systematically (a) selecting a set of snippets that are directly related to the patient's health conditions and behavioral stage of change; (b) synthesizing the selected patient-specific snippets to yield a seamless personalized educational package. Our compositional information personalization strategy accounts for fine-grained distinction between patients along multiple dimensions, and hence generates highly personalized educational packages [10]. In the forthcoming discussion we discuss the main components of PULSE—i.e. (a) a behavioral change model; (b) a patient data capture template; (c) a patient profile; (c) a message library storing the educational material as snippets; (d) the personalization logic that maps the patient profile to relevant snippets; (e) a presentation template to synthesize the snippets; and (f) a delivery medium to present the personalized educational package to the patient.

### Behavior Change Model

For CVD risk management, we leverage behavioral models to explain and predict the patient's adoption of health-promoting behaviours or elimination of health-damaging behaviours. We use the Transtheoretical Model (TTM) of intentional behavior change as it guides the patient through the process of modifying problem behavior(s) and acquiring positive behaviors [9]. TTM consists of three key constructs: (i) Stage of Change - a characterization of a person's readiness to take and sustain action; (ii) The behavioral processes of change, representing how change occurs from one stage to another; and (iii) The decisional balance measures that indicate the patient's progress through the stages. In PULSE, we designed educational interventions that correspond to patient's needs at different stages of change. Table 1 shows our abstraction of the integrated TTM variables as used in personalizing interventions for CVD risk management.

*Table 1 – Transtheoretical Model for CVD risk management*

| Stage of Change | Behaviourial Change Process | Decisional Measures | Pros Vs. Cons |
|---|---|---|---|
| **Stage 1: Pre-Contemplation** | Consciousness Raising, Dramatic relief | Confidence low Temptation high | Pros < Cons |
| **Stage 2: Contemplation** | Self Reevaluation, Self Liberation | Confidence low Temptation moderate | Pros <= Cons |
| **Stage 3: Preparation** | Social Liberation | Confidence moderate Temptation moderate | Pros >= Cons |
| **Stage 4: Action** | Stimulus control, Counter conditioning | Confidence moderate, Temptation low | Pros > Cons |
| **Stage 5: Maintenance** | Contingency management, Helping relationship | Confidence high, Temptation low | Pros > Cons |
| **Habit** | No message needed | Confidence very high, Temptation very low | Pros >> Cons |

### Patient Data Capture Template

The patient Data Capture Template (DCT) systematically records patient information—i.e. demographics, behaviour and clinical risk factors—needed to generate personalized educational material. We used the commercially available Wellsource Coronary Risk Profile that assesses CVD risk based on the FHS risk calculator. We made some modifications to it to meet (a) SCORE requirements; and (b) Canadian healthcare standards—in particular target levels for risk factors suggested by the Canadian Association of Cardiac Rehabilitation report.

We divided the DCT into four distinct sections: *(1) Demographic Data; (2) Health History Data; (3) Clinical Data; and (4) Risk Behaviour Data*. The first two DCT sections collect data describing the patient's characteristics and his/her non-modifiable risk conditions, whereas the last two DCT sections collect clinical and behavioural data relating to CVD risk factors (such as smoking, dietary choices, alcohol consumption, stress, depression), which can potentially be modified through lifestyle changes. In total the DCT collects 28 parameters that cover a range of risk conditions and risk factors, such as age, smoking status, amount of regular exercise, eating practices, alcohol consumption, stress, depression, blood pressure, glycemic control values, and behaviour change readiness. The patient data for all the parameters is used to design a patient profile.

A feature of the DCT is that it automatically prompts lifestyle change readiness questions whenever the patient's response is not in accordance with the accepted targets as suggested by Canadian guidelines. Figure 1 shows the readiness question posed to the patient after he/she confirms a smoking habit.

| | |
|---|---|
| **Behavioural Data: Smoking** | Indicate your present smoking practices.<br>___ never smoked<br>___ quit smoking more than a year ago<br>___ quit smoking more than 6 months ago<br>___ quit smoking within the last 6 months<br>√ currently smoke cigarettes |
| **Behavioural Data: Readiness to Change** | Are you ready to make lifestyle changes to improve your health by stopping to smoke ?<br>___ no interest in making any lifestyle change *(Stage 1)*<br>___ thinking about making a lifestyle change *(Stage 2)*<br>___ making plans to achieve a change *(Stage 3)* |

*Figure 1 - DCT for checking on smoking and then based on the patient's response we ask the readiness to change.*

**Patient Profile**

The patient profile characterizes the patient along multiple dimensions in order to guide the selection of patient-specific snippets. It includes: (a) patient information collected via the DCT, (b) new patient information calculated using the DCT data, e.g. patient's body mass index, (c) the patient's computed SCORE value, and (d) the patient's stage of change for each risk behaviour, as illustrated in Table 1. The patient profile comprises three components as follows:

*CVD Risk Profile* describes the patient's absolute risk of CVD death and co-morbid conditions using the SCORE algorithm [8], which estimates the 10-year total cardiovascular risk of death. SCORE uses patient data on age, gender, smoking, systolic blood pressure (SBP), and total cholesterol (TC) and HDL cholesterol ratio to calculate the patient's risk category as percentages that lead to tertiles of risk as follows: ≤1% (low risk); 1 - 5% (moderate risk); and >5% (high risk). For example, a 60 year-old, non-smoking female patient with a SBP of 140 mmHg and TC:HDL ratio of 6.2 mmol/L would have a 10-yr CVD death risk of 2%, which means moderate risk.

The *Staged Risk Factor Profile* contains the patient's behavioural information and stage of change for specific modifiable CVD risk factor behaviours, such as smoking. We use the TTM to determine the patient's stage of change, for all potential risk behaviours, based on his/her response to questions relating to her/his readiness to modify the risk behaviour. We ask a readiness question—e.g. are you ready to make lifestyle changes to improve your health? The patient's response is used to determine the readiness to change along the five stages shown in Table 1—i.e. No present interest in making any lifestyle change infers *Stage 1*; Thinking about making a lifestyle change infers *Stage 2*; Making plans to achieve this change infers *Stage 3*; Recently started implementing this change infers *Stage 4*; and Have been doing this for six months or more infers *Stage 5*.

*Non-staged Risk Factor Profile* comprises additional information pertaining to other risk factors and conditions that are not integrated with TTM, for instance risk factors concerning eating practices, blood cholesterol levels, blood pressure, etc. This information is used to select educational messages for all non-staged risk factors and risk conditions.

**Message Library**

The message library contains a large volume of topic-specific educational interventions represented as fine-grained *snippets* of information. Each snippet addresses a specific aspect of a risk factor pertaining to specific patient feature. Snippets form the building blocks for a detailed and personalized educational package. Snippets vary in information coverage, ranging from a single sentence to a number of paragraphs and they collectively cover the range of potential variations of patient characteristics. Their sources were (a) staged lifestyle modification materials, based on the TTM, for the risk factors—i.e. smoking, overweight, stress, depression, and physical inactivity; and (b) non-staged educational resources for other risk factors—i.e. BP, lipids, eating practices, glycemic control, and alcohol. This material originated from the these Canadian sources: (a) "The Healthy Heart Kit" from the Public Health Agency; (2) Cardiovascular & Pulmonary Health in Motion Cardiac Rehabilitation Program at the QE II Health Sciences Centre in Halifax; (3) The Heart Disease: Prevention section of the Heart & Stroke Foundation website; and (4) Health Canada's "Food Guide to Healthy Eating" and "Physical Activity Guide to Healthy Active Living."

In the message library, at the first-level the educational material was categorized in terms of staged and non-staged. At the next-level, the staged material was categorized into five snippets categories, corresponding to the five Stages of Change. And, the non-staged material was categorized into six snippet categories—i.e. introductory (opening statements), informational (suitable action), definitional (meaning), motivational (incentive), factual (evidence), and gender-specific (suitable for one gender). In each case, the key educational information was selected from the original material to form a risk factor's snippet. For example, information from the cholesterol brochure was used to create snippets as follows. An initial sentence containing "Cholesterol is …" was converted to a *definitional snippet*. Information following the heading "Get the Facts …" was converted to a *factual snippet*. The sentence "What you eat plays an important role..." led to an *introductory snippet*. Discussion of cause and effect such as "Decreasing your blood cholesterol level by 1% …", led to a *motivational snippet*. Statements such as "If you want to lower your risk of heart disease try…" formed *informational snippets*. Gender-specific information, such as "Women tend to …", resulted in a *gender-specific snippet*. Local experts in CVD prevention and rehabilitation were engaged to verify the information content and coverage contained within each snippet.

**Personalization Decision Logic**

The personalization decision logic determines the selection of the relevant snippets based on a given patient profile. To establish the decision logic, we first developed a mapping matrix that contained the 14 risk conditions identified in the DCT and potential messages targeting these risk conditions. Next, the matrix was translated into symbolic decision rules—i.e. if-then statements—that map the profile elements in the IF part of the rule to specific messages listed in the THEN part of the rule. Figure 2 shows exemplar personalization decision logic. We developed around 300 rules that are executed by a rule-based engine employing forward reasoning.

```
If Gender = female and Exercise = no regular exercise
   Then <GenderF link> and <GenderF premenopause&exercise link>
If Gender = female and Exercise=five or more days per week
   Then <GenderF link>
If Gender = postmenopausal female and Depression=yes
   Then <GenderF link> and <GenderF post menopause> and
          <GenderF post menopause&depression>
If Gender = postmenopausal female and Depression=no
   Then <GenderF link> and <GenderF post menopause>
```

*Figure 2 - Sample personalization decision logic*

**Information Presentation Template**

The function of the information presentation template is to organize the selected snippets in a meaningful manner. The presentation template was divided into four sections: (1) The *Introductory* section provides a brief description about the document title, patient's name, date, clinic name (site) and the contents of the personalized document; (2) The *CVD Risk Profile* section provides both textual information and a graphical display of the patient's absolute risk of CVD death as computed by the SCORE algorithm. We present (a) a bar-chart displaying the 10-year risk of CVD death with comparison to a patient with an ideal risk profile; and (b) a pie chart displaying the contribution of a patient's modifiable risk factors to her/his total risk (see Figure 3ab); (3) The *Progress* section provides a graphical display of changes in a patient's modifiable risk factor values over time; and (4) The *Risk Factor Management* section provides information on each risk factor relevant to the patient. Each risk factor has its own sub-section complete with an introductory brief, the patient's current results, evidence-based target values, and lifestyle modification and risk management education. We recognize that managing risk factors may require lengthy educational messages leading to information overload. Therefore, the template contains 'expandable' segments that can be accessed by clicking a hyperlink that leads to detailed information.

**Delivery Method**

In PULSE, the educational material can be viewed online (in a web browser) or printed as a PDF document. Interaction with the PULSE system is initiated by a healthcare professional in a primary care setting. The practitioner enters the patient data into the DCT and then PULSE generates the personalized educational package.

## Working Example

To demonstrate the working of PULSE we generate educational material for two patients. Through a comparison between the education packages generated for each patient we will be able to demonstrate the efficacy of PULSE. The two hypothetical patients are: Ms. Adams, aged 48 years, with a SCORE value of 1% (moderate CVD risk) and Mr. Brown, aged 60, has a SCORE value of 8% (high CVD risk). Figure 3ab displays the CVD risk profile presented to Mr. Brown.

Table 2 shows for each patient their data used to calculate risk assessment, the stage of change for their risk factors and the messages selected by the personalization logic. The personalization effect is illustrated by viewing the diversity of the number and type of messages received by each patient. Ms. Adams receives 25 snippets in comparison to Mr. Brown receiving 42 snippets. Overlap is their profiles results in the selection of some similar snippets. Yet, differences between their profiles results in selection of different snippets—Mr. Brown receives 3 BP messages as his BP levels are not normal, whereas Ms. Adams does not get any messages as her BP level was normal; Mr. Brown receives 2 additional lipids messages as his LDL and TG levels are higher than accepted targets, whereas Ms. Adams' values for these variables were normal; Ms. Adams receives an additional gender-specific exercise message at Stage 2 (Contemplation), whereas Mr. Brown receives at Stage 1 (Pre-contemplation). In summary, the diversity of snippets selected for each patient illustrates fine-grained personalization of their educational packages.

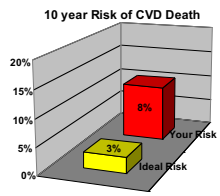


*Figure 3a-Risk profile*

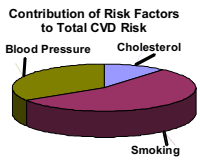


*Figure 3b-Risk factors*

## Evaluation Study

We conducted a survey-based pilot study to evaluate (A) patients' willingness to follow the suggestions offered by PULSE, and (B) the quality of the information being presented with respect to the patient's profile. The survey presented 22 questions using 5-point Likert scales. The survey evaluated patient's intention to follow treatment suggestions in part A, and their impression of the quality of the information in part B. Six (6) patients with CVD risk factors were recruited at a medical clinic where they were under treatment for those cardiovascular risks. 83% of the responses to part A were positive, and 91% responding positively to part B (Table 3). For part A the survey comprised 10 questions, such as "Do you intend to try any of the suggestions to manage your cholesterol levels within the next 30 days"; "Do you intend to try the suggestions to healthy eating within the next 30 days", and so on. For part B the survey comprised 12 questions, such as "How useful would the information be in helping you manage your cardiovascular risk"; "The information on each of the topics was individualized"; "The information on each of the topics was new"; "The information on each of the topics was personally relevant", etc.

*Table 3- Survey results for part A and B*

| | Positive | Neutral | Negative |
|---|---|---|---|
| **Part A** | 34 | 7 | 1 |
| **Part B** | 61 | 6 | 0 |

A patient's readiness to change behavior, based on PULSE educational messages, was as follows: Stage1-No present interest in making a change (1); Stage2-Thinking about make a lifestyle change (3); Stage3-Making plans to make a change (5); Stage4-Recently started making a change (8); Stage5-Have been doing this for 6 months or more (1). The responses show that PULSE is having a positive influence on the behavior of the patients, as Stage 3 and 4 (for their different

*Table 2 – Comparison of personalization results for two patients. The underlined snippets are common between both patients*

| Risk Factor | Patient 1 | SoC | # of Msgs | Message ID | Patient 2 | SoC | # of Msgs | Message ID |
|---|---|---|---|---|---|---|---|---|
| Age | 48 years | | | | 60 years | | | |
| Gender | Female | | | | Male | | | |
| Health Problems | None | | 3 | <GenderF_link> <GenderF_menoLink_Ex> <BP_fh> | Hypertension | | 4 | <BP_ph> <EP_bpLink_EP> <CVD_fh> <BP_fh> |
| Family History | Hypertension | | | | CVD and high blood cholesterol | | | |
| Blood Pressure | 138/88 mmHg | | 0 | | 144/96 mmHg | ***Stage 3*** | 3 | <BP_info> <SBP_mot> <BP_gmlink> |
| Lipid Profile | TC 6.8 mmol/L, HDL 1.0 mmol/L, LDL 2.3 mmol/L, TG 1.6 mmol/L | ***Stage 4*** | 4 | <LP_info> <LP_TCHDL> <LP_mot> <LP_Link> | TC 5.1 mmol/L, HDL 1.1 mmol/L, LDL 2.5 mmol/L, TG 1.8 mmol/L | ***Stage 2*** | 6 | <LP_info> <LP_TCHDL> <LP_mot> <LP_LDL> <LP_TG> <LP_link> |
| Glycemic Control | FPG 6.9 mmol/L, HbA1c 6.8% | | 2 | <GC_info> <GC_link> | FPG 5.9 mmol/L, HbA1c 5.8% | | **0** | |
| Weight Control | weight (62kg), height (1.58m), waist (87cm) | | 0 | | weight (96kg), height (1.84m), waist (103cm) | ***Stage 2*** | 6 | <WM_info> <WM_wc> <WM_mot> <WM_Stage2> <WM_link1> <WM_link2> |
| Smoking | Quit smoking > 1 year ago | | 0 | | Smoker | ***Stage 2*** | 4 | <Sm_Stage2> <Sm_info> <Sm_link1> <Sm_link2> |
| Exercise | 1 day/ week | ***Stage 2*** | 5 | <Ex_Stage2> <Ex_gf> <Ex_mot> <Ex_link1> <Ex_link2> | 0 days/ week | ***Stage 1*** | 4 | <Ex_Stage1> <Ex_mot> <Ex_link1> <Ex_link2> |
| Alcohol | 2/day and not > 9/week | | 0 | | 2/day and not > 14/week | | **0** | |
| Depression | No | | 0 | | Yes | ***Stage 4*** | 2 | <De_Stage4> <De_info> |
| Stress | Yes | ***Stage 3*** | 3 | <St_Stage3> <St_link> <St_info> | No | | 0 | |
| Dietary Habits | | | 8 | <EP_intro> <EP_fibre> <EP_fat> <EP_fruitvege> ….. | | | 13 | <EP_intro> <EP_grains> <EP_salt> <EP_meat&alt> …... |
| **Total Msgs** | | | **25** | | | | **42** | |

conditions) are the most prevalent. The results conclude that the educational interventions by PULSE is not only accepted by patients but is also deemed by patients as personalized.

## Conclusion

Human behaviour is a key determinant of health improvement, yet its importance has not been fully appreciated in designing patient-specific educational interventions. Notwithstanding the effective organization, usability and relevance of healthcare information prescribed to patients, it can still not be guaranteed that the information will have the desired impact if it does not take into account the patient's behavioral attitudes towards self-management and self-improvement. The PULSE approach presented here is grounded in the belief that the efficacy of any patient educational intervention is contingent on the patient's readiness to change their behaviour. We presented a personalized patient education system that purports a unique synergy between evidence-guided CVD risk assessment—i.e. the SCORE algorithm—and the TTM for assessing the stage of change for risk behaviours, such that their combination leads to a rich patient profile. We have developed a novel compositional personalization method that maps the fine details of the patient profile to specialized educational messages—i.e. snippets. We dynamically compose an educational package that comprises interventions that correspond to the patient's physiological data, risk category and behavioral predisposition to lifestyle modifications. We addressed the challenge of transforming a wide range of evidence based guidelines and recommendations to a set of discrete messages, where each message needs to satisfy three inclusion criteria—i.e. medical, risk and behavioral. The feature of our work is that it purports a pragmatic methodology for designing personalized educational material for other medical problems. In conclusion, this project is a step towards empowering patients with accessible, up-to-date and pertinent information about CVD risk factors, lifestyle modifications and behavior change strategies.

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