TU WIEN Informatics

Towards Semantic Interoperability for Behavior Change Driven Serious Games and Gamified Mobile Applications - Platform Engineering for Prevention of NCDs

Digital Catalysts for NCD Prevention

DISSERTATION

zur Erlangung des akademischen Grades

Doktor der Technischen Wissenschaften

eingereicht von

Dipl.-Ing. Christoph Aigner, BSc
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an der Fakultät für Informatik

der Technischen Universität Wien

Betreuung: Ao.Univ.Prof. Dipl.-Ing. Dr.techn. Thomas Grechenig

Diese Dissertation haben begutachtet:

Prof. Dr. Sylvia Thun	Dr. John Henry

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Registration Number 00525400

to the Faculty of Informatics

at the TU Wien

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Dipl.-Ing. Christoph Aigner, BSc

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Wien, 27. August 2025

Christoph Aigner

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Kurzfassung

Jeder von uns ist für seine Gesundheit und sein körperliches und geistiges Wohlbefinden verantwortlich. Ob wir uns für gesunde Lebensmittel entscheiden, mit dem Rauchen aufhören, unseren Alkoholkonsum einschränken, aktiv bleiben oder uns um unser psychisches Wohlbefinden kümmern – unsere täglichen Entscheidungen sind die Bausteine unserer Gesundheit. Eine langfristige Verhaltensänderung kann zwar eine Herausforderung darstellen, ist aber nicht unmöglich. Selbst wenn wesentliche Änderungen im Verhalten vorgenommen werden, sind diese aber oft nicht von Dauer.

Nicht übertragbare Krankheiten (NCDs) werden nicht durch Infektionen oder andere Menschen übertragen, sondern entstehen durch ungesunde Verhaltensweisen und sind auf dem Vormarsch. Zu den häufigsten Beispielen gehören Herz-Kreislauf-Erkrankungen, Krebs, Diabetes und chronische Atemwegserkrankungen. Diese Krankheiten sind für schätzungsweise 41 Millionen Todesfälle pro Jahr verantwortlich, was Erstaunlichen 74% aller weltweiten Todesfälle entspricht. Hauptursachen für diese Problematik sind Risikofaktoren wie Bluthochdruck, Bewegungsmangel, Tabakkonsum, hoher Cholesterinspiegel, Übergewicht/Adipositas, Alkoholkonsum und ein hoher Blutzuckerspiegel. Eine wichtige Möglichkeit für eine einzelne Person, die oben genannten Risikofaktoren zu reduzieren, besteht darin, ihren Lebensstil dauerhaft zu ändern. Sogenannte Serious Games, also Spiele, die nicht nur unterhalten, sondern auch zusätzliche Ziele verfolgen; Gamification, also die Verwendung von Spielelementen in spielfremden Kontexten; und Techniken zur Verhaltensänderung (BCTs) können eingesetzt werden, um die oben beschriebenen Probleme zu überwinden.

Daher beschreibt und diskutiert diese Dissertation die Entwicklung konkreter Serious Games und gamifizierter mobiler Apps zur Bekämpfung nichtübertragbarer Krankheiten. Insgesamt wurden sechs Applikationen entworfen und prototypisch umgesetzt, davon drei Serious Games und drei gamifizierte mobile Anwendungen. ”Food Pyramid Escape”, ”NutriMine” und ”Nutrition Garden” konzentrieren sich auf Ernährung, während ”BreathIn” die Rauchentwöhnung thematisiert und ”recoverApp” und ”MoodBooster” sich auf die psychische Gesundheit als jeweilige Risikofaktoren für nicht übertragbare Krankheiten beziehen. Diese Arbeit präsentiert ebenfalls eine vergleichende Analyse dieser Spiele und Apps und bezieht dabei zwei weitere Anwendungen aus der Forschungsgruppe des Autors ein und erstellt darauf aufbauend ein Framework, welches Best Practices in den folgenden Schlüsselbereichen beleuchtet: Organisatorische Interoperabilität, Best Practices für De-

sign und Entwicklung, das Ökosystem der Serious Games, Benutzerfreundlichkeit sowie Qualitäts- und technische Aspekte. Außerdem wird die semantische Interoperabilität, der von diesen Apps generierten, gesundheitsbezogenen Daten hervorgehoben, um nachhaltigen Nutzen von verhaltensändernden Spielen und gamifizierten Apps für Patienten, Kliniker und die Wissenschaft ziehen zu können.

Keywords: *Serious Games, Gamification, Techniken zur Verhaltensänderung, Semantische Interoperabilität*

Abstract

Each of us is responsible for our health and physical and mental well-being. Whether making healthier food choices, quitting smoking, moderating alcohol consumption, staying active, or prioritizing mental health, our daily decisions are the building blocks of our health. While long-term behavior change can be challenging, it is not impossible. Even if significant changes are made, they often do not last.

Non-communicable diseases (NCDs) are not transmitted through infection or other people but emerge due to unhealthy behaviors and are on the rise. The most prevalent examples include cardiovascular diseases, cancers, diabetes, and chronic respiratory diseases. These diseases account for an estimated 41 million deaths annually, a staggering 74% of all global deaths. Major risk factors such as high blood pressure, lack of physical activity, tobacco use, high cholesterol, overweight/obesity, alcohol consumption, and high blood sugar are at the core of this issue. A significant opportunity for individuals to reduce the abovementioned risk factors is to change their lifestyle permanently. Serious games, which are games that not only entertain but serve additional goals; gamification, which can be understood as using game elements in non-gaming contexts; and behavior change techniques (BCTs), can be used to overcome the problems described above.

Therefore, this thesis describes and discusses the construction of tangible, serious games and gamified mobile apps aimed at combating NCDs. A total of six concepts were designed and prototypically implemented: three serious games and three gamified mobile applications. "Food Pyramid Escape", "NutriMine" and "Nutrition Garden" focus on nutrition, while "BreathIn" addresses smoking cessation, and "recoverApp" and "MoodBooster" pertain to mental health as their respective NCD risk factors. This work furthermore presents a comparative analysis of these games and apps, alongside two additional applications from the author's research group, constructing a tangible framework that highlights best practices in the following key areas: organizational interoperability, design and development best practices, the serious games ecosystem, usability, and quality and technical aspects. It also emphasizes the semantic interoperability of health-related data generated by these apps to ensure sustainable benefits from behavior change-driven games and gamified apps for patients, clinicians, and scientists.

Keywords: *serious games, gamification, behavior change techniques, semantic interoperability*

Contents

CHAPTER 1

Introduction

According to Johan Huizinga's "Homo Ludens," [1] a foundational work in the study of play first published in 1938 that can be loosely translated as "The playing person," play is older than culture because culture always presupposes human society. He stated that animals did not wait for humankind to teach them their playing and that human civilization has added no additional feature to the idea of play [1]. Huizinga describes the term play, even in its simplest form, as more than a sheer physiological phenomenon or a psychological reflex but a significant function. It, therefore, has a meaning, implying a nonmaterialistic quality like the nature of the thing itself [1]. Not only did Huizinga manage to define the term "play" profoundly, he also added additional concepts to it that are still important in game studies to this day, for example, the term "magic circle," which can be described as a boundary that delineates play from non-play since, according to Huizinga, play is fundamentally separate from everyday life and players are motivated by the intrinsic enjoyment of their activity [2]. There is also some criticism about Huizinga's definition of play. For example, Roger Caillois, a French sociologist, criticized his definition, among other things, as being too narrow since Huizinga's main characteristic of play is the competitive aspect. Caillois himself defined four characteristics of play: competition (also called "Agon"), chance (also called "Alea"), simulation (or "Mimicry"), and vertigo (or "Ilinx") [3]. Caillois criticized Huizinga's definition of play as being too broad as well. In his opinion, Huizinga failed to precisely delineate between the domain of "play" and the domain of "sacred" and "institutional" in a cultural sense.

Considerable time has passed since pioneers in gaming studies, such as Huizinga and Caillois, illustrated the importance of play. The concepts of play and games are often used interchangeably, even though they embody distinct characteristics and implications in both psychological and sociocultural contexts. Play can generally be characterized as a more open-ended activity in which make-believe and world-building are crucial factors [4]. In contrast, games, conversely, can be defined by their structured nature, which includes specific rules, objectives, and often competitive elements in which participants compete by

making ambiguous decisions [5]. Games, especially video games, have become an integral part of our modern society, mainly for recreational and social purposes, influencing various aspects of culture, entertainment, education, and economics [6]. Video games are deeply ingrained in modern culture, disrupting traditional entertainment and becoming a prominent element of on-screen technoculture [7]. They are acknowledged for creating new social and cultural worlds that facilitate learning by integrating thinking, social interaction, and technology [8].

Additionally, video games are recognized as a heritage component, with scholars discussing their depiction of history and cultural heritage [9]. Those facts raise a legitimate question about the opportunity to use games and playful elements beyond the abovementioned purposes, for example, for educational or medical applications. The scientific field of serious games and gamification, as well as its many fields of application, like education, training, marketing, and health, tries to answer this question in many ways, as can be seen by numerous articles published on these topics in recent years. This dissertation focuses on the design and development of serious games, respectively, gamified mobile applications, particularly for changing one's behavior to prevent non-communicable diseases and, on top of that, construct a semantic interoperable application framework that not only serves as an organizational and technical bracket around the designed applications but will also provide the possibility to exchange and use (medical) data in a meaningful way by leveraging standards from the medical informatics domain and provide best practices for the future development of applications in the particular field of NCD prevention.

1.1 Problem Description

Many people find it challenging to make conscious decisions about their health, both physical and mental. Whether it is choosing healthy foods, quitting smoking, reducing alcohol consumption, exercising, or maintaining good mental health, making long-term behavioral changes can be difficult. Even if someone successfully changes their behavior significantly, it typically only lasts for a short time. Therapies such as psychotherapy, fitness coaching, or dietary treatment show promise in helping patients achieve lasting behavior change, but they are often costly and only occasionally covered by health insurance. For example, by examining the present conditions in Australia and Canada, the work of Bartram et al. [10] presents compelling evidence of disparities in access to psychotherapy and other mental health services based on income.

Non-communicable diseases (NCDs) are not contagious and are caused by unhealthy behaviors. They are becoming increasingly common [11]. Some well-known examples are cardiovascular diseases, cancers, diabetes, and chronic respiratory diseases. NCDs account for around 41 million deaths each year, which is roughly 74% of all deaths globally. Major risk factors for these diseases include tobacco use, alcohol consumption, lack of physical activity, high blood pressure, being overweight or obese, high blood sugar, and high cholesterol. Addressing and reducing these risk factors is important

to combat NCDs effectively [12]. In the outcome of Jianhui Zhao et al. [13], it was revealed that while advancing age remains a non-modifiable risk factor for cancer, which is considered an NCD, the incidence for patients under 50 years old is rising. Early-onset cancer deaths grew by a remarkable 79,1% between 1990 and 2019. Jianhui Zhao et al. further state that risk factors identified for early-onset cancers are comparable to the ones identified by the WHO for NCDs. The authors projected that the global incidence would increase by 31% in 2030. This work shows that NCD prevention can be valuable, even for younger age groups. Another facet of NCD risk factors that was long neglected is mental disorders in combination with prevention. O'Neil et al. [14] have shown that NCD prevention and management historically focused on cardiovascular diseases, type 2 diabetes, cancer, and chronic respiratory diseases. Despite recent developments in the integration of typical mental illnesses, prevention and control of these disorders remain largely separate and independent. Therefore, O'Neil et al. propose a shared disease prevention and control framework. An article that links mental health and campaign priorities by the NCD alliance, devised for the 2019 United Nations high-level meeting on NCDs, likewise proposed that governments should address the common risk factors and systems barriers to reduce early and preventable suffering and death by integrating mental health into the response to NCDs. According to Jacka et al. [15], there is evidence that indicates that unhealthy diets are also risk factors for mental disorders, particularly depression, and dementia, and thus can be considered a multiplicator for the risk of contracting NCDs.

According to Dörner et al. [16], serious games can be defined as digital games designed to entertain the audience and achieve at least one additional goal. These extra goals are called characterizing goals and can be, for example, learning or health-related applications [16]. Numerous categories of serious games are currently known in the digital health domain. These can be, for example, exergames that encourage people to become more physically active, medical education games and simulations, lifestyle behavior change games, medical diagnosis learning games, and many more [17]. Serious games can include textual, graphical, haptic, and audio elements to create concise gaming experiences [18], [19]. The term "serious game" must be clearly distinguished from the term "gamification." Gamification can be described as an informal umbrella term for using game elements in non-gaming systems to improve user experience and engagement. Adding such concepts and elements to non-gaming applications and platforms can be called "gamifying." Dörner et al. [16] state that gamified applications are typically but not necessarily less of a game than full serious games, meaning that only parts of a particular application are related to game elements/mechanics.

A significant opportunity for individuals to reduce NCD risk factors is to change their lifestyle. Even though people are becoming more aware of medical conditions and risk factors involved with NCDs and, therefore, are more inclined to change their lifestyles, and this can be partially attributed to the impact of mass media - most are still finding it hard to change their behavior and maintain it for an extended period. Behavior change techniques (BCTs) can be used to overcome the problems described above. In the work

of Michie et al., BCTs are structured procedures incorporated as active components of an intervention to change behavior [20]. For example, the goal-setting BCT can be used to define a daily walking goal or to specify how many fruits or vegetables one should ingest per day. Another example of a BCT is the self-monitoring of behavior BCT. With this BCT, the individual could be asked to record, within a personal diary, whether they have engaged in a daily two-minute tooth brushing routine before bedtime [21]. These BCTs were successfully used in serious games and gamified mobile applications. For example, Baranowski et al. [22] concluded that serious game–based behavior change is an exciting form of media-based intervention and that the many desirable outcomes warrant moving forward in this area.

Games for behavior change can produce lots of relevant personal, game, behavioral, or clinical data. This data will usually lie dormant in the respective app and, therefore, cannot be used for future episodes of care. Also, secondary usage, for example, for clinical or behavioral research, is only possible with semantic interoperable app data availability. With the European Health Data Space (EHDS) program being a "key pillar" for the European Health Union [23], a joint effort of EU countries to prepare and respond together to health crises and work together to improve prevention, treatment, and aftercare [24], an even greater emphasis should be placed on secondary use of medical data. Furthermore, the work of Peters et al. [25] states that patients and their caretakers would benefit considerably from integrating semantically rich and standardized health data into existing hospital information systems or electronic health records.

Therefore, the author of this thesis suggests constructing tangible serious games and gamified mobile apps to combat NCDs and, on top of that, assembling a framework that emphasizes the semantic interoperability of health-related data generated by using such apps to ensure lasting health benefits of behavior change-driven games and gamified apps for patients using them. This framework will allow users to save relevant medical data into lifelong personal, institution-wide, and nationwide electronic health records in a semantically interoperable way. The availability of that data enables patients and doctors to use it as part of future healthcare scenarios. Continuative usage must be established in a bidirectional way, meaning using before-stored data for as many use cases as possible is essential, not just holding data in health records. The gathered datasets can improve future patient care by helping doctors monitor the patient's health, make suitable choices for therapy, and also, anonymously, improve overall health care for scientific/clinical studies and research.

The work presented within this thesis can be understood as a unique and novel approach to addressing the demand for effective health interventions in the domain of non-communicable disease prevention by bridging the gap between gaming and health promotion, emphasizing interactive and engaging applications that can facilitate behavior changes and the interoperable exchange of medical and game data.

1.2 Motivation

The author believes that serious gaming and interoperability are crucial in addressing the challenges of behavior change and health improvement in lowering NCD risk factors and, therefore, preventing NCDs. Harnessing the potential of games and interoperable applications can enhance preventive healthcare and NCD management. People can be motivated to adopt positive lifestyle changes, resulting in the reduction of NCD risk factors by using innovative and engaging serious games along with gamification aspects in applications. Additionally, the definition of an interoperable framework enables the exchange of medical and other important patient data, promoting collaboration and the sharing of best practices in the development of impactful health applications.

The author of this thesis has always had a deep scientific curiosity and interest in video games, whether it concerned console or PC games. The author started with a scientific publication as a co-author for a serious game in stroke rehabilitation in 2019. Before this collaboration, semantic interoperability within the healthcare domain was the author's main scientific interest. Presenting the work mentioned above at an international conference sparked the author's interest in (serious) gaming and gamification for healthcare. The idea grew to combine gaming with the topic of semantic interoperability. Furthermore, the author also knows from firsthand experiences how living and especially sustaining a healthy lifestyle can be a very hard challenge. The main motivation for the author was to combine these topics with looking for lasting ways to change unhealthy behavior and thus strive for a longer and healthier life.

1.3 Expected Results

The expected results of this dissertation were the conception, prototypical implementation, and evaluation of behavior change-driven serious games and gamified mobile applications to combat NCD risk factors. Each application first underwent a requirement analysis phase, incorporating feedback from users and clinical experts. After that, each app was implemented prototypically and playtested with the help of users from the respective target group. A total of six applications, three of which were serious games, were developed to cover a wide range of game mechanics, BCTs, and common NCD risk factors, including nutrition, smoking cessation, and mental health.

Each developed app's results, conclusions, and findings were the foundation for constructing an interoperable app framework for behavior change-driven serious games and gamified mobile applications to combat NCDs specifically. This framework included a requirement catalog and best practices for designing and implementing apps and games specific to NCD prevention. The framework also used medical informatics standards to ensure the semantic interoperability of patients' data produced from the applications and games mentioned above. The usability and practicability were shown prototypically by developing an HL7 FHIR (Fast Healthcare Interoperability Resources) implementation guide that allows for the incorporation of terminologies such as SNOMED CT (Sys-

tematized Nomenclature of Medicine Clinical Terms) and LOINC (Logical Observation Identifiers, Names, and Codes) and also includes own set of terminologies and value-sets. HL7 FHIR was chosen particularly for its wide adoption within the field of medical informatics. According to a survey about the state of FHIR conducted in 2024 by HL7 International in cooperation with the company "Firely," the majority of respondents said that FHIR is being used, at least for a few use cases. Lithuania and Switzerland reported that FHIR is being used as their main standard for healthcare data exchange [26].

The main target groups of this work are healthcare professionals (clinicians, doctors, therapists, nurses) since they are responsible for treating patients and can prescribe games and apps, if possible by law and regulations, or at least suggest them; patients since they are the main users of the applications and many want to change their behavior and thus reduce their NCD risk factors; developers and creators of serious games, since many parts of the proposed interoperable framework are relevant for the development of novel games and apps; governmental organizations because they are responsible for regulating applications and can integrate them into larger campaigns; and researchers because they might have a strong interest in anonymous game, behavioral and medical data, that these apps produce.

As part of this work, this dissertation stated and answered the following three research questions:

Research question 1 (RQ1): Which classes of requirements can be identified for behavior change-driven serious games, respectively, mobile applications that incorporate gamification elements to prevent NCDs, and what would actual classes of implementations look like?

The first research question emphasizes the design and prototypical development of serious games and gamified applications for NCD prevention. In the context of this research question, the terms "classes of requirements" and "classes of implementations" indicate that, initially, it was uncertain how detailed the outcomes would be - whether they would provide in-depth results or remain at a higher level. Additionally, it was unclear what empirical evidence could be found in the existing literature. As a result, the author was unable to determine whether the requirements and implementations would be abstract or specific, leading to the use of the term "classes."

Research question 2 (RQ2): Which classes of personal, game, behavioral, or medical data do behavior change-driven serious games, respectively, gamified mobile apps to prevent NCDs, have in common, and how can patients and clinicians benefit from them if personal or electronic health records incorporate such data?

This research question focuses on the specific datasets produced by interacting and playing serious games and gamified applications and how they can be used in different scenarios.

Research question 3 (RQ3): How can a semantic interoperable and technical

framework for behavior change-driven serious games, respectively, gamified mobile apps, be defined? What are the best practices for the design and implementation of such applications? Which health informatics standards can be used to represent personal, game, behavioral, or medical data interoperably, and how can these datasets be integrated into healthcare records?

This research question emphasizes the development of an interoperable framework containing best practices for designing and developing NCD-prevention games and apps and an implementation guide for personal, game, behavioral, and medical data.

1.4 Methodology

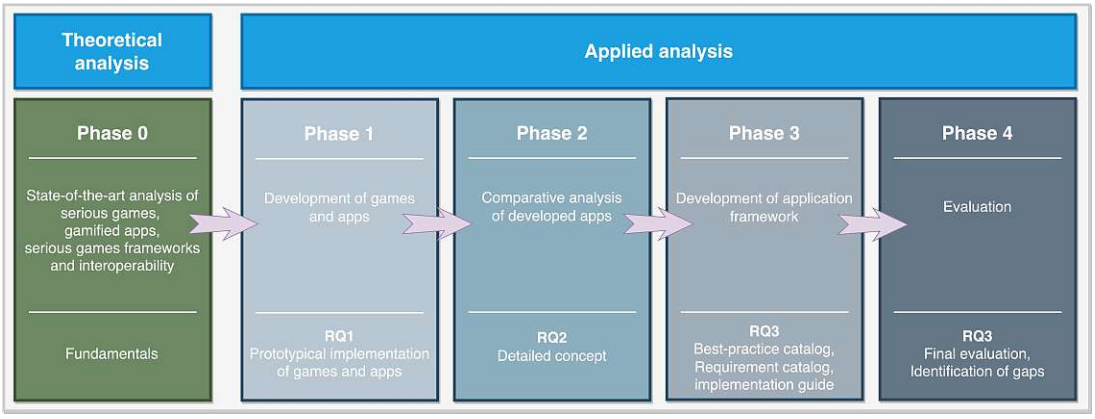


Figure 1.1: Methodology of this dissertation

The methodology of this dissertation consisted of five principal phases separated into a preliminary theoretical and an applied analysis stage. These phases include a research and analysis phase, a practical implementation/evaluation phase, two practical phases concerning the development of the interoperable framework, and a conclusion/summary phase.

The methodology was divided into five distinct phases to ensure a systematic and comprehensive approach to the complexities of achieving semantic interoperability in serious games and gamified applications for NCD prevention. Each phase had a specific purpose, starting with an analysis of the theoretical background and the current state of applications. The analysis was followed by the development of tangible games and applications and concluded with a framework that served as an organizational bracket and defined best practices for NCD prevention applications. Figure 1.1 provides an overview of all phases, depicting the outcomes and relevant research questions for each of the five phases.

A more comprehensive overview of the applied analysis stage can be found in Chapter 4.

1.4.1 Phase 0: Literature Review and State-of-the-art Analysis

The first phase comprised a literature review and multiple brainstorming sessions with peer researchers in similar research fields. Then, a comprehensive state-of-the-art analysis of applications and games in behavior change, specifically NCD prevention, was conducted. Relevant state-of-the-art work for this dissertation was identified, evaluated, and categorized. The gathered data served as the fundamentals for the subsequent phases.

1.4.2 Phase 1: Prototypical Implementation and Evaluation of Applications

This phase involved constructing prototypes, each investigating a different part of NCD prevention, e.g., smoking cessation, nutrition/fitness, and mental health. A requirement analysis was conducted for each application, involving people from the target group, especially those who want to live healthier lives and change their behavior, as well as field experts. Afterward, a prototypical implementation followed by a comprehensive evaluation was done for each application. Three apps were serious games (one of them was a modification of an existing video game). The other three were mobile applications with extensive gamification elements. All six apps focused on behavior change and the prevention of NCDs. During this phase, the author answered research question 1 (RQ1).

1.4.3 Phase 2: Comparative Analysis of Developed Apps

This phase comprised a comparative analysis of all developed applications and included concepts published by the author's research group before this thesis. The results of the developed apps were analyzed, organized, and used as the foundation for a detailed concept of the interoperable framework. The author answered research question 2 (RQ2) within this phase.

1.4.4 Phase 3: Development of an Interoperable App Framework for NCD Prevention Games and Apps

In this phase, the results of the preceding phase were used as the foundation for an interoperable application framework for behavior change-driven serious games and gamified mobile apps to prevent NCDs. As part of this framework, the data elements and structure were technically defined and constructed as a prototypical implementation guide using the international standard HL7 FHIR. A requirement catalog was defined. Furthermore, best practices for designing and implementing applications within behavior change and NCD prevention were derived and presented systematically. The author answered research question RQ3 during this phase.

1.4.5 Phase 4: Summary and discussion

Finally, the results were summarized, and a conclusion was drawn. The research questions were discussed and assessed in detail, and the next steps regarding future work were laid

out.

1.5 Publications

The author began to publish scientific articles in 2019 as a co-author of a paper about a serious game for stroke rehabilitation for the IEEE SeGAH (International Conference on Serious Games and Applications for Health) in Kyoto, Japan [27]. In 2020, the author published his first paper as a first author, a mobile health solution called recoverApp [28], which is used extensively for the results of this dissertation. The author further published work as a first author in 2021, Food Pyramid Escape [29], three in 2023 (Nutrition Garden [30] and BreathIn parts one and two [31], [32]), and two in 2024 (NutriMine [33] and the first part of the interoperable framework [34]). For the semantic interoperable framework, a paper was written that was accepted within the renowned "JMIR Serious Games" journal [35]. Nine scientific articles were published as a first author and used extensively for this thesis's results. Outcomes directly used within this work will be marked with a framed box at the beginning of each chapter. Figure 1.2 gives an overview of all publications of the author on a timeline and also shows which papers were greatly used for the results of this work (marked as "Core" on the x-axis in the diagram) and which were used as an additional source (marked as "Additional"), for example for serious gaming research in general or the state-of-the-art part.

> The direct citation of a section or a paragraph from a publication of the thesis's author is indicated by a frame box at the beginning of each chapter or section/subsection.

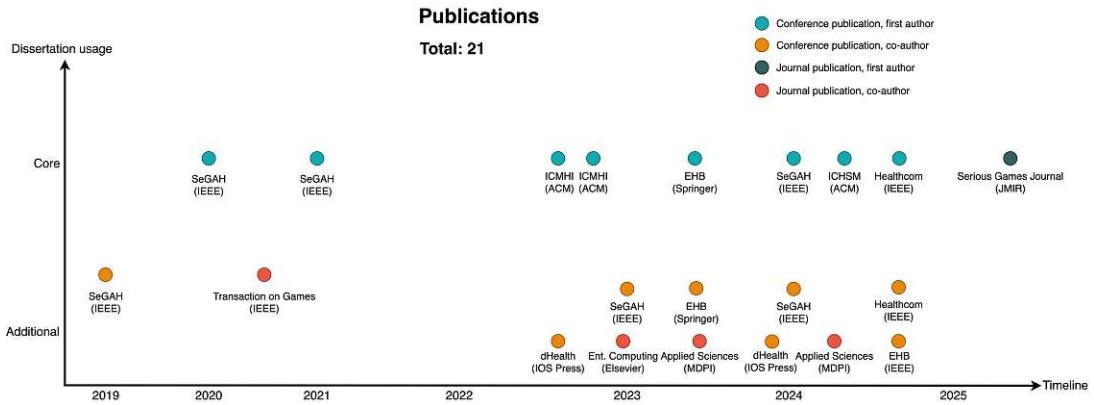


Figure 1.2: Publications by the author

1.5.1 Conference publications

The following list depicts all conference papers the author was involved at the time of submission in chronological order (total of 16):

- René Baranyi, Pawel Czech, Christoph Aigner, Florian Walcher, Thomas Grechenig; "Reha@Stroke - A Mobile Application to Support People Suffering from a Stroke Through Their Rehabilitation"; IEEE 7th International Conference on Serious Games and Applications for Health; 2019
- Christoph Aigner, Matthias Eder, René Baranyi and Thomas Grechenig; "recoverApp - A mobile health solution to support people in stationary rehabilitation"; IEEE 8th International Conference on Serious Games and Applications for Health; 2020
- Christoph Aigner, Eva-Maria Resch, Amir El Agrod, René Baranyi, Thomas Grechenig; "Food Pyramid Escape - A serious escape game for the support of nutritional education in Austria and beyond"; IEEE 9th International Conference on Serious Games and Applications for Health; 2021
- Lukas Rast, René Baranyi, Karl Pinter, Dominik Hölbling, Christoph Aigner, and Thomas Grechenig; "Standard Mobile Phones Plus a Balance Board are Sufficient: Designing a Serious Game for Better Knee Rehabilitation"; dhealth; 2023
- Christoph Aigner, Victoria Zeillinger, Kevin Baur, René Baranyi and Thomas Grechenig; "BreathIn – A Serious Game to Support Patients with Smoking Cessation"; ICMHI; 2023
- Christoph Aigner, Greta Hofmann, Sylvia Winkler, René Baranyi and Thomas Grechenig; "Nutrition Garden - A gamified mobile app for motivating people to eat specific food to prevent non-communicable diseases"; ICMHI; 2023
- René Baranyi, Lukas Rast, Karl Pinter, Christoph Aigner, Dominik Hoelbling and Thomas Grechenig; "FruitGrind: Analysis, Design and Development of a Serious Game Supporting Knee Rehabilitation Using a Smartphone Attached to a Balance Board"; 2023 IEEE 11th International Conference on Serious Games and Applications for Health (SeGAH); 2023
- Christoph Aigner, René Baranyi, Dominik Hoelbling, Kevin Baur, Victoria Zeillinger and Thomas Grechenig; "Analysis, Implementation, and Assessment of a Serious Game for Smoking Cessation: Investigating Design and Playtesting Outcomes"; The 11th International Conference on E-Health and Bioengineering - EHB; 2023
- René Baranyi, Stefan Kaim, Christoph Aigner, Dominik Hoelbling and Thomas Grechenig; "WristReha - Using Serious Game Tech for a Low Cost Yet Efficient Wrist Rehabilitation Process"; The 11th International Conference on E-Health and Bioengineering - EHB; 2023
- René Baranyi, Marko Zivojinovic, Dominik Hoelbling, Christoph Aigner, Werner Hoerner, and Thomas Grechenig; "Knee Rehabilitation Reimagined: A Serious Game called SquatEmUp utilizing the Wii Fit Balance Board"; dhealth; 2024

- Christoph Aigner, Kilian Köck, René Baranyi, Sylvia Winkler, Katharina Weindl and Thomas Grechenig; "NutriMine - A serious game modification for Minecraft to support people keeping a healthy diet"; IEEE 11th International Conference on Serious Games and Applications for Health; 2024

- Christoph Wimmer, Felix Ledóchowski, René Baranyi, Christoph Aigner and Thomas Grechenig; "Design and Evaluation of First-/Third-Person Hybrid Locomotion Techniques in Virtual Reality for Enhanced Accessibility in Healthcare"; IEEE 11th International Conference on Serious Games and Applications for Health; 2024

- Christoph Aigner, René Baranyi and Thomas Grechenig; "Foundations of an Interoperable Framework for Serious Games and Gamified Mobile Apps in Non-communicable Disease (NCD) Prevention"; Proceedings of the 2024 7th International Conference on Healthcare Service Management, in ICHSM '24. New York, NY, USA: Association for Computing Machinery; 2025

- Christoph Aigner, Marco Moser, Olivia Carina Wolfsberger, René Baranyi, Vanessa Hohenegger, Thomas Grechenig; "MoodBooster - A Gamified App to Support Stress Reduction in University Students"; IEEE Healthcom 24; 2024

- René Baranyi, Mustafa Isikoglu, Christoph Aigner, Dominik Hoelbling and Thomas Grechenig; "Leveraging Serious Game Mechanics to Boost Vaccine Literacy: Insights and Outcomes"; IEEE Healthcom 24; 2024

- René Baranyi, Lukas Weber, Christoph Aigner, Vanessa Hohenegger, Sylvia Winkler, and Thomas Grechenig; "Voice-Controlled Serious Game: Design Insights for a Speech Therapy Application"; The 12th International Conference on E-Health and Bioengineering - EHB; 2024

1.5.2 Journal publications

The following section lists all journal papers at the time of submission in chronological order in which the author was involved (total of 5):

- René Baranyi, Pawel Czech, Stefan Hofstätter, Christoph Aigner and Thomas Grechenig; "Analysis, design and prototypical implementation of a mobile Serious Game, entitled Reha@Stroke, to support rehabilitation of stroke patients"; IEEE Journal - Transactions on Games (ToG) - Special Issue on Serious Games for Health; 2020

- René Baranyi, Amina Hasimbegovic, Sylvia Winkler, Christoph Aigner, Paul Spiesberger and Thomas Grechenig; "Supporting Sustainable Development Goals through a Gamified mHealth Application for People with Albinism in Africa"; Journal of Entertainment Computing - Sustainability in Smart Educational Games and Gamification Systems; 2023

- Jonas Galli, René Baranyi, Dominik Hoelbling, Karl Pinter, Christoph Aigner, Werner Hörner, Thomas Grechenig; "Prevention and Rehabilitation Gaming Support for Ankle Injuries Usable by Semi-Professional Athletes Using Commercial Off The Shelf Sensors"; MDPI Journal of Applied Sciences; 2023
- René Baranyi, Christoph Hirber, Lukas Roehrling, Christoph Aigner, Dominik Hoelbling, Werner Hoerner, Thomas Grechenig; "VR-Powered Wrist Therapy: Developing a Therapist-Driven Exit The Room Serious Game with Hand Gesture Interactions"; MDPI Journal of Applied Sciences; 2024
- Christoph Aigner, René Baranyi, Thomas Grechenig; Digital Catalysts for Noncommunicable Disease Prevention Serious Games and Gamified Applications: Framework Design Study; JMIR Serious Games; 2025

1.5.3 Additional scientific work

The author has performed various assignments within the scientific community as part of the work for this dissertation. The author was a session chair for the IEEE SeGAH conference in 2018, which took place in Vienna, Austria, and for the IEEE Healthcom in 2024, which took place in Nara, Japan. Furthermore, the author was also part of the program committee for the following conferences:

- IEEE Healthcom 2022
- IEEE Healthcom 2024
- IEEE SeGAH 2023
- IEEE SeGAH 2024

The author is also a reviewer for the "Elsevier" journal "Entertainment Computing," a member of the Association for Computing Machinery (ACM), a member of Institute of Electrical and Electronics Engineers (IEEE), a member of HL7 Austria, and a member of the "IOP-Expertenkreis" from gematik, Germany [36].

1.6 Structure

This thesis is structured as follows. Chapter 2 gives an in-depth summary of the theoretical foundations incorporated into this work's design and development. This overview includes a medical background focusing on non-communicable diseases, risk factors, and prevention, as well as a technical background in mobile health, serious gaming, gamification, psychology theories, behavior change techniques, semantic interoperability, and requirement engineering.

The following Chapter 3 provides a profound overview of state-of-the-art games and apps for mental health in rehabilitation, student mental health, nutritional education

and weight management, food and calorie tracking, and smoking cessation. It concludes with a state-of-the-art analysis of interoperability and frameworks within the domain of serious games for health.

Chapter 4 revisits the section "Methodology" and provides a detailed overview of the methodologies utilized for each game and app that was developed. It also discusses the subsequent phases that compared these applications and established an interoperable technical framework.

Chapter 5 presents the results of this thesis in the form of a thorough description of the games and apps designed and developed for NCD prevention. It concludes with constructing an interoperable NCD-prevention serious games framework, including best practices and an implementation guide for personal, game, behavioral, and medical data.

Chapter 6 discusses the results and findings, emphasizing answering the research questions stated in the Section "Expected Results."

The final Chapter 7 concludes this dissertation and gives a clear summary of limitations and future work.

CHAPTER 2

Theoretical Foundation

This chapter presents the theoretical foundation of this thesis. It provides a comprehensive overview of the medical background by discussing common non-communicable diseases such as cardiovascular diseases, cancer, chronic respiratory diseases, and diabetes. It also explores modifiable risk factors for NCDs, including nutrition, smoking, and mental health.

Additionally, the chapter introduces the technical aspects of the mobile health domain (mHealth) and explains concepts related to serious gaming and gamification. It further delves into psychological theories and behavior change.

Lastly, the chapter covers semantic interoperability by introducing key standards from HL7, IHE, and openEHR and providing a brief overview of relevant medical terminologies.

The chapter concludes with a short introduction to requirement engineering.

2.1 Medical Background

This chapter gives an overview of the most important non-communicable diseases and relevant modifiable risk factors for the serious games and gamified apps that were designed and implemented as part of this thesis's results.

2.1.1 Non-communicable Diseases

According to the World Health Organization (WHO) and the International Federation of Red Cross and Red Crescent Societies (IFRC), non-communicable diseases (NCDs) can be defined as medical conditions that are not infectious, and, thus, cannot be transmitted from one person to another [11], [12]. They are also known as chronic diseases and tend to last a long time [12]. The main types of NCDs are cardiovascular diseases, such as heart attacks and stroke, cancers, chronic respiratory diseases, most prominently Chronic

Obstructive Pulmonary Disease (COPD), respectively, asthma and diabetes [12]. They result from genetic, physiological, environmental, and behavioral factors [12]. According to the WHO, they kill 41 million people each year, which is equivalent to 74% of all deaths globally. Another important fact is that each year, 17 million people die from an NCD before the age of 70. 86% of these deaths occur in low- and middle-income countries (of all NCD deaths, 77% are happening in low- and middle-income countries) [12].

Risk factors for NCDs can be divided into three main categories [12]: Modifiable behavioral risk factors such as an unhealthy diet, physical inactivity, tobacco use, and the harmful use and abuse of alcohol all increase the risk of contracting one or multiple NCDs. For example, tobacco use accounts for over eight million deaths every year, including exposure to second-hand smoke. Metabolic risk factors, including raised blood pressure, overweight/obesity, hyperglycemia, and hyperlipidemia, also increase the risk of contracting NCDs. Finally, environmental risk factors can also contribute to NCDs. For example, air pollution contributes to 5.7 million deaths, which are due to NCDs like stroke, ischaemic heart disease, COPD, and lung cancer [12].

Minimizing the aforementioned risk factors is crucial in NCD prevention. According to the IFRC, 80% of heart diseases, strokes, type 2 diabetes, and over one-third of cancers can be prevented by cutting out tobacco, eating a healthy diet, being physically active, and stopping harmful use of alcohol [11]. Lifestyle modifications are crucial in preventing and managing NCDs [37]. For example, a Mediterranean-type diet, rich in fruits, vegetables, whole grains, and healthy fats, has been associated with lower rates of NCDs [37]. Moreover, public health initiatives promoting awareness and education about NCD risk factors are essential for effective prevention strategies [38]. A recent study by Islami et al. [39] stated that in 2019, an estimated 40% of all incident cancers and 44% of all cancer deaths in adults aged 30 years and older in the United States were attributable to potentially modifiable risk factors which they noted as cigarette smoking, second-hand smoke, excess body weight, alcohol consumption, consumption of red and processed meat, low consumption of fruits and vegetables, dietary fiber and dietary calcium, physical inactivity, ultraviolet radiation, and seven carcinogenic infections.

Figure 2.1 visually shows the most important NCDs and the corresponding risk factors. The image was taken from a campaign of the IFRC and the International Federation of Pharmaceutical Manufacturers & Associations (IFPMA) called "4 Healthy Habits" that enabled facilitators and volunteers from over 33 countries to raise awareness about the risks of contracting NCDs, encourage healthy habits and perform basic screening among their communities [40].

People living with one or multiple NCDs are particularly vulnerable in crises because they may require continuous care over long periods [11]. In the event of a crisis, this care can be disrupted, and the flow of medicine can be restricted, leading to health complications that require additional treatment and expense. Coordinating care between healthcare workers and settings is difficult or even impossible in crises [11]. NCDs may also limit the ability of a person or their family to cope with certain emergencies. Therefore, according to the IFRC, a longer-term and more comprehensive approach is needed to address NCDs during

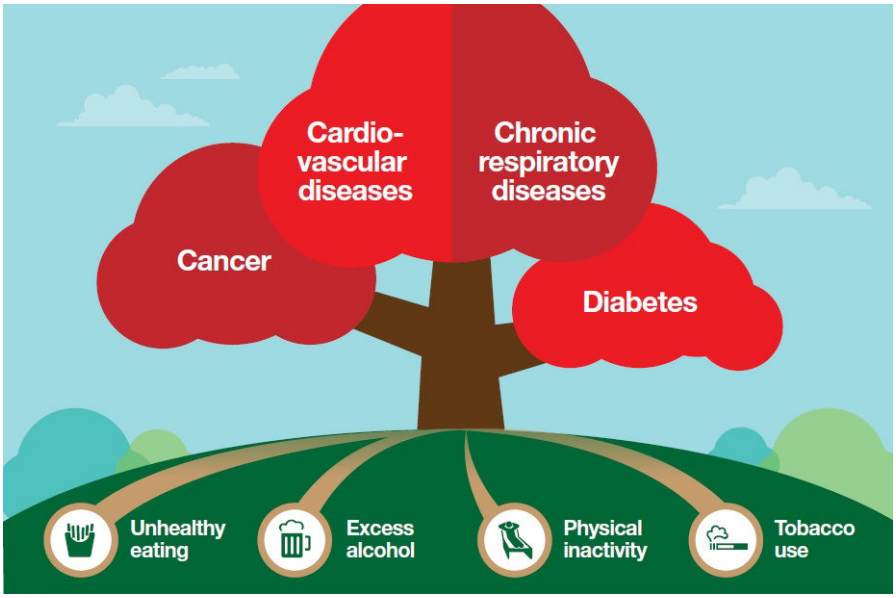


Figure 2.1: 4 Healthy Habits initiative [40]

humanitarian settings [11]. NCD prevention is particularly crucial in low- and middle-income countries, where the prevalence rapidly increases due to urbanization, lifestyle changes, and aging populations [41], [42]. Further studies also suggest that NCDs are compounded by socio-economic inequalities, with poorer populations disproportionately affected [43], [44]. Additionally, humanitarian crises are more common in these regions.

The transition from communicable to non-communicable diseases is evident in many regions, particularly in India, where studies indicate that NCDs have become the leading cause of death, surpassing communicable diseases [45], [46]. This shift is attributed to the risk factors mentioned above [47], [48]. For instance, a study in India found that nearly half of the older adult population suffers from at least one chronic non-communicable illness, highlighting the significant health challenges faced by this demographic [49].

Cardiovascular Diseases

Cardiovascular diseases (CVDs) can be described as a group of disorders of the heart and blood vessels [50] and cover a wide array of disorders, including diseases of the cardiac muscle and vascular systems supplying the heart, brain, and other vital organs [51]. They cause an estimated 17.9 million deaths each year and are, therefore, the leading cause of deaths globally [50]. The most important types are coronary heart disease, a disease of the blood vessels supplying the heart muscle; cerebrovascular disease, a disease of the blood vessels supplying the brain; peripheral arterial disease, a disease of blood vessels supplying the arms and legs; rheumatic heart disease, damage to the heart muscles and valves from rheumatic fever due to infection with streptococcal bacteria, congenital heart disease (congenital disabilities of the heart) and deep vein thrombosis and pulmonary

embolism which are blood clots that can dislodge and move to the heart and lungs [52].

Myocardial infarction (commonly known as heart attack) and strokes are usually acute events and are mainly caused by a blockage of the blood flow. The most common reason for this is a build-up of fatty deposits on the inner wall of blood vessels supplying the heart or brain (arteriosclerosis) [52]. Strokes are caused by a disruption in the flow of blood to certain parts of the brain either because of the occlusion of a blood vessel (ischemic stroke) or the rupture of a blood vessel (hemorrhagic stroke) [51]. Ischemic heart disease (angina pectoris and acute myocardial infarction), stroke, and congestive heart failure account for at least 80% of CVDs in all income regions [51].

Congestive Heart Failure (CHF) can be considered the end stage of many heart diseases. It can be characterized by abnormalities in myocardial function and neurohormonal regulation, resulting in fatigue, fluid retention, and reduced longevity. It is caused by pathological processes that affect the heart. The incidence and prevalence of CHF rise dramatically with age, and it occurs more frequently in men [51].

Rheumatic Heart Disease (RHD) results from an acute rheumatic fever (ARF). ARF is an autoimmune response to a specific streptococci group and affects the joints and the heart valves. The most serious complications include valvular stenosis, regurgitation due to valvulitis, or a combination of both. It is also a predisposing factor for infective endocarditis [51].

Cancer

Cancer is a complex and multifaceted disease characterized by uncontrolled cell growth, influenced by genetic and environmental factors. Recent studies have highlighted the significance of genetic predispositions in various cancer types, as well as the role of lifestyle choices in modulating cancer risk. According to the WHO, cancer is the second leading cause of death globally, accounting for an estimated 9.6 million deaths, or 1 in 6 deaths, in 2018. Lung, prostate, colorectal, stomach, and liver cancer are the most common types of cancer in men, while breast, colorectal, lung, cervical, and thyroid cancer are the most common among women [53].

Cancer refers to more than 100 forms of the underlying disease since almost every tissue in the human body can spawn malignancies; some even yield several types [54]. Normal cells reproduce only when instructed to do so by other nearby cells. This collaboration ensures that each tissue maintains size and architecture appropriate to the human body's needs. In contrast, cancer cells violate this biological scheme by following their internal agenda for reproduction. Furthermore, they can migrate from where they begin to nearby different tissues and form masses at distant sites in the body, a concept called metastases. Malignant cells become more aggressive over time and can become lethal when they disrupt vital tissue and organs [54].

Genetic factors play a crucial role in the development of many cancers. For instance, hereditary mutations in genes such as BRCA1 and BRCA2 are well-documented contrib-

utors to breast and ovarian cancers, with studies indicating that these mutations account for a significant proportion of ovarian carcinoma cases [55].

Lifestyle factors also significantly influence cancer risk, particularly in genetically predisposed populations. A prospective cohort study indicated that maintaining a healthy lifestyle could mitigate the genetic risks associated with certain cancers, such as colorectal and breast cancers [56].

Various types of cancer can be classified based on their origin, histological characteristics, and genetic mutations. Breast cancer is one of the most frequent types of cancer, with significant research focusing on its various subtypes, including triple-negative breast cancer (TNBC) and lobular carcinoma. TNBC, which lacks estrogen, progesterone, and HER2 receptors, is known for its aggressive nature and poor prognosis, accounting for approximately 12-17% of all breast cancer cases [57]. Lung cancer, especially in the form of non-small cell lung cancer (NSCLC), is another major type of cancer, comprising about 85% of all lung cancer cases. The most common histological subtype of NSCLC is adenocarcinoma, which has a high prevalence of epidermal growth factor receptor (EGFR) mutations, especially among Asian populations [58]. Colorectal cancer (CRC) is also a significant health concern, with its incidence and survival rates varying across different populations. Research has indicated that the treatment approaches for CRC are generally uniform across hospitals. However, variations in patient outcomes may arise from differences in tumor characteristics and treatment regimens [59]. Gastric cancer is another type that has garnered attention, particularly regarding the detection of circulating tumor DNA (ctDNA) as a biomarker for diagnosis and monitoring. Specific mutations and methylation patterns in ctDNA can provide insights into the type of cancer and its progression, highlighting the potential for liquid biopsies in cancer management [60].

Chronic Respiratory Diseases

Chronic Respiratory Diseases (CRDs) can be described as diseases that affect the airways and other structures of the lungs. The most common diseases are Chronic Obstructive Pulmonary Disease (COPD), asthma, occupational lung diseases, and pulmonary hypertension. Smoking tobacco is considered to be the main risk factor. Additional risk factors include air pollution, occupational chemicals and dust, and frequent lower respiratory infections during childhood. CRDs are not curable, which is why the main treatment methods focus on controlling symptoms and improving daily life for people living with CRDs with treatments that open air passages and improve shortness of breath [61].

The pathophysiology of CRDs often involves complex interactions among various cytokines, which play critical roles in the inflammatory processes underlying these diseases. Atamas et al. [62] highlight that cytokines contribute to lung pathology in multiple chronic respiratory conditions, indicating a shared inflammatory pathway. This systemic inflammation not only exacerbates respiratory symptoms but also increases the risk of comorbidities, such as cardiovascular diseases and diabetes, which are prevalent among

patients with CRDs [63]. For instance, individuals with asthma are at a heightened risk for cardiovascular complications due to the systemic effects of chronic inflammation [63]. Environmental factors significantly influence the development and exacerbation of CRDs. Exposure to pollutants, such as dust and smoke, has been shown to increase the incidence of respiratory symptoms, particularly in occupational settings [64]. For example, Asfaw et al. [65] found that workers with a family history of chronic respiratory diseases were three times more likely to develop symptoms, suggesting a genetic component alongside environmental triggers. Furthermore, the interplay between physical activity and chronic respiratory conditions is critical, as decreased physical activity can worsen respiratory symptoms and overall health outcomes [66].

According to Labaki and Han [67], CRDs have received proportionately less public attention and less research funding than other NCDs despite a high number of people affected. According to them, 545 million people worldwide had a CRD in 2017, an increase of 39,8% since 1990. High-income regions had the highest prevalence, while South Asia and sub-Saharan Africa had the lowest. Their finding confirms that CRDs are common and are associated with substantial morbidity and mortality. According to Soriano et al. [68], the prevalence of CRDs has increased markedly, with COPD projected to be the third leading cause of death by 2030, affecting over 300 million individuals globally. This rise in prevalence is attributed to various factors, including environmental pollutants, lifestyle choices such as smoking, and genetic predispositions [69].

COPD is a common lung disease that causes restricted airflow and breathing problems. The most common symptoms of COPD are difficulty breathing, a chronic cough, and the feeling of tiredness. Further symptoms are tightness in the chest, frequent respiratory infections, weight loss, and swelling in feet, ankles, or legs. Symptoms can sometimes get worse quickly. These are called flare-ups and usually last a few days, often requiring additional medicine [70].

It is a diverse disease that ranges from bronchitis to lung emphysema [72]. Chronic bronchitis irritates the bronchial tubes, which carry air to and from the lungs, while emphysema is a breakdown of the wall of the alveoli, see Figure 2.2 [71]. The pathophysiology of COPD involves a complex interplay of genetic, environmental, and lifestyle factors, particularly smoking, which is the most significant risk factor for the disease [73], [74]. The decline in lung function, often measured by forced expiratory volume in one second (FEV1), is a hallmark of COPD progression, with various studies indicating that not all patients experience a rapid decline in lung function [73], [74]. This variability suggests that early identification and intervention are crucial for managing the disease effectively.

Diabetes

Diabetes is a chronic disease that occurs either when the pancreas does not produce enough insulin to regulate blood glucose or when the body cannot effectively use the insulin it produces [75]. Hyperglycemia, a term for raised blood glucose, is a common

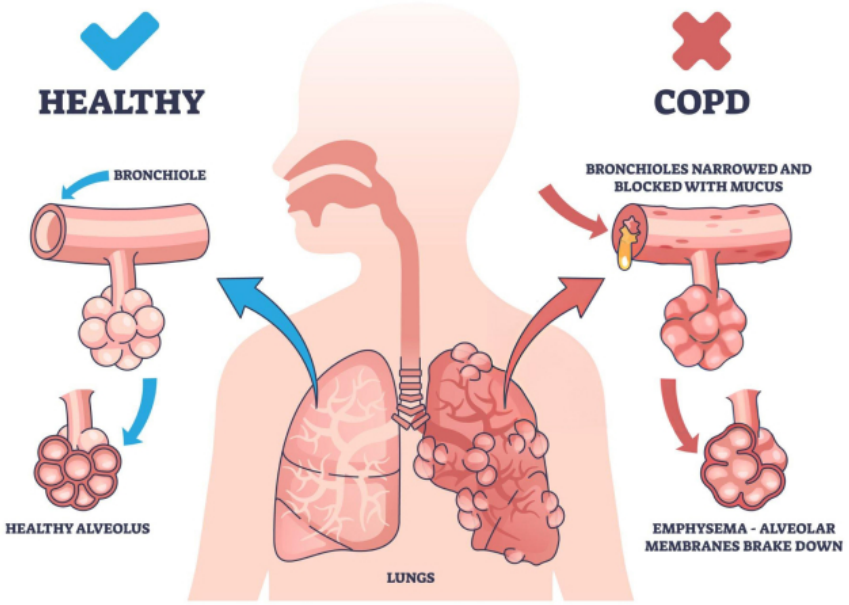


Figure 2.2: Chronic bronchitis and emphysema [71]

effect of uncontrolled diabetes, which can lead to serious damage to the nerves and blood vessels. There are three main forms of diabetes: type-1, type-2, and gestational diabetes [75]. However, assigning a type of diabetes to an individual often depends on the circumstances present at the time of diagnosis, leading to many patients not fitting easily into a single class [76]. Figure 2.3 gives an overview of etiologic types and stages.

Type-1 diabetes is characterized by deficient insulin production and requires daily insulin administration to the body. It was previously known under the term insulin-dependent, juvenile, or childhood-onset diabetes [75]. According to the WHO, in 2017, there were 9 million people diagnosed with type-1 diabetes, the majority of them from high-income countries [75]. Typical symptoms are frequently polyuria, polydipsia, weight loss, and fatigue [77].

Type-2 diabetes affects how the body uses glucose for energy. It stops the body from using insulin properly, which can lead to high blood sugar levels if not treated, which can cause serious damage to the body. Symptoms are usually very mild, and frequently, there are no complaints from patients [77]. This form of diabetes often goes undiagnosed for many years, and most patients with this form are obese or may have an increased percentage of body fat distributed predominantly in the abdominal region [76]. Lifestyle changes, especially reaching and keeping a healthy body weight, staying physically active with at least 150 minutes of moderate exercise each week, avoiding sugar and saturated fat, and smoking cessation, are the best ways to prevent or at least delay the onset of type-2 diabetes [75].

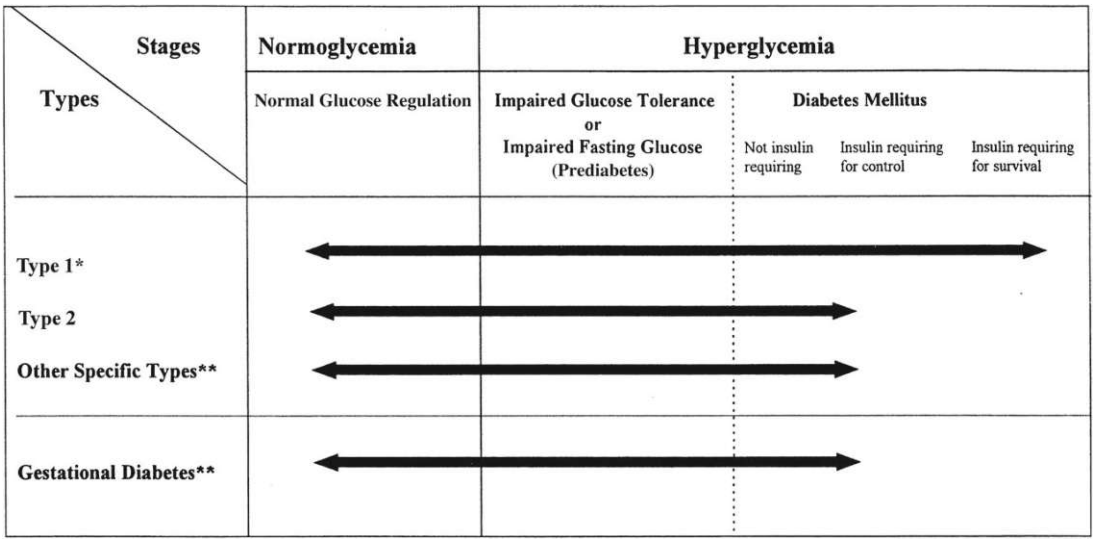


Figure 2.3: Disorders of glycemia [76]

Gestational diabetes occurs during pregnancy and is hyperglycemia with blood glucose values above normal but below that of diagnosed diabetes. Women who are affected have an increased risk of complications during their pregnancy and at delivery. Additionally, these women and their children may face an increased risk of developing type-2 diabetes in the future [75].

2.1.2 Nutrition and Diet

Proper nutrition and a balanced diet are essential for health and well-being. Food is necessary to support bodily structures such as muscles, tissues, and organs, facilitate bodily functions, and provide energy for the body's construction, decomposition, and modification processes. According to the WHO, better nutrition is related to the improved infant, child, and maternal health, stronger immune systems, safer pregnancy, and childbirth, lower risk of NCDs, and longevity [78]. Malnutrition can take different forms and can threaten human health. The most prominent forms are overweight, obesity, undernutrition, and inadequate vitamin or mineral intake [78]. The WHO further states that malnutrition's developmental, economic, social, and medical impacts can be serious and lasting for individuals, communities, and countries [78].

Nutrients

The study of nutrition is based on an understanding of intermediary metabolism. For the human body to use nutrients, it must first break food down into usable components by digesting and absorbing them via various mechanisms [79]. Nutrients can be described as vital organic and inorganic substances required by the body to maintain health, support growth, and facilitate physiological functions. They can be divided into two

major groups. Macronutrients provide the human body energy, whereas micronutrients support human metabolism and are normally consumed only as trace elements. The three major chemical compounds of macronutrients are proteins, carbohydrates, and lipids (commonly known as fats). Alcohol can also be considered a macronutrient because it has the second-highest caloric value. Still, since it is not required by the human body to survive and is considered an NCD risk factor, it was omitted in further discussion of nutrition within this chapter. Along with water, macronutrients constitute the major portion of most foods and are required in relatively large amounts by the body [80]. Micronutrients, the second group, comprise vitamins and minerals that are also vital for metabolic processes [81]. Carbohydrates, proteins, lipids, and vitamins are organic molecules, so they are referred to as organic nutrients. In contrast, minerals and water are inorganic molecules, so they are referred to as inorganic nutrients [80], as depicted in Figure 2.4. The energy that is provided by proteins, carbohydrates, and lipids is measured in kilocalories (abbreviated as kcal) or in kilojoules (abbreviated as kJ) [80].

	CARBON	HYDROGEN	OXYGEN	NITROGEN	MINERALS
Inorganic nutrients					
Minerals					✓
Water		✓	✓		
Organic nutrients					
Carbohydrates	✓	✓	✓		
Lipids (fats)	✓	✓	✓		
Proteins[a]	✓	✓	✓	✓	
Vitamins[b]	✓	✓	✓		

[a] Some proteins also contain the mineral sulphur.

[b] Some vitamins contain nitrogen; some contain minerals.

Figure 2.4: Elements in the six classes of nutrients [82]

Proteins Proteins belong to the class of macronutrients and are mainly needed for the growth and maintenance of body structures and to regulate and facilitate body processes. They also provide the body with energy, approximately 4 kcal per gram. Food items like fish, meat, milk, poultry, eggs, vegetables, legumes, and grains provide the body with proteins [80]. They comprise 20 different amino acids that can be divided into essential and non-essential [82]. More than half of the amino acids are considered non-essential because the body can synthesize them for itself, even though proteins in food usually contain those amino acids as well. There are nine essential amino acids that the human body cannot produce itself, at least not in sufficient quantities, and therefore, these must be supplied by the diet [82].

Carbohydrates Carbohydrates provide a readily available energy source to the body in the form of 4 kcal per gram. They include sugars, milk, fruit, and starches, such as those in vegetables, legumes, and grains. Most fiber is also carbohydrate but provides little energy since it cannot be digested. It is, however, very important for gastrointestinal health. Fiber is found in vegetables, fruits, legumes, and whole grains. Sugars are considered the simplest form, whereas starches are a more complex form of carbohydrates [80].

Lipids Lipids, commonly called fats and oils, provide the human body with 9 kcal per gram. They are, therefore, considered a concentrated source of energy in food and a lightweight storage form of energy in the body. Several types of them are important in nutrition. Triglycerides are most abundant in foods and in the body. Butter and oil that are added during food cooking and the layer of fat under a person's skin are mostly composed of triglycerides. They are made up of different fatty acids with different health effects. Diets high in saturated fatty acids increase the risk of contracting NCDs, whereas diets high in unsaturated fatty acids can actually reduce these risks. Cholesterols are another lipid type that can also increase the risk of contracting NCDs if the body has high levels of it in the blood [80].

Water Water makes up about 60% of an adult's body weight and, unlike other nutrients, is considered only a single substance. Since the human body cannot store water, it must be constantly replaced as part of the diet. Water acts as a lubricant, a transport fluid, and a regulator of body temperature [80].

Vitamins Vitamins are a term for 13 substances that can be described as organic molecules that do not provide energy but are vital to regulating various body processes. Each substance has a different structure and provides a unique function in the body. Many are involved in providing energy from carbohydrates, lipids, and proteins. Others are needed in processes such as bone growth, vision, blood clotting, oxygen transport, and tissue growth and development [80].

Minerals Minerals are inorganic molecules that do not provide energy. Some are important structurally, and others have regulatory roles. They are needed for bone strength, the transport of oxygen, the transmission of nerve impulses, and numerous other functions. Although requirements for many minerals have been established, some are required in such small amounts that their role in maintaining health is still not fully understood [80].

Overweight, Underweight, and Malnutrition

The food that people consume has an enormous impact on health and the development of NCDs in the future. Consuming too little or too much nutrients will cause malnutrition,

which can be avoided by choosing a healthy diet that meets the correct nutrient and energy needs [80].

Overnutrition can be described as a form of malnutrition caused by an excess of energy or nutrients [80]. According to WHO statistics, 2.5 billion adults were overweight in 2022. Of these, 890 million were living with obesity [83]. The WHO defines both terms with the help of the body mass index (BMI), which is calculated by dividing the square of the body height in meters by the body weight in kilograms. If an adult has a BMI greater than or equal to 25, the person is considered overweight, a condition of excessive fat deposits. A BMI greater than or equal to 30 is considered obesity, a chronic complex disease defined by excessive fat deposits that can impair health. Figure 2.5 gives an overview of the prevalence of overweight (BMI greater than or equal to 25) among adults worldwide [83].

Undernutrition is a form of malnutrition caused by a deficiency of energy or nutrients. It may be caused by a deficient intake, increased requirements, or an inability to absorb or use nutrients. The most severe form of undernutrition is starvation, a deficiency of energy that causes weight loss, poor growth, the inability to reproduce, and, in severe cases, death. Some nutrient deficiencies can quickly cause symptoms, such as dehydration from a water deficiency. Other deficiencies may take much longer to become apparent, for example, osteoporosis, which can occur after years of consuming a calcium-deficient diet [80]. According to the WHO, in 2022, 390 million adults and 190 million children and adolescents aged 5-19 years were underweight. An estimated 149 million children under the age of 5 years suffered from stunting, meaning they were too short for their age. Nearly half of deaths among children under 5 years of age were linked to undernutrition [84].

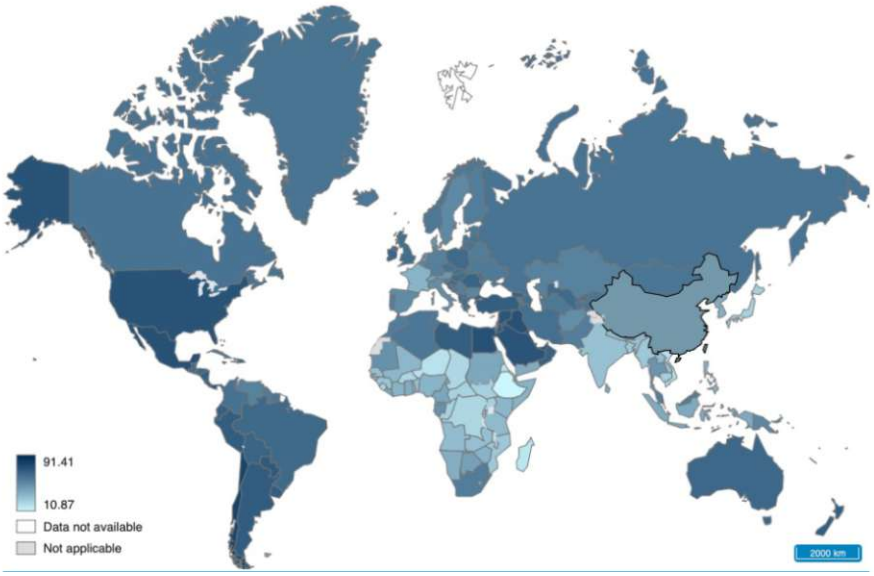


Figure 2.5: Prevalence of overweight among adults (BMI >= 25) [85]

Healthy diet

People decide what and when to eat in personal ways, often based on behavioral or social motives rather than on an awareness of their diet's importance to health [82]. Those decisions can be because of personal preferences, like certain tastes, habits at certain times of the day, ethnic heritage or tradition, social interactions, marketing, availability, convenience, and economy [82].

According to the WHO, a healthy diet contains fruits, vegetables, legumes, nuts, and whole grains. People should eat at least five portions of fruit and vegetables daily, excluding potatoes, sweet potatoes, cassava, and other starchy roots. Less than 10% of total energy intake should come from free sugars, and less than 30% should come from fats. Intake of saturated and trans-fats should be even less or avoided in the case of industrially produced trans-fats. Less than 5g of salt should be ingested daily [86]. Implementing and maintaining such a diet can be hard and not always affordable. According to statistics of the World Bank [87], around 2.8 billion people could not afford a healthy diet in 2022, with global food prices on the rise due to disruptions by COVID-19 and the war in Ukraine.

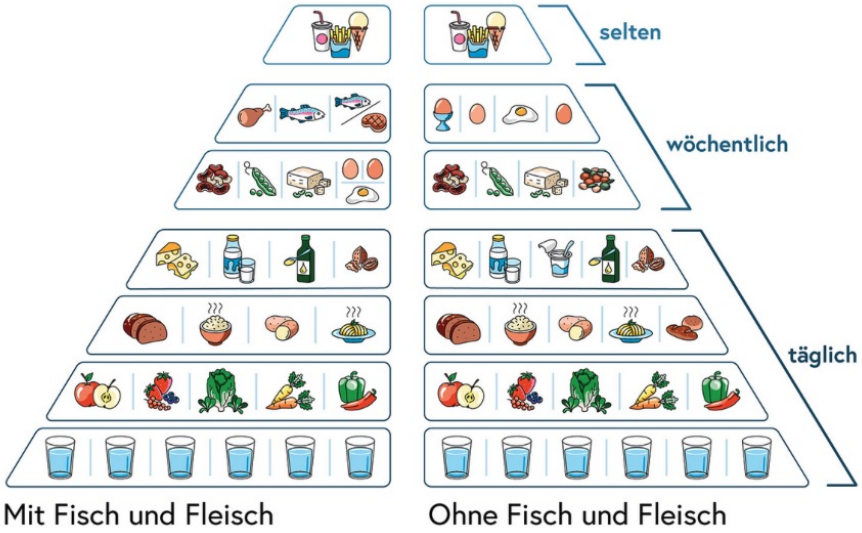


Figure 2.6: Austrian food pyramid [88]

Many nations have their own national diet recommendations. For example, the Austrian Agency for Health and Food Safety (AGES) publishes the Austrian food pyramid that depicts seven layers of food item recommendations as seen in Figure 2.6. The foundational four layers at the bottom contain food items that should be consumed daily, starting with water, fruits and vegetables, cereals and potatoes, dairy products, oil, nuts, and seeds. The next two layers contain food items that should be eaten multiple times a week, with legumes and eggs recommended three times a week and fish and meat, respectively,

once a week. The top layer contains fatty, sweet, and salty food items, which should only be consumed seldom [88].

Other nations have similar programs; for example, in Germany, the German food pyramid was published by the German Federal Center for Nutrition (BZfE) [89].

2.1.3 Smoking and Smoking Cessation

Smoking tobacco is a worldwide epidemic and, therefore, a public health threat, killing over 8 million people per year worldwide. More than 7 million of those deaths are the result of direct tobacco use, while around 1.3 million are the result of exposure to second-hand smoke. Since all forms of tobacco use are harmful, there is no safe level of exposure [90].

According to the WHO, in 2020, 22.3% of the population were tobacco users, and around 80% of them lived in low- and middle-income countries [90]. A very recent study from the UK by Jackson et al. [91] estimated that the average loss of life per cigarette smoked is approximately 20 minutes, 17 for men and 22 for women. The study authors further suggested that the epidemiological data they observed indicated that the harm caused by smoking is cumulative. The sooner the person stops, the longer they will live. They concluded that a person smoking 10 cigarettes per day who quits smoking could prevent the loss of a full day of life after only a week of not smoking. According to McEwen et al. [92], long-term chronic smokers can expect to lose, on average, ten years of their lives. They further state that half to two-thirds of all long-term smokers die prematurely because of their smoking and do so on average 20 years earlier than non-smokers. Furthermore, lifelong regular smokers can expect to experience diseases of old age prematurely because smoking impairs lung function, the circulatory system, and the immune system. It is also strongly linked with non-fatal debilitating diseases, including age-related deafness and blindness [92].

There are three major components of cigarette smoke: nicotine, tar, and carbon monoxide [92].

The main tobacco substance is nicotine, named after the tobacco plant Nicotiana tabacum. It was first isolated from the plant in 1828 by German chemists Posselt and Reimann, who considered it a poison. It is a hygroscopic oily liquid mixable with water in its base form. As it enters the body, it is quickly distributed through the bloodstream and can cross the blood-brain barrier. Nicotine has a mood-altering effect on the body by being both a stimulant and a relaxant. However, the apparent relaxing effect of smoking only reflects the reversal of the tension and testiness that develop during nicotine depletion [93]. Nicotine is understood to be the drug in cigarettes that is addictive, meaning it is what keeps smokers smoking, but does not cause cancer and has a mere small effect on the risk of cardiovascular diseases [92].

Tar is the name given to all other chemicals in particles of cigarette smoke. There have been approximately 4000 chemical components identified in cigarette smoke, of which

over 40 are known to cause cancer. These substances are linked to NCDs like CRDs and cardiovascular diseases [92].

Carbon monoxide is a gas that gets inhaled by smokers, is linked to cardiovascular diseases, and has adverse effects in pregnancy [92].

According to McEwen et al. [92], a large number of people with mental health problems smoke cigarettes, suggesting a strong link between smoking and a range of psychiatric disorders, notably mood disorders, schizophrenia, and alcohol and drug dependence, but it is unclear if smoking causes or worsens these conditions. Low mood is also a withdrawal symptom, and cases of major depression have been reported following smoking cessation [92].

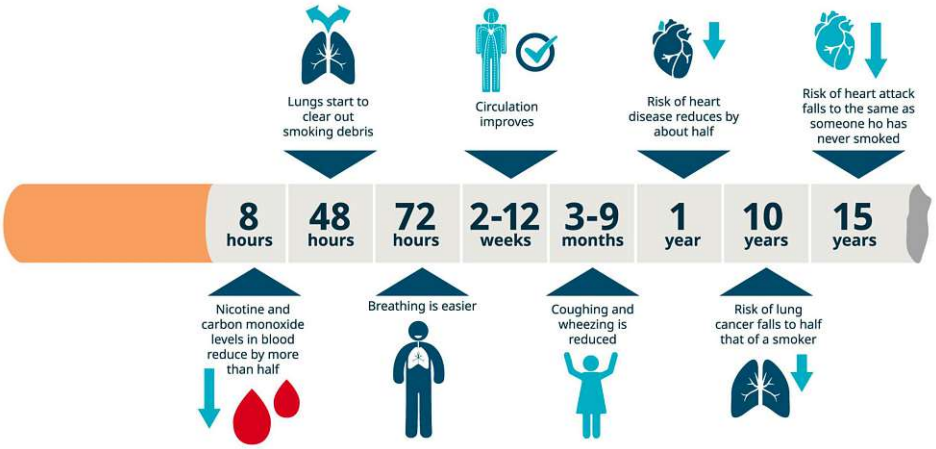


Figure 2.7: Health benefits of smoking cessation over time [94]

Smoking cessation or quitting can be described as the process of discontinuing the practice of inhaling smoked substances [93]. Quitting smoking reduces the risk of smoking-related diseases greatly but is sometimes hard to achieve, requiring repeated treatments [95]. Figure 2.7 shows the health benefits of smoking cessation over time [94]. Even though most former smokers quit without using a specific treatment, many of them are available and include brief help from a doctor, behavioral therapies (such as training in problem-solving), and over-the-counter or prescription nicotine replacement products like nicotine patches, gums, lozenges, inhalers, and nasal sprays [95]. Brief advice from general practitioners leads between 1% and 3% of patients to stop smoking for at least six months by triggering a quit attempt [92]. Therapies can occur as intensive one-to-one interventions by health professionals and specialists, via telephone counseling, or as group interventions [95].

2.1.4 Mental Health

Mental health can be understood as a multifaceted concept that includes emotional, psychological, and social well-being. Galderisi et al. [96] describe it as a dynamic state

of internal tranquility that enables individuals to use their abilities in harmony with the universal values of society. This state includes basic cognitive and social skills, the ability to recognize, express, and modulate one's emotions, and empathize with others. It gives a person flexibility and the ability to cope with unfavorable life events and functions in social roles. A harmonious relationship between body and mind represents an important component of mental health that contributes to the state of internal serenity [96].

Mental health is not merely the absence of mental illness but also involves the ability to handle stress, relate to others, and make healthy choices. Poor mental health and mental illness are not the same. Persons can experience poor mental health and not be diagnosed with a mental illness, which are conditions that affect a person's thinking, feeling, mood, or behavior and may be occasional or long-lasting. There are more than 200 classified types of mental illnesses, and those include most prominently anxiety disorders, attention deficit hyperactivity disorder (ADHD), disruptive behavioral disorders, depression, eating disorders, personality disorders, post-traumatic stress disorder, schizophrenia, and substance-use disorders. Persons with mental illnesses can, however, experience periods of physical, mental, and social well-being. Mental illnesses are among the most common health conditions, and several factors can contribute to the risk of contracting them, including traumas, history of abuse, biological factors, use of alcohol or recreational drugs, loneliness, and other medical conditions [97].

The prevention of mental, emotional, and behavioral disorders focuses on addressing known risk factors such as exposure to trauma [97]. Poor mental health can be associated with social disadvantages. Poverty, discrimination, and violence can have a powerful influence on mental health in low- as well as high-income countries [98]. Pilgrim et al. [98] further suggest that evidence on the effectiveness of public health and social interventions for promoting mental health is evident. Mental health promotion involves actions that support people in adopting and maintaining healthy ways of life and creating living conditions and environments that facilitate health. That includes actions like advocacy, policy and project development, legislative and regulatory reform, communications, and research and evaluation [98]. Singh et al. [99] state that prevention and promotion of mental health are essential in reducing the growing magnitude of mental illnesses. Research suggests that mental health promotion and preventative measures are cost-effective in preventing or reducing mental illness-related morbidity, both at the societal and individual levels [99]. Unfortunately, little effort has been made globally, resulting in stagnation in the implementation of effective mental health services. Therefore, policymakers and health practitioners must be sensitized about linkages between mental- and physical health to effectively implement various mental health promotive and preventive interventions that also include individuals with chronic physical illnesses [99]. Mental health promotion is especially important since mental health disorders are strongly linked to an increased risk for mortality due to associated physical health issues such as NCDs [100]. Frameworks that link NCD prevention and mental health are already available to mitigate such issues [14].

2.2 Mobile Health (mHealth)

The concept of mobile health (mHealth) has sparked many debates, discussions, and research studies. It embodies a transformative concept that utilizes smartphones' technological and computing capabilities to enhance healthcare connectivity and delivery services [101]. According to Istepan [101], this definition is very narrow, especially in what the author refers to as the "post-smartphone era." Istepan identified related topics like sensors, artificial intelligence (AI), cloud computing, big data, and the Internet of Things (IoT) that are part of the mHealth domain. The WHO defines mHealth as a medical and public health practice and an eHealth component supported by mobile devices such as smartphones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices. It involves not only the use of a smartphone's core utility as a voice and messaging device but also utilizes more complex functionalities and applications like 4G, Global Positioning System (GPS), and Bluetooth technology [102]. Figure 2.8 gives an overview of the building blocks of the mobile health domain [103].

Common mHealth devices used today can be divided into two groups: mobile device apps, which are software applications on smartphones and tablets that have been developed to accomplish certain health purposes, and wearable fitness devices or trackers, which are devices that users have to wear, particularly for tracking and monitoring health and fitness activities. Patient monitoring devices, mobile telemedicine, and telecare devices also fit the term [104].

A wide range of mobile device apps are available for consumers through mainstream mobile platforms like "Google Play" and "Apple App Store." Some apps are available for free, while others require payment to download. Other apps come preinstalled and are shipped with smartphones, such as "Apple Health" and "Samsung Health" [104]. The COVID-19 pandemic popularized mobile health applications, particularly regarding contact tracing and patient assessment [105]. An example is the app "Stopp Corona," provided by the Austrian Red Cross, which could be used for anonymous contact tracing [106]. It utilized a feature of the operating system called "Exposure Notification," developed jointly by Apple and Google to assist governments and public health authorities with contact tracing while prioritizing user privacy and security as core design principles. It employs "Bluetooth Low Energy" technology to register contact with other smartphone users and demonstrates a successful way to apply sensor and device data from mobile phones in the mobile health domain [107].

Wearable fitness trackers can be defined as mini-computers that use sensors to gather various types of activity and body data from their users. Common types of sensors include accelerometers to detect and track movement, motion sensors to monitor different kinds of physical activities, altimeters used for elevation and altitude tracking, compasses to determine the direction and assist with outdoor navigation, GPS to track workouts, gyroscopes to measure orientation and angular velocity, and bioimpedance sensors to gauge the resistance of body tissues, enabling the collection of various body signals like respiratory rate, skin response, heart rate, and sleep patterns. Moreover, ambient light

sensors can adjust display brightness, and proximity sensors can be used to conserve energy by deactivating components when not in use [104].

Modern fitness trackers also include innovative sensors such as optical heart rate sensors, peripheral oxygen saturation (SpO2) sensors to measure blood oxygen levels, echocardiogram sensors, gesture sensors, ultraviolet radiation sensors, magnetometers, and electrodermal activity sensors to assess stress alongside skin temperature sensors. Many sensors can collaborate to achieve specific functions. For instance, precise movement tracking can be attained by combining an altimeter and barometer with GPS. Alternatively, they can function independently to deliver individual measurements. Most wearables come with software that connects them to a smartphone or tablet, helping users visualize, share, and analyze their activity levels and habits. Thus, fitness trackers can help individuals monitor their health data by allowing them to set health goals and reminders [104].

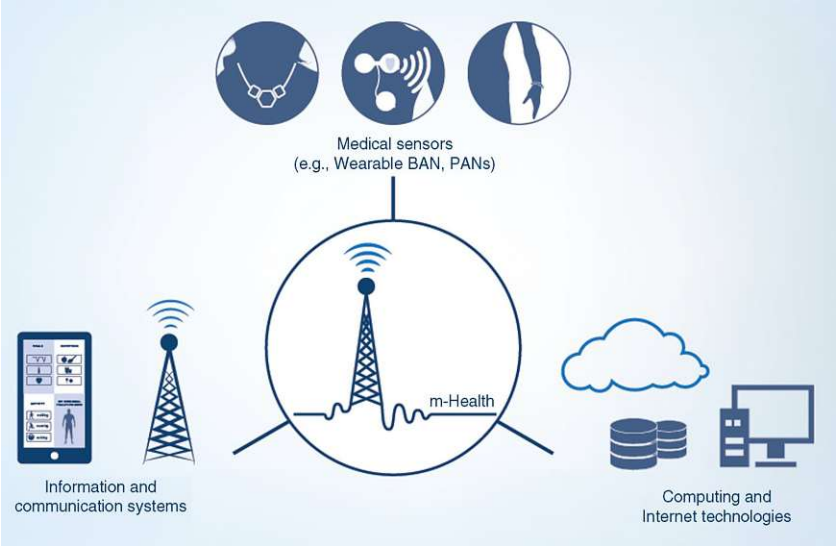


Figure 2.8: Building blocks of mHealth [103]

Another term commonly used within the mHealth domain is medical apps. Health and medical apps are often used interchangeably but do not necessarily mean the same thing [108]. Maaß et al. concluded that according to the literature, medical apps are considered a subset of health apps. They both utilize similar technological functions and devices. However, medical apps are specifically designed for clinical and medical purposes and are subject to legal regulation as mobile medical devices. In contrast, health apps do not have a specific legal classification [108].

More than 20 million people in Germany use health and medical apps, as stated by the "ePatient Survey" from 2020 [109]. Currently, in Germany, there are three distinctive kinds of mHealth Apps [110]:

- Lifestyle Apps (e.g., fitness tracker, nutrition apps)
- Service-oriented apps (e.g., medication tracker, vaccination status monitor)
- Medical apps (diagnosis and/or therapy-related, certified medical device)

Even though mobile health apps are becoming more and more popular, concerns about their quality and safety remain while government, clinicians, and health researchers are struggling to determine how to adequately evaluate the content and function of mobile health apps to guide consumers toward apps that will effectively and safely support their health [111].

One of the main concerns among users is security and data privacy. Since wearables capture large amounts of data that can be considered personal and sensitive in nature, the primary concern is that such significant quantities of data can easily be used to determine the identity of an individual when breached or compromised. Another concern is the reliability and accuracy of the collected data. For example, step count data can be underestimated or overestimated, and health readings can vary depending on the device. Other factors include battery life, ease and convenience of use, and device costs [104].

The European Union (EU) published the Medical Device Regulation (MDR) as regulation 2017/745 in May 2017. Medical device manufacturers in the EU must adhere to it. The scope of the MDR covers active implantable medical devices and a range of products without an intended medical purpose [112]. Germany passed the Digital Healthcare Act in 2019, which served as a "fast track" for regulatory and reimbursement possibilities for digital health applications in Germany [113]. DiGAs are defined as lower-risk medical devices. According to Europe's Medical Device Regulations, these fall into class I or IIa. DiGAs are applications that can be prescribed and are digital, CE-certified medical devices. They are being used in the fields of diabetes care, cardiology, logopedics, psychotherapy, and physical therapy. They are normally provided as mobile apps but can also be browser-based or PC software-based. They must prove that they positively impact health and must be approved by the "Bundesinstitut für Arzneimittel und Medizinprodukte" (BfArM). Since January 2023, it has been possible to extract care-relevant medical information from DiGAs into the national medical health record in Germany. The data entries can be achieved by using the "DiGA Toolkit" and "DiGA Device Toolkit" MIOs; see Section 3.6.2.

The mHealth domain is growing, and its importance is rising, but challenges remain. A study by Rathbone et al. [114] has shown that mHealth interventions for self-guided care using mobile apps and SMS messages can succeed. A total of 27 studies were analyzed and showed improved physical health and reduced anxiety, stress, and depression. Becker et al. [115] provide perspectives on the future of mHealth in their work. They identified several challenges, e.g., high attrition rates, the digital divide of society, and the intellectual capabilities of the users.

2.3 Serious Gaming and Gamification

Games, in general, can be defined as a specific form of playing behavior with characteristics such as rules and an identifiable outcome. For example, simply hitting a random target with a ball can be considered playing with a toy but not a game. For it being a game, it requires rules such as a precise definition of the target the ball must hit and points that are awarded when the described target was hit according to predefined rules, making it quantifiable who is in the lead, if the game is being played by more than one participant [16].

2.3.1 Definition of Terms

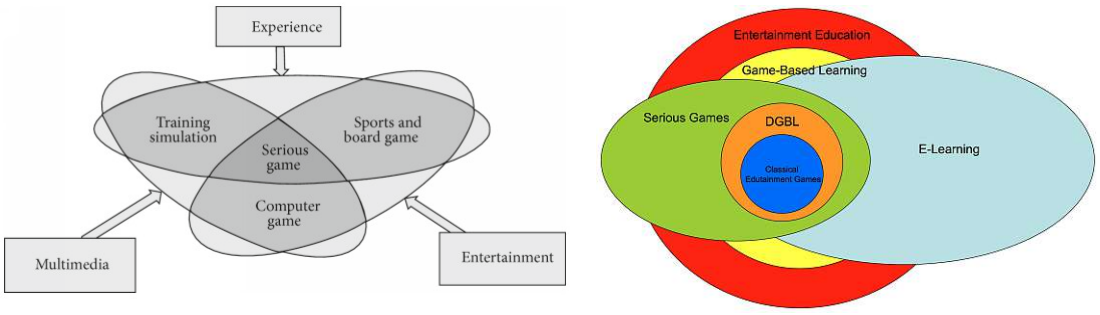
Serious games can be understood as games to entertain and achieve at least one additional goal. Doerner et al. [16] additionally define them as digital games, which are games that use some computing machinery, e.g., personal computers, smartphones, or video game consoles. The term can be used for non-digital games as well. Clark C. Abt, a US researcher who used games for training and education and was credited for initially defining the term serious game, provides examples like math-related games that could be used in schools [116]. Abt [117] defined serious games as games that have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement, which does not mean that serious games cannot be entertaining. Another example of a non-digital serious game is "The New Alexandria Simulation" by Jansiewicz, designed to teach the basics of the US political mechanisms [116].

Serious games are not of a particular game genre. They can be action-adventure, strategy, or sports games. The term serious game must also be distinguished from the term gamification. Gamification can be understood as transferring game methodologies or elements to non-game applications and processes, for example, badges, achievements, challenges, and rewards in fitness applications [16]. Often, serious games are intended for learning, but that is not the only possible characterizing goal. For example, "America's Army" is a serious first-person shooter game where the player controls a US Army soldier that is used as a recruitment tool for the United States Armed Forces [118], "Re-Mission" is a serious game for young cancer patients where the player has to fight cancer in the human body by controlling nanobots [119], "This Ware of Mine" is a war survival game where the player is in charge of a group of civilians and has to find resources to build facilities for shelters [120], "FoldIt" is an online puzzle game helped to decipher the crystal structure of the Mason-Pfizer monkey virus, an AIDS-causing virus [121], and "Minecraft Education Edition" is a special classroom version of the very popular sandbox game Minecraft that helps to build STEM skills, unleash player creativity and drive better problem-solving capability [122], [123].

Serious games can be divided into categories according to their characterizing goals and include lifestyle behavior change, medical diagnosis, enterprise management, decision support, development of social skills, analysis of causal mechanism, creation and defense of arguments, development of conflict resolution strategies, arousal of fantasy, the elevation

of civic engagement, promotion of ethical values, persuasion and recruitment to causes and campaigning in politics [16]. The motivation behind creating serious games and pursuing entertainment goals lies in the creator wanting to provide the users with fun experiences, increase user motivation, and reach users on an emotional level [16]. Laamarti et al. [124] defined three major components for serious games: experience, entertainment, and multimedia, as seen in Figure 2.9a.

A special form of serious games is exergames. These digital games combine exercise with gameplay and can improve health status and provide social and academic benefits, especially within the youth [125]. They can use mobility and technical abilities like Wi-Fi, GPS, audio, and smartphone cameras to create personalized and highly responsive user experiences without being constrained to consoles [126]. Playing exergames can increase caloric expenditure, heart rate, and coordination. It may also include psychosocial and cognitive impacts like increased self-esteem, social interaction, motivation, attention, and visual-spatial skills [127]. A popular example is "Pokemon Go." According to Khamzina et al. [125], the game was associated with a statistically significant but clinically modest increase in daily steps taken among players. Another example is "Zombies, Run!" which, according to Farič et al. [126], is the world's most popular running exergame app. It was released in 2012 and co-created with the novelist Naomi Alderman. It is an immersive post-apocalyptic audio augmented reality story where the player needs to collect supplies to build a base for remaining survivors [126].



(a) Definition of serious games [124]

(b) Relationships between serious games and other educational concepts [128]

Figure 2.9: Classification of serious games

Simulators can also be considered a subset of serious games due to their educational objectives. They are tools replicating real-world processes or systems for training or analysis, focusing on realism and fidelity to actual scenarios [129]. A popular example that had its first release in 1982 is "Microsoft Flight Simulator," which was designed to be a comprehensive simulation of civic aviation [122].

Despite Dörner et al. mentioning the many characterizing goals, serious games are traditionally closely related to learning. Figure 2.9b shows the relationships between serious gaming and other educational concepts. Entertainment education refers to

attempts to make learning enjoyable. Game-based learning can be understood as a subset of this, including using digital and non-digital games for learning and educational purposes. Serious games have application fields outside of education and learning; for example, serious games for health. Digital game-based learning (DGBL) is a serious game concept that incorporates education and learning as the main or sole purpose. Classical edutainment video games that experienced their beginning in the 1990s are one segment of DGBL [128].

Gamification was first used in 2008 and originated in the digital media industry. Deterding et al. [130] define it as using game design elements in non-game contexts. The goal of gamification is to use specific design features or motivational affordances of entertainment games in other systems to make engagement with them more motivating. Gamified systems typically include motivational features such as immediate feedback on success, ongoing progress updates, and goal-setting through various interface elements, including point scores, badges, levels, challenges, and competitions. They also provide relatedness support, social feedback, recognition, and comparisons through leaderboards, teams, and communication functions. Additionally, autonomy support is fostered by allowing users to customize their avatars and environments, choose their goals and activities, and follow narratives that offer emotional and value-based reasons for engaging in certain activities [131].

2.3.2 Serious Games Standards

The following section provides a brief introduction to standards for serious games in health and learning. It discusses the DIN norm on serious games and SCORM, a standard for learning games.

DIN Norm on Serious Games

The German Institute for Standardization (DIN) published a specification for serious game metadata in 2018 [132]. This specification aims to define a serious games metadata format that enables developers and publishers to describe their games in a standardized manner, allowing potential users to find them more easily. The structure of the format is hierarchical and can be extended. Currently, it defines three levels. Level 1 includes mandatory information about the game, such as the game ID, title, primary goal (including a description), abstract, keywords, genre, game modes, the language used, potential age restrictions, target user group, price, platform, and more. A complete list of all elements required for core Level 1 can be found in Table B.1 within the DIN specification [132].

Listing 2.1: DIN norm level 1 and 2 in Backus-Naur notation [132]

```
SG-MD: gameInfo useInfo distributionInfo technicalInfo
       involvedPartyInfo qualityInfo? metadataInfo
       otherInfo? overallScore?
```

Level 2 introduces additional optional information. Examples include a subtitle of the game, alternative titles, further goals, the source of a keyword, censorship details, and other relevant information. An overview of the first two levels in Backus-Naur notation can be found in the code listing 2.1 [132].

The final third level represents the application profiles that contain domain-specific content. The specification includes two exemplary domains: serious games for learning and serious games for health. Examples of level 3 data elements for health games include information about health topics and diseases for which the game was developed, programs and guidelines related to therapy plans (e.g., American College of Sports Medicine guidelines for exercise training), health-related devices, legal information regarding the use of the game as a medical device, and many more. Example elements for the application profile on learning games include gameplay elements, information about the curriculum and competency model, game genre, type, classifications, and ESRB ratings [132].

SCORM

SCORM is a standard that can be utilized with learning games. The "Sharable Content Object Reference Model" describes a method for delivering eLearning content across multiple platforms. Its key components include the Content Aggregation Model (CAM), which establishes a framework for packaging learning content, and the RTE (Run Time Environment), which specifies an interface to facilitate communication between the learning content and the system that initiates it [133].

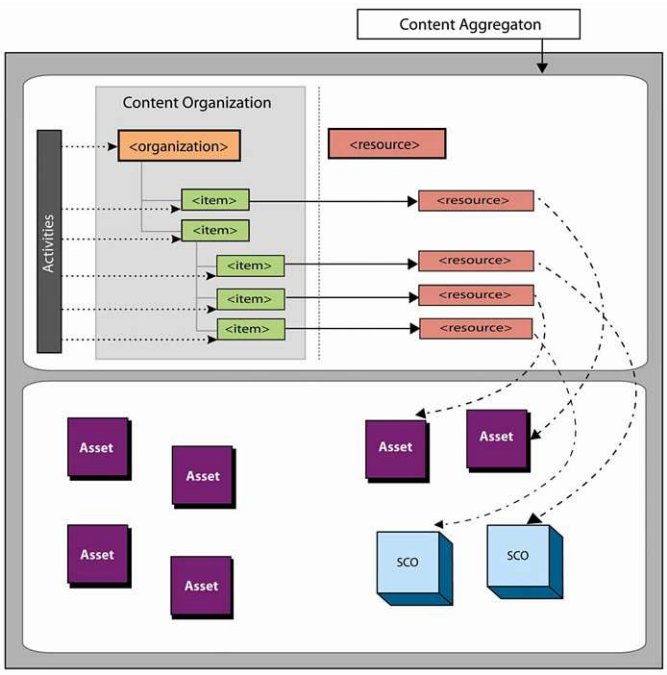


Figure 2.10: Conceptual illustration of content aggregation [134]

The CAM describes the SCORM components that can be used to build learning experiences from learning resources and also defines how the resources are aggregated and organized into higher-level units of instruction. The CAM is made up of assets, shareable content objects, activities, content organization, and content aggregations. Assets are the basic building blocks of learning resources such as text, images, sound, assessment objects, or any other data element that can be rendered by web clients and presented to a learner. A sharable content object (SCO) can be understood as a collection of one or more assets that describe a single learning resource. Activities are meaningful units of instruction that may provide a sharable content object or asset or may be composed of several sub-activities. Content organizations are representations or maps that define the intended use of content through organized units of instruction. Content aggregation can be used as both an action and a way of describing conceptual entities. It can describe the action or process of composing a set of functionally related content objects so that the set can be applied in a learning experience. Figure 2.10 shows the concept of content aggregation within the SCORM standard [134].

The SCORM run-time environment (RTE) is responsible for launching content objects, establishing communication between the learning management system and sharable content objects, and managing the tracking information that can be communicated between them [135].

2.4 Psychology Theories and Behavior Change

The following section discusses psychological models and theories, categorizing them into motivation, action, and organizational theories. It also provides an overview of behavior change models and techniques.

2.4.1 Models and Theories

According to Michie et al. [136], three broad groups of psychology theories are relevant to the field of behavior change. These are the motivation theories, the action theories, and the organization theories.

Motivation theories

Motivation theories mostly explain the behavior of people who are not in a state where they intend to change something about their behavior [136]. An example is the Self-Determination Theory (SDT), introduced by Deci and Ryan in 1985 and evolved from intrinsic and extrinsic motivation studies. It defines three psychological needs as the basis of intrinsic motivation and behavior: autonomy, the need to control the course of a person's life; competence, the need to be effective in dealing with the environment; and relatedness, the need to have close, affectionate relationships with others [137].

Another example is the social cognitive theory from Albert Bandura, who is also known for his work on observational learning, self-efficacy, and reciprocal determinism [138]. It

emphasizes the learning that occurs within social contexts. People are viewed as active agents who can both influence and are influenced by their environment. This theory further states that we learn new behaviors by observing the behavior of others and the consequences of their behavior. If the behavior is rewarded, we are likely to imitate it [138].

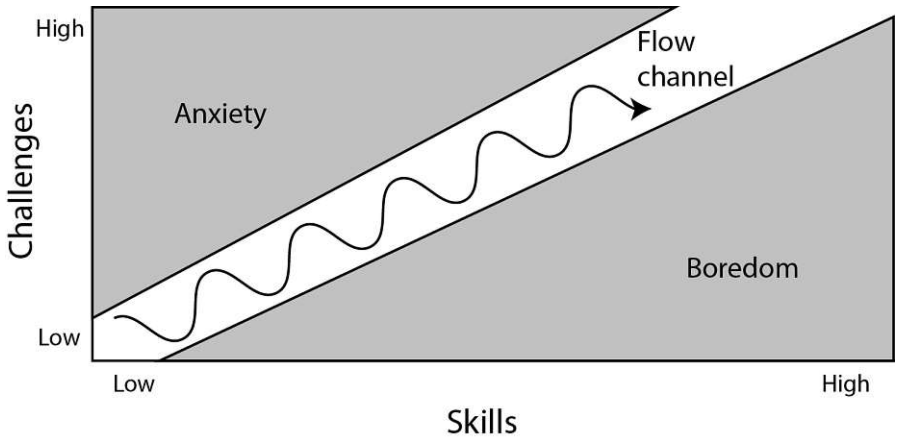


Figure 2.11: Flow theory [139]

Another important theory is the flow theory. Proposed by Csikszentmihalyi, it is a psychological concept that describes the state of optimal experience when individuals are fully immersed in an activity for its own sake. This flow state is characterized by a complete concentration on the task, a feeling of oneness with the activity, and a loss of self-consciousness and a feeling of calmness and serenity [140]. The key dimensions that characterize the flow experience include challenge-skill balance, clear goals, immediate feedback, intense concentration, the merging of action and awareness, perception of control, altered perception of time, intrinsic reward, and loss of self-consciousness [141]. Flow theory should be regarded when designing games since it is essential for players to enjoy games continuously. According to Schell [139], key components to create activities that put players into a flow state are clear goals, no distractions, direct feedback, and persistent challenges. Flow activities must stay in the narrow margin of challenge between boredom and frustration; see Figure 2.11.

Action theories

Action theories mostly explain the behavior of people who decided to act on a particular behavior or identified a need to change [136]. An example is the transtheoretical model of change (TTM) introduced by Prochaska and DiClemente in 1984. It defines five stages of change [142]:

- Pre-contemplation, meaning the person has no intention to take action within the next six months.

- Contemplation, meaning the person intends to take action within the next six months.
- Preparation, meaning an intention to take action soon.
- Action, being within the first six months of the changed behavior.
- Maintenance, changed behavior for more than six months.

A sixth stage was added later called Termination, meaning the person has no temptation to relapse and 100% confidence.

Organizational theories

Organizational theories mostly explain behavior change at higher-order social and systems levels instead of the level of the individual. Examples include the demand-control model, diffusion theory, group theory, and goal theory [136].

Habits

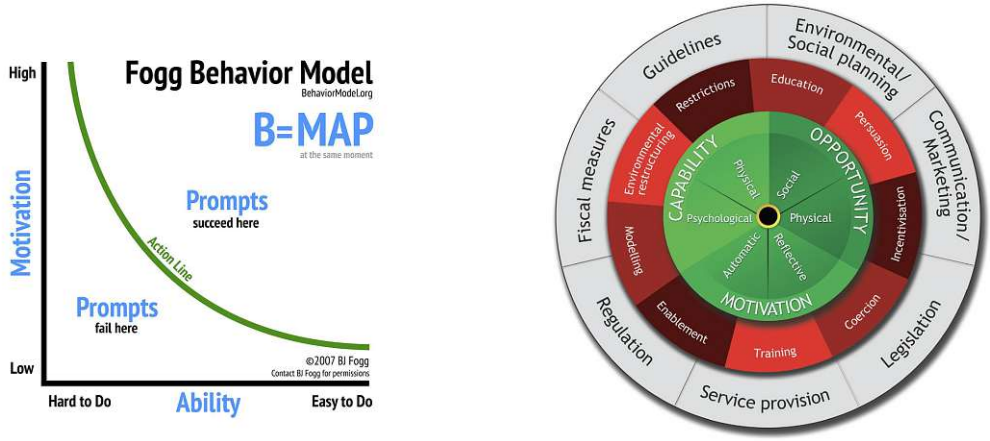
Habits can be defined as settled or regular practices that are hard to give up and are an automatic reaction to a specific situation. The stimulus-response habit can be understood as a fundamental mechanism underpinning instrumental or purposeful behavior. Through repetition and learning, environmental stimuli automatically prompt responses initially made spontaneously by a subject [143].

The Fogg Behavior Model by BJ Fogg, also called the "B=MAP" model, considers that there are three key factors that need to be present for any behavior (B) to occur: motivation (M), ability (A), and prompts (P). If these three elements are present at any given time, the person is pushed above the defined threshold for the action to do the behavior. This observation means that if the motivation is high enough, people will overcome barriers to performing a certain behavior. In contrast, if the ability is high enough or the behavior is very easy, people will perform the behavior even if motivation is low [144], see Figure 2.12a.

2.4.2 Behavior Change Model

Behavior Change Techniques

Behavior change techniques (BCTs) are systematic procedures included as active components of interventions designed to change behavior. A BCT is an observable, replicable entity specified by an active verb and clarity about the desired behavior change with enough detail to achieve good agreement between experts and the smallest component of an intervention designed to change a certain behavior. It can be used alone or in combination with other BCTs [20].



(a) The Fogg behavior model [145] (b) Behavior change wheel [146]

Figure 2.12: Overview of behavior models

Michi et al. [21] defined a comprehensive taxonomy of behavior change techniques that includes 93 techniques that were hierarchically clustered into 16 groups. These are goals and planning, feedback and monitoring, social support, shaping knowledge, natural consequences, comparison of behavior, associations, repetition and substitution, comparison of outcomes, reward and threat, regulation, antecedents, identity, scheduled consequences, self-belief, and covert learning.

Behavior Change Wheel

The Behavior change wheel by Michie et al. [146] was developed from 19 frameworks of behavior change identified in a systematic literature review and is based on the COM-B model. The COM-B model can be used to identify what needs to change. It stands for "Capability Opportunity Motivation - Behavior." It can be considered the starting point for the behavior change wheel to understand behavior in the context in which it occurs. For a behavior to occur, there must be "capability" to do it, "opportunity" for the behavior to occur in terms of a conducive physical and social environment, and there must be sufficient strong "motivation." Each component of the COM-B model can be divided into two types. Capability can either be physical or psychological to perform the behavior. Opportunity can be physical or social. Motivation can be reflective or automatic. These are indicated by the green inner layer of the wheel; see Figure 2.12b. The second red layer describes the nine intervention functions, which are broad categories of means by which an intervention can change behavior. These are education, persuasion, incentivization, coercion, training, restriction, environmental restructuring, modeling, and enablement. The behavior change wheel maps the COM-B targets to these intervention types. The outer grey layers depict seven policy categories representing the decisions made by authorities that help to support and enact the interventions. These are communication/marketing, guidelines, fiscal, regulation, legislation, environmental/social

planning, and service provision. Within the wheel, the intervention types are mapped to these policy options [146].

2.5 Semantic Interoperability

Interoperability refers to the ability of diverse systems and organizations to work together to exchange and use information. Two types of interoperability can be defined: Syntactic interoperability is given if two or more systems can communicate and exchange data using the same data formats and protocols. On the other hand, semantic interoperability describes the ability to automatically interpret information that is exchanged meaningfully and accurately to produce useful results for users. Both communication partners must defer to a common information exchange reference model to achieve semantic interoperability. The context of the information exchange requests must be unambiguously defined, meaning what is sent is the same as what is understood [147]. Semantic interoperability is especially important in health informatics due to its complexity, frequent variation and evolution, and the differences between the information technologies and the health domain [148]. Figure 2.13 shows how the cardiological concept "Tetralogy of Fallot" can be transmitted meaningfully from one clinician to another. Between healthcare systems, interoperability is more about conversations than the pure transmission of messages [147]. Interoperability in healthcare is needed at the level of user interface, user experience, provider and patient experience, and engagement [147].

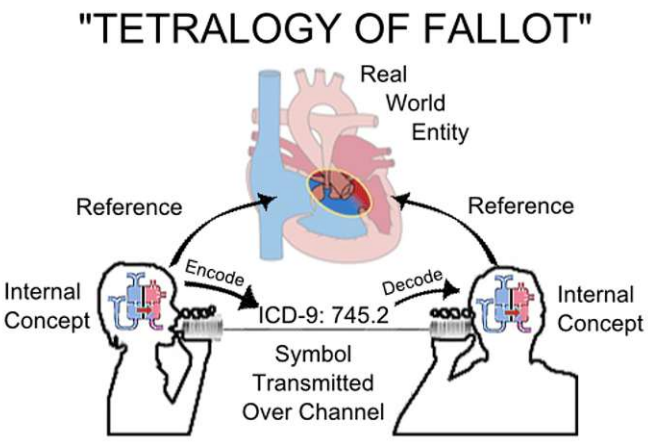


Figure 2.13: Semantic interoperability [147]

2.5.1 Standards For the Exchange of Medical Data

Many standards from different institutions are available for the exchange of medical data. Some only define exchange formats, while others describe full specifications of electronic health records. This section features standards from HL7 International, Integrating

the Healthcare Enterprise (IHE), openEHR International, SNOMED International, and Regenstrief Institute.

HL7 Standards

HL7 International is a nonprofit standards organization based in the USA, although many countries have local centers of competence, for example, in Austria, "HL7 Austria," and in Germany, "HL7 Deutschland." The most well-known standards are: HL7v2.x, HL7v3 RIM, HL7 CDA, and HL7 FHIR.

HL7 v2.x The HL7 standard version 2 is able to transfer structured messages between healthcare applications. It is still one of the most important and widely-used HL7 standards in the world and has been continuously developed since 1988. The current version from 2019 is HL7 V2.9. Version 2.5 was also published as an ISO standard (ISO/HL7 27931:2009) in 2009 [149].

HL7 v2 messages are usually sent in response to trigger events. The name of the message is derived from the message type and trigger event; for example, all patient administration messages are of type "ADT," which stands for "admission, discharge, transfer" [150]. The message format was defined by HL7 International and contains different segments separated into fixed fields with separators. The standard also defines the meaning of each field. Alternatively, V2.x messages can be encoded in a tagged format based on XML [149].

Field, component, and sub-component separators indicate boundaries between elements. The carriage return <CR> character with an American Standard Code for Information Interchange(ASCII) decimal value of 13 is used for segment separation. The field separator, the vertical bar character (|), is always the fourth character of each segment. Two adjacent field separators (||) indicate an empty field. For the component separator character, the caret symbol (^) and for the subcomponent separator, the ampersand (&) symbol is being used. The repetition separator, the tilde character (~), is used to separate the first occurrence or repetition of a field from the second occurrence [150].

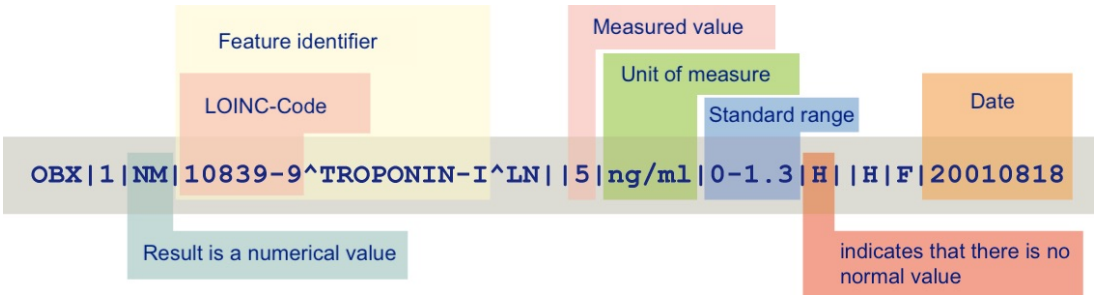


Figure 2.14: HL7 v.2x message (translated by the author) [151]

Figure 2.14 shows an example of an HL7 v2.x message with distinct segments differently colored and described. Common segments found in HL7 v2 messages include the message

header (MSH), event type (EVN), patient identification details (PID), patient visit (PV1), request and specimen details (OBR), result details (OBX) and Z-segments. HL7 v2 allows users to develop their own segments, message types, and trigger events using names beginning with the letter Z, thus called Z-segments. Z-segments are widely used and can be placed anywhere in an HL7 v2 message. They can be considered the main reason why there are so many different variants of HL7 v2 messages [150].

Data types in HL7 v2 are separated into simple and complex data types and are the basic building blocks for content. Every field, component, and subcomponent in HL7 v2 has a defined data type. Simple data types include date (DT), date and time (DTM), timestamp (TS), formatted text (FT), ID representing a value from an HL7-defined table, IS representing a value from a user-defined table, numeric (NM), set id (SI), string (ST), and text (TX). Complex data types are used to handle items such as codes and identifiers, names and addresses, and other complex data types.

HL7 v3 HL7 Version 3 is a family of formal standards for exchanging medical data that was planned to be the successor of HL7 Version 2. The foundation for creating messages is a generic and consistent data model, the Reference Information Model (RIM), also published as ISO standard ISO/HL7 21731:2006. The RIM specifies the grammar of V3 messages and the basic building blocks of the language, their permitted relationships, and datatypes. It was conceived as a universal reference model for healthcare interoperability that should cover the entire healthcare domain. Messages and documents are implemented in XML. The RIM defines a set of predefined attributes with a specified datatype for each class that are the only ones allowed for messages. These attributes and datatypes become elements and attributes in HL7 v3 XML messages [150].

The RIM consists of four base classes: "Act" to model the action as part of a medical treatment or encounter; "Entity" for persons, organizations, and places; "Role" for patients, doctors, and related persons; and "Participation" to model the participation of an activity. There are two further classes: "RoleLink" relationship, e.g., patient-clinical, and "ActRelationship," documenting the relationship between treatments [152]. Figure 2.15 gives an overview of the base and subclasses [150].

The "Act" class represents a record of something that has occurred or will occur. Acts can be related to each other via the "ActRelationship" class. A full representation of an "Act" includes identifying the kind of the act, what happens, the actor who performs it, and the objects or subjects, for example, a patient, that the act affects. Additional information like location, time, manner, reasons, and motives can be provided for an "Act." Important "Act" specializations are Observation, Procedure, Substance, Administration, Supply, and PatientEncounter; see Figure 2.15 [150].

The "Entity" class is the second main backbone class of the RIM and represents any living or non-living thing. It can also represent a group of things, a category, or a kind of thing. The "Entity" class has four main specializations: LivingSubject, Material, Place, and Organisation, see Figure 2.15 [150].

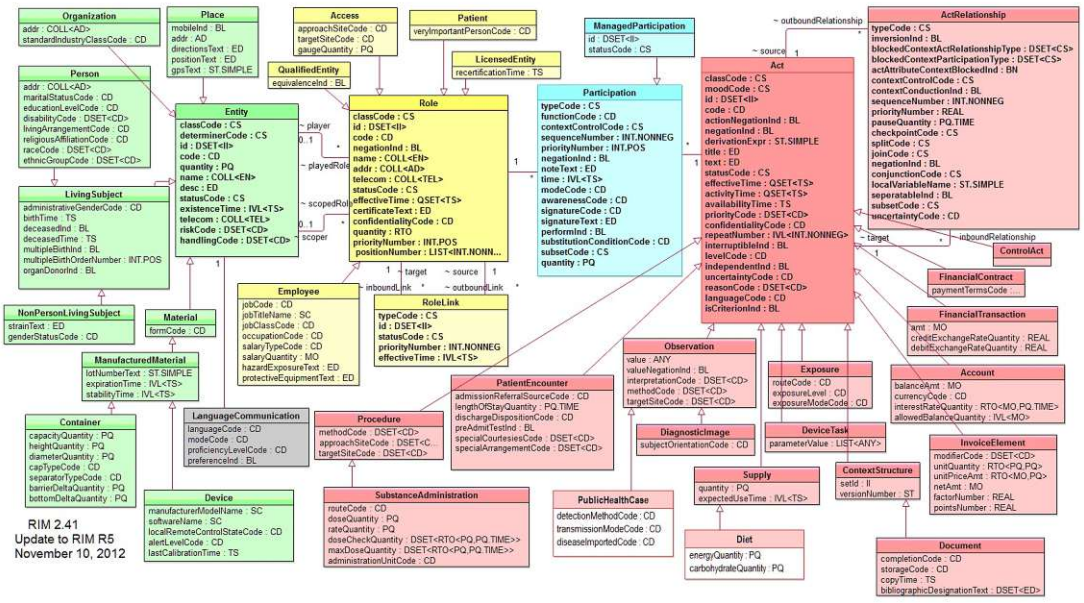


Figure 2.15: HL7v3 RIM normative content [150]

The "Role" class, the third main backbone class of RIM, can be defined as the competency of an "Entity" that plays a "Role." There are a wide variety of roles, including people such as patients, practitioners, employees, places such as hospitals, homes, clinics, or places of birth, organizations such as care providers, employers or suppliers, things such as drugs, instruments, or computer systems and responsible entities such as parent, employer or manufacturer, see Figure 2.15. A simple way of linking roles, such as between jobs in an organization or medical team members, is achieved with the "RoleLink" class [150].

HL7 v3 has multiple supported datatypes. Basic datatypes include boolean (BL), binary (BIN), string (ST), encapsulated data (ED), integer (INT), real number (REAL), physical quantity (PQ), and money (MO). Furthermore, HL7 v3 supports instance identifiers (UUIDs and OID-based identifiers), coded datatypes, dates and times, names and addresses, generic collections like sets or lists, and special fields [150].

Even though the development of the RIM and its related specifications was an enormous effort, and as an informatics standard, it served its purpose, it failed as a construct for producing standards that developed into an engineering success, ultimately leading to the demise of the v3 specification framework. Nevertheless, the RIM specification does hold practical value as the underlying framework for the HL7 CDA standard [150].

HL7 CDA HL7 Clinical Document Architecture (CDA) is a significant standard within the domain of medical informatics. It can be used to define and exchange clinical documents, such as hospital discharge letters. A document can be understood as a distinct stand-alone artifact to convey human understanding with each document,

including metadata stating the contextual details. HL7 CDA is very widely used, for example, in the Austrian national health record system (ELGA). CDA uses XML for the representation of the document and defines three levels [150]:

- CDA Level 1 has a header that contains basic metadata and a human-readable body, for example, a PDF document, a JPEG image, or a text document.
- CDA Level 2 allows the body to be either an unstructured binary object or one or more structured sections. Each section contains an XML markup part serving as the narrative block.
- CDA Level 3 allows each section to include machine-processed entries encoded as HL7 v3 clinical statements at almost any level of granularity

The CDA header is a common element to all three levels. Its primary purpose is to provide structured metadata about the document that can be used in document registers and databases to classify, find, and retrieve documents. The root class of all CDA documents is a HL7 v3 Act called "ClinicalDocument." Every document has at least three participations: patient, author, and steward, denoting the organization that keeps a permanent copy of the record [150].

The CDA body can, according to the three levels defined, either contain a non-XML body or a structured body. Nonstructured bodies may contain any human-readable data, including text or images. Structured bodies contain one or more sections. Each section contains a human-readable narrative block that should accurately convey the meaning of that particular section. A section can contain any number of entries that are called clinical statements. A clinical statement can be defined as an expression of a discrete item of clinical information recorded because of its relevance to patient care. It may have several participants, including subject, author, location, performer, participant, and informer. A clinical statement can be one of the following specializations [150]:

- Observation: Covers a broad range of statements related to history, examination, test, diagnosis, and prognosis.
- Procedure: May refer to specimens or images and is also used for surgical procedures.
- Encounter: Covers most administrative procedures involving an interaction between patients and healthcare providers.
- Substance Administration: Refers to products such as medication mainly used for prescribing and administering drugs.
- Supply: This is mainly used for dispensing drugs or other medical supplies.
- Organizer: This is a specialization of the Act class designed to support grouping information into clusters.

- Act: Can be used as a generic class if no other specializations apply.

CDA templates can constrain the use of CDA documents. A CDA template is an expression of a set of rules that apply additional restrictions to a portion of an instance of data. Templates allow rules to be applied to all or any part of a CDA document, including roles, sections, and entries. CDA templates have a template ID and a set of metadata to describe the purpose and use, and they may be stored in repositories. The metadata includes a globally unique identifier, name, description, version, an ID of the model from which it is derived, the RIM version, and publication details. Currently, most CDA templates have been implemented in Schematron and are used primarily for validating CDA document instances [150].

HL7 FHIR A relatively new standard that leverages current web technologies and tries to combine the preceding standards HL7 v2, HL7 v3, and HL7 CDA is HL7 Fast Healthcare Interoperability Resources (FHIR) [153]. FHIR defines a set of modular components called resources for exchanging medical data. These can be assembled into working systems that solve real-world clinical and administrative problems. The standard is suitable for mobile phone apps, cloud communication, electronic health record-based data sharing, and server communication on large institutional healthcare providers. The standard also defines an API that implementers can use by supporting RESTful architectures. A FHIR resource can be represented in XML or JSON format and can be created, read, updated, or deleted via HTTP web service endpoints [154].

Figure 2.16 shows an example of a FHIR patient resource. The FHIR standard has defined resources for administrative content and a wide variety of clinical concepts. A resource has an identity (a URL) by which it can be addressed, a type, a defined set of data as described by the definition of the resource type, and a version that changes if the contents of the resource change. The content of a resource is a set of elements that have either primitive values or child elements, defined in a strict hierarchy. Some elements may have more than one datatype depending on the type of data that applies. The main categories are "Foundation," "Base," "Clinical," "Financial," and "Specialized." A key feature of resources is that they can refer to other resources; for example, a "Condition" resource can reference an "Observation" resource as evidence for the diagnosis. Every resource includes a human displayable form called the narrative, an idea carried over from the HL7 CDA standard and technically a limited form of HTML. The FHIR specification defines two kinds of datatypes for FHIR resources: primitive datatypes and complex datatypes. Primitive datatypes are base datatypes like Boolean, Integer, String, Decimal, Instant, DateTime, and many others from which everything else is built. Complex datatypes are reusable assemblies of elements that represent common patterns encountered in more than one place in the specification, for example, "HumanName," "Address," or "CodeableConcept" [150].

HL7 FHIR allows the standard to be adapted to specific needs. Any element in a FHIR resource can carry one or more extension elements in addition to the normal content.


```
<Patient xmlns="http://hl7.org/fhir">
  <id value="glossy"/>
  <meta>
    <lastUpdated value="2014-11-13T11:41:00+11:00"/>
  </meta>
  <text>
    <status value="generated"/>
    <div xmlns="http://www.w3.org/1999/xhtml">
      <p>Henry Levin the 7th</p>
      <p>MRN: 123456. Male, 24-Sept 1932</p>
    </div>
  </text>
  <extension url="http://example.org/StructureDefinition/trials">
    <valueCode value="renal"/>
  </extension>
  <identifier>
    <use value="usual"/>
    <type>
      <coding>
        <system value="http://hl7.org/fhir/v2/0203"/>
        <code value="MR"/>
      </coding>
    </type>
    <system value="http://www.goodhealth.org/identifiers/mrn"/>
    <value value="123456"/>
  </identifier>
  <active value="true"/>
  <name>
    <family value="Levin"/>
    <given value="Henry"/>
    <suffix value="The 7th"/>
  </name>
  <gender value="male"/>
  <birthDate value="1932-09-24"/>
  <careProvider>
    <reference value="Organization/2"/>
    <display value="Good Health Clinic"/>
  </careProvider>
</Patient>
```

Figure 2.16: An example of a FHIR Patient resource [154]

A basic extension is a pair comprising a URL element that identifies the extension and a value. Anyone can define and publish extensions independently but is encouraged to use a central registry to find existing extensions rather than define their own. The base FHIR specification describes a set of resources that can be modified with FHIR profiles. A FHIR profile allows one to extend, restrict, and change the cardinality of attributes within a given resource. A set of profiles, extensions, value sets, and code systems can be understood as a FHIR implementation guide [150], [155].

2.5.2 Terminologies

The following section covers the most important medical terminologies: LOINC, primarily used for laboratory values, and SNOMED CT, which is considered the most comprehensive medical terminology currently available.

LOINC

Logical Observation Identifiers Names and Codes (LOINC) is a set of identifiers, names, and codes for identifying health measurements, observations, and documents developed and maintained by the Regenstrief Institute, a US nonprofit medical research organization.

LOINC is used for laboratory values and clinical observations. The current version is 2.78, released in 2024, and contains 104.054 terms [156]. LOINC codes distinguish a given observation across six dimensions, called LOINC parts [157]:

- Component (Analyte): The substance or entity being measured or observed.
- Property: The characteristic or attribute of the analyte.
- Time: The interval over which an observation was made.
- System (Specimen): The specimen or thing upon which the observation was made.
- Scale: Defines how the observation value is quantified - quantitative, ordinal, or nominal.
- Method: A high-level classification of how the observation was made. This part is optional.

LOINC codes currently have a length of 3 to 7 characters. The last digit is a check digit, always preceded by a hyphen [157].

LOINC names are always unique. Each code has three names: the fully specified name (FSN), which is used in mapping; the long common name (LCN), which is the primary display name and is, therefore, more clinician-friendly than the FSN; and a short name which is less than 40 characters long and can be used for example as a column header [150].

SNOMED CT

Systematized Nomenclature of Medicine Clinical Terms (SNOMED CT) is considered to be the most comprehensive, multilingual clinical healthcare terminology in the world published by the International Health Terminology Standards Development Organisation (IHTSDO) trading as SNOMED International and based in London, UK. It can be used to retrieve and analyze clinical data, clinical documentation, and reporting. It has more than 350.000 active concepts, about one million English descriptions, and more than 1.4 million relationships as part of the January 2020 release. It is much more comprehensive than other medical terminologies. For example, the International Classification of Diseases 11th Revision (ICD-11), which is considered a global standard for diagnostic health information used by the WHO primarily for mortality and morbidity statistics, currently has only over 100.000 medical diagnostic index terms [158].

SNOMED CT is a coding scheme used to identify concepts and terms and a multidimensional classification, enabling concepts to be related to each other, grouped, and analyzed according to different criteria. The SNOMED CT identifier (SCTID) is used to identify one of the three core building blocks: concepts, descriptions, and relationships. The SCTID is an integer between 6 and 18 digits long, and its internal structure includes an

item identifier that is between 3 and 8 digits long, a 7-digit namespace identifier which is only used in extensions, a 2-digit partition identifier, and a single check-digit [150].

Concepts Concepts represent clinical thoughts organized from the general to the more detailed within every hierarchy. These hierarchies allow detailed clinical data to be recorded and later accessed or aggregated at a more general level [159].

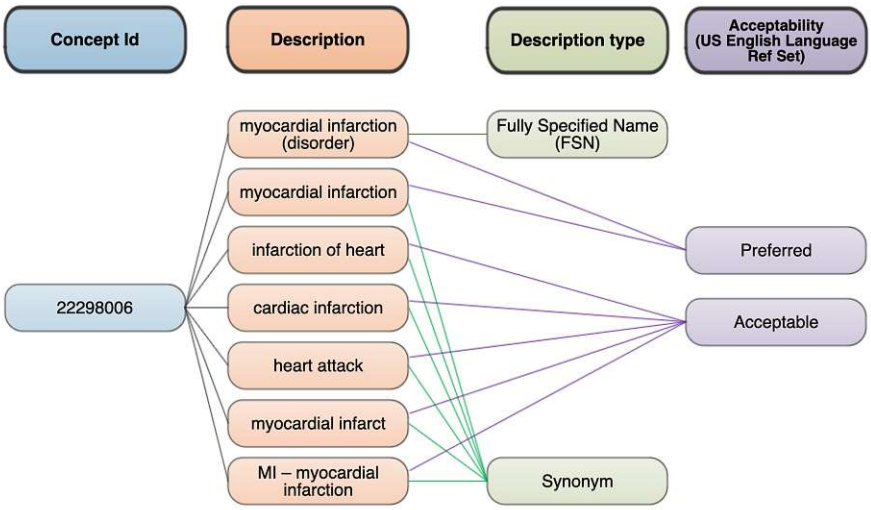


Figure 2.17: SNOMED CT example of descriptions for a single concept [160]

Descriptions Every SNOMED CT concept is assigned a set of textual descriptions. These provide human-readable forms for every concept. Two types of descriptions represent every concept: the Fully Specified Name (FSN) and synonyms. Each concept has one synonym marked as "preferred." Other synonyms can be marked as "acceptable." Figure 2.17 gives an overview of the descriptions used for the single concept "Myocardial Infarction" with SCTID 22298006. This concept has multiple names, two of which are tagged as preferred within the US English language set. "Myocardial infarction (disorder)" is considered to be the FSN [160].

Relationships Relationships represent associations between two concepts. They are used to logically define a concept's meaning in a way computers can process. The relationship type represents the meaning of the association between the source and destination concepts. An example is the "is a" relationship type that is used within the hierarchies of SNOMED CT [160].

Hierachies Concepts are explicitly related by subtype relationships to parent concepts immediately above them, forming hierarchies. A particular concept may have parents, ancestors, as well as children and descendants. SNOMED CT has about 19 top-level

hierarchies, which descend from a single root concept, "SNOMED CT concept," with the code 138875005. SNOMED CT hierarchies fall into three main groups: object hierarchies, which mainly comprise concepts that are likely to be qualified; value hierarchies, which are concepts that act as values in object-attribute-value triples; and a miscellaneous group.

2.5.3 Standards For Electronic Health Records and Best-Practices

This subsection discusses openEHR, a comprehensive standard for electronic health records, and the IHE initiative for best practices in health informatics.

openEHR

openEHR is a nonprofit organization that has developed a technology-independent dual model architecture, including a reference model, archetypes, and templates. openEHR consists of a technical standard for an EHR platform and domain-developed clinical models to define content. The concept includes a lifelong, patient-centric shared health record, data, and clinical process support [161]. Key aspects of the openEHR standards are the clinical data repository and the two-level information modeling [150].

Clinical Data Repository The Clinical Data Repository (CDR) can be understood as a standards-based healthcare information datastore that abstracts the physical architecture behind a standard API that is based in a core reference model architecture and associated querying syntax [150].

Two-Level Information Modelling The information model definition in openEHR is split into a reference model that includes datatypes, basic structures, and generic architectural concepts. Some concepts are also shared with the ISO 13606-1 Electronic Health Record Communication standard, although details differ. The reference model does not define healthcare domain concepts. They are defined by a separate technical layer known as archetypes and templates. Archetypes are detailed health information models shaped as constraints on the reference model. Templates can be used in clinical records. They aggregate the archetypes required to underpin a clinical interaction and constrain the included archetypes to just the data elements required for a particular situation. Archetypes and templates are created, shared, and published using custom tooling, separately from the reference model [150].

IHE

Integrating the Healthcare Enterprise (IHE) is an initiative by healthcare professionals and the industry to improve the way computer systems in healthcare exchange and share information. It was established in 1999 by the Healthcare Information Systems and Management Society (HIMSS) and the Radiological Society of North America (RSNA). They use existing standards, for example, from HL7, to form best practices. The starting

point was radiology, with a clear overlap of standards. A big part of IHE has also been the development of IT infrastructure standards for use across departmental and institutional boundaries [150].

IHE is classified into two major domains: clinical and operational domains. Users with clinical and operational experience identify integration and information priorities within each domain. Vendors develop standards-based solutions to address those priorities. The profiles in each domain are developed and documented by a technical committee. The main artifact for each domain is the technical framework documentation. Currently, the following IHE domains are addressed: IT Infrastructure, Patient Care Coordination, Radiology, Radiation Oncology, Cardiology, Dental, Devices, Endoscopy, Pathology and Laboratory Medicine, Pharmacy, Quality, Research and Public Health, and Eye Care [162].

An important part of IHE's work has been the development of IT infrastructure standards for use across departmental and institutional boundaries [150]. The XDS (Cross-Enterprise Document Sharing) profile is widely used within many national health record systems such as the ELGA, the Austrian national health record, ePA, the national health record in Germany or eFA an electronic case record system for clinicians in Germany.

IHE XDS offers a distributed collaborative approach to sharing clinical documents from different healthcare organizations based on standardized metadata. Portals based in XDS have a central registry, the XDS document registry, with one or multiple repositories, the XDS document repositories, which may be physically or logically separate. The registry contains standardized metadata describing the content of each item, whereas the repository can contain any electronic content. XDS is the core specification linked to other IHE specifications and profiles. The basic XDS profile has been refined to support special requirements for DICOM images (XDS-I), HL7 CDA medical summaries (XDS-MS), and structured laboratory reports (XDS-Lab). Other important IHE profiles that are linked to XDS cover point-to-point transmission (XDM - Cross-Enterprise Document Media Interchange and XDR - Cross-Enterprise Document Reliable Interchange), patient identity management (PIX - Patient Identity Cross-Referencing and PDQ - Patient Demographics Query), information retrieval (DSUB - Document Metadata Subscription and MPQ - Multi-Patient Queries) and several security profiles. [150].

2.6 Requirement Engineering

This section provides a basic overview of the requirement engineering methods used for the concepts described in this thesis. Requirement Engineering (RE) can be described as a coordinated set of activities for exploring, evaluating, documenting, consolidating, revising, and adapting the objectives, capabilities, qualities, constraints, and assumptions that a system to be designed should meet based on problems raised by a current system and opportunities provided by novel technologies [163]. Lamsweerde [163] defines three dimensions of RE, the "Why," "What," and the Who," see Figure 2.18. The "Why" dimension is concerned with the definition of objectives the new system should achieve.

The "What" dimension focuses on the functional services that the system being designed should provide to meet those objectives. Finally, the "Who" dimension addresses the assignment of responsibilities to stakeholders for achieving the objectives, services, and constraints among the many components of the system to be designed.

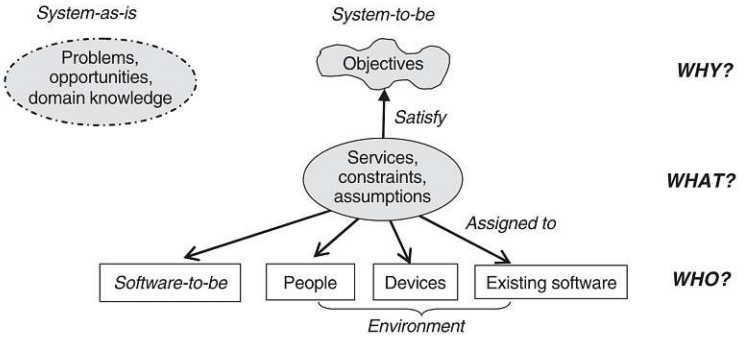


Figure 2.18: Three dimensions of requirements engineering [163]

2.6.1 Defintion of Requirements

Requirements are the foundation of every software product. They serve as basic building blocks for the design, development, validation, and verification of software. The quality of requirements is crucial, as inconsistencies are a common problem in software development. According to the IEEE Standard 610.12, a requirement can be understood as a condition or capability needed by a user to solve a problem or achieve an objective [164]. Requirements can range from an abstract description of a service to a detailed functional specification and are usually not stable, often changing throughout the process. Software projects must have a vision and a scope that define the primary use of the system [165]. The main source of requirements is the stakeholders, who can be defined as all individuals involved with an interest in the respective software project [165]. Additional sources for requirements may include standards, norms, laws, privacy concerns, security considerations, functionalities of alternative systems, and even hidden rules. Requirements can be separated into functional, non-functional, and domain requirements [165].

2.6.2 Requirement Modeling

Modeling languages are essential in the process of requirement analysis. The most relevant language at present is the Unified Modeling Language (UML). It is a general-purpose visual language that consists of various diagrams that cover different views of the system that need to be designed. Domain-specific modeling languages can be used for requirement modeling within distinct application areas in addition to UML. UML was developed by the "Object Management Group" and defines two principal types of diagram models: behavioral and structural models. Examples of behavioral model diagrams include the use case diagram, the activity diagram, and the sequence diagram. Examples of structural

model diagrams are the class diagram, the package diagram, the component, and the deployment diagram [165].

2.6.3 Requirement Analysis

According to IEEE Standard 610.12, requirement analysis can be defined as the process of studying user needs to arrive at a definition of system, hardware, or software requirements [164]. It is the process of inferring actual requirements for a system. Different methods can be used to analyze requirements, such as nonstructured methods by using natural language, semi-structured methods that restrict natural language vocabulary and define additional properties, or fully structured methods that follow a specific syntax, notation, or formal specifications. Common methods include the concepts of "Use Cases" and "User Stories" [165].

A use case can be business or system-related and is defined as an interaction between a user and the system to complete a functional goal. The level of detail can vary, but in general, described workflows should not be modeled in a way that is too complex. Special templates, which can include UML use case diagrams, should be used to define use cases [165].

User stories are widely used within agile software development settings and can be defined as a brief description of system functionalities from the customer's point of view using customer terminologies. The description can be very brief since agile software development focuses on the continuous change of requirements and, therefore, involves customers during the whole development process to adapt and refine them constantly. User stories should be finely grained, focusing on a single functionality, and capable of being implemented within 1-3 weeks to ensure completion within one development sprint [165].

Another possibility is the use of business processes as a method for requirements analysis, especially for process-oriented organizations. Processes are either already modeled or can be modeled as part of the requirement analysis. Different artifacts can be derived from those processes, depending on the system architecture. There are three principal types of business processes: management processes that are concerned with the operation of the entire organization, core processes that reflect the core business and offer value to the customer, and support processes that support the management and core processes by providing certain resources and deal with the administration of these resources. A standard for the modeling of such processes is the "Business Processing Modeling Notation" (BPMN). Its notation resembles that of UML activity diagrams, and its goal is to define a common language for all business stakeholders. BPMN defines four high-level elements: flow objects, which are nodes within the diagram and can be further split into events, activities, and gateways. Furthermore, BPMN defines connection objects, which are used to connect flow objects, swimlanes, which can be used to organize and categorize activities, and artifacts, which can be split into data objects, groups, and annotations [165].

The design and prototypical implementation of low-fidelity user interfaces are essential activities in requirement analysis. By visualizing the interface of a system, users can better understand how to interact with it and how exactly information is shown. This visualization also allows users to participate in the analysis process more actively. The quality of UIs is a crucial factor in the acceptance of software systems [165].

CHAPTER 3

State-of-the-art

This chapter gives an overview of relevant work in the domains of serious games in healthcare, behavior change, mobile health (mHealth) solutions that incorporate gamification elements, and general digital health applications related to NCD prevention. Furthermore, suitable work about serious gaming frameworks and interoperability, identified in this dissertation's initial research phase, is described in detail. The author took some of these state-of-the-art descriptions from applicable first-author publications, added additional relevant work, and specifically structured them for this chapter.

The structure of this chapter is designed to align with the background of the developed games and apps. It begins with applications focused on mental health in rehabilitation, which serve as the foundation for the developed app recoverApp [28]. The chapter then progresses to a section on mental health apps specifically designed for students, the foundation for MoodBooster [166]. It is followed by games that promote nutritional education, laying the groundwork for Food Pyramid Escape [29] and NutriMine [33]. Next, applications for food and calorie tracking, which form the basis for Nutrition Garden [30] are explored, and applications and games aimed at smoking cessation, providing the foundation for BreathIn [31]. Finally, the chapter addresses interoperability and frameworks, establishing a foundation for the interoperable framework. The chapter concludes with a comparative summary of all analyzed apps and tries to embed the principal findings of the state-of-the-art analysis into the results of this thesis.

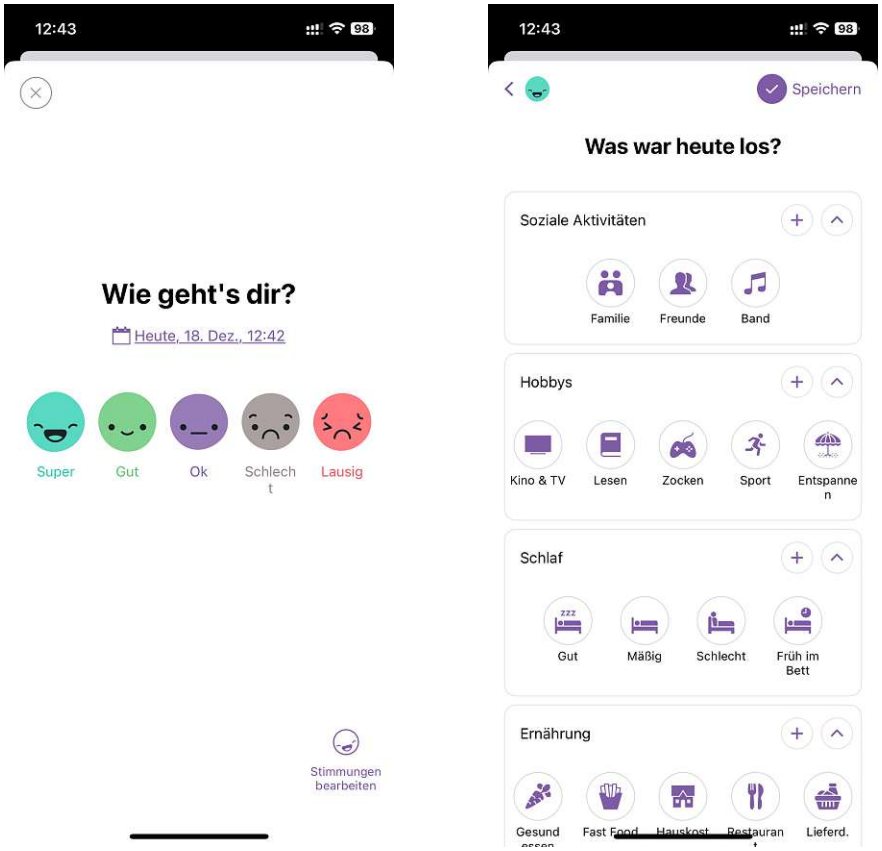
3.1 Applications For Mental Health in Rehabilitation

This section highlights state-of-the-art applications for mental health in rehabilitation. Numerous apps already exist in this field, either directly addressing patients' mental health or facilitating the entire rehabilitation process.

Note: A version of this whole section was published by Aigner et al. in [28].

3.1.1 Dailyo

"Daylio" is one of the most popular mood-tracking applications on the Google Play Store [167]. The app has been downloaded over 5 million times and was developed by Slovakian company Habitics. A basic version is available free of charge. The main feature of "Daylio" is the collection of data regarding mood and tracking activities over the course of a day. By adding their mood, users can choose a value between "Very Good" and "Very Bad." Activities can also be added and augmented with icons. The scientific bases for this application are the "Day Reconstruction Method," "Activity Monitoring and Scheduling," and "Goal Setting." The screenshots in Figure 3.1 show the mood and diary entry interfaces.



(a) Mood entry (b) Detailed diary entry

Figure 3.1: Screenshots of "Daylio" [167]

3.1.2 MindShift

The mobile health app "MindShift" was developed together by the Canadian welfare organization "Anxiety Canada Association" and the "British Columbia Mental Health and Addiction Services" and can be downloaded for free [168]. The main goal of this app is to provide users with information about anxiety as well as providing techniques for relaxation, mindfulness, and the development of effective thinking. The current anxiety level can be tracked multiple times a day by using a ten-step scale. Additionally, the app supports the tracking of concrete symptoms and features a diary function. The gathered data can be visualized with different diagrams. Unlike "Daylio," this app uses the "Experience Sampling Method" as a variant of the BCT "Self Monitoring of Behavior."

3.1.3 Happify

"Happify" is an app developed by a New York-based Start-Up of the same name and is based on positive psychology interventions for people suffering from depression and anxiety [169]. A basic version can be downloaded for free for the Android and iOS platforms. Additional content can be accessed through a monthly subscription ("Happify+"). The content is divided into tracks. These tracks are comprised of activities, games, and challenges that should help users focus on positive emotions instead of negative ones. By accomplishing certain goals, additional content for the chosen track can be unlocked (e.g., a diary function, mood tracking, etc.).

3.1.4 MindDoc

The app "Moodpath" (now called "MindDoc") can be used for psychological analysis that is based on questions users have to answer multiple times a day [170]. This data can then be used to derive a report about the general mental health state of the user. Moodpath was developed by the German company MindDoc Health and can be used as a support tool for ongoing therapy either by the patients themselves or by the treating therapist in the course of Cognitive Behavior Therapy. The app can be used in a basic version for free and is available on Android and iOS. Users can track their mood on a five-step scale multiple times a day. The entry can be augmented by adding additional information about thoughts, emotions, and experiences. The gathered data is being visualized in the form of a calendar view and different diagrams. The app's core feature is generating a report about the general mental health state of the user. The app assesses mental health every two weeks based on tracking data three times daily. "MindDoc" is available on prescription as part of the DiGA project in Germany [171].

3.1.5 Wellpepper

"Wellpepper" is a "Software-as-a-Service" platform for creating and tracking individually defined care plans for therapists and patients. It can be used in different medical care situations, including primary care. The US-based company provides an annual subscription model based on a cloud solution that is available only in the United States.

The application is comprised of different modules that can be individually licensed. A core feature of Wellpepper is the creation of care plans that can either be designed from scratch or based on well-proven clinical protocols. These plans include all relevant stages of therapy and can be applied for preoperative and postoperative care in an inpatient or ambulant scenario. Wellpepper was evaluated by clinical trials conducted with the aid of their research partner, Boston University [172].

3.1.6 Summary of Applications For Mental Health in Rehabilitation

Rehabilitation is a sought-after domain for mobile health applications. Different solutions are available to support the rehabilitation process of patients. To the author's knowledge, no comparable solutions to recoverApp presented as part of this thesis currently exist. Most of the available software products focus on physical therapy instead of psychological interventions and behavior change. These apps are targeting specific diseases and rehabilitation methods. Most of the analyzed apps concentrate on two main features, namely the depiction of exercises relevant to the rehabilitation process and the provisioning of information material to increase the effectiveness of those exercises.

3.2 Student Mental Health Apps

Note: A version of this whole section was published by Aigner et al. in [166].

Stress affects many people, including university students, who face considerable pressure from their studies, social life, and personal responsibilities. As stress becomes more common, finding ways to help students cope is essential. Kassymova et al. [173] discuss practical stress management techniques for students and teachers. The study aims to understand how stress affects students' academic success and health and proposes coping techniques in physiological, cognitive, behavioral, and psychological domains. Van Ameringen et al. [174] outline that barriers to treatment, such as insufficient facilities and trained professionals, financial constraints, social stigma, structural obstacles, and low perceived need for treatment, have been identified in the research. Hence, treatment methods are needed to overcome these barriers. There are various stress-reducing techniques available today that leverage emerging technologies. One of the techniques presented by Ray et al. [175] involves augmented reality and virtual reality (AR/VR). Their comprehensive review and findings show that AR/VR can improve overall health and well-being. Another method to reduce stress involves the use of apps. As stated by Statista, 89% of Austrians aged 15 and older owned a smartphone in 2023 [176]. This widespread ownership makes apps highly accessible to the majority of people. Shamsujjoha et al. [177] highlighted the availability of numerous health-related apps, including those aimed at promoting mental well-being and stress management. In the same context, Van Ameringen et al. [174] provide a thorough mental health app literature

overview. They studied published reports of apps designed to help with DSM-5 anxiety and mood disorders, OCD, and PTSD.

Similarly, Lau et al. [178] conducted a systematic review to assess the therapeutic contents and features of psychosocial wellness and stress management apps available for public download. Among all the apps studied in the review, the "Headspace" app had the most evidence supporting its effectiveness [179]. This app focuses on meditation and relaxation by offering exercises and other content like sleep stories, music playlists, and animated videos. Registration and annual payment are needed to use the "Headspace" app. "Headspace" also includes multiple gamification features like achievements, badges, colorful aesthetics, optional notifications, minimal text, animations, and social influence [180]. Another app for mental well-being and stress management is the "BetterHelp" app, which offers online therapy sessions with real and licensed therapists [181]. According to Alzoubi et al., [182], "BetterHelp" faced controversy surrounding its advertising and user privacy practices. The app requires users to register and make payment for the therapy sessions. Concerns were raised about the transparency of "BetterHelp's" registration process and how users' data would be handled and protected.

Hoffman et al. stress the importance of maintaining user interest and motivation to enhance the effectiveness of stress management apps [183]. According to the authors, gamification, which involves incorporating elements of games into non-game situations, aims to enhance apps for behavior change by making them more enjoyable, motivating, and engaging. They studied gamification techniques in stress management apps and how they align with evidence-based stress management methods and behavior change techniques. Ladakis et al. [184] present a VR-based gamified method to decrease stress levels in work environments. De Aquino Lopes et al. [185] introduced a technique for addressing stress by concentrating on emotions. To achieve this, they integrate serious games with flow theory and VR/AR techniques, taking into account individual patient requirements. Carlier et al. [186] explored the potential of using a serious game to alleviate stress and anxiety in children with ASD, along with a parent application to support both children and their parents. The "Happify" app [169] was also mentioned in the review of Lau et al. [178] and was already explained more in-depth in Section 3.1. This app incorporates several functions and gamification elements, such as progress tracking, rewards, and interactive activities, to control emotional well-being. Unlike the "Headspace" app, this one is free but requires registration.

The reviewed works show the effectiveness of different stress-reducing apps. However, none have focused on utilizing game techniques specifically designed for university students. Considering that many students face financial constraints but own smartphones, a mobile game approach could offer a cost-effective solution using the advantages of serious gaming. Moreover, many apps require registration, which some users may find inconvenient or discouraging, particularly if they wish to maintain anonymity or are reluctant to share personal information. Existing apps like "BetterHelp" for online therapy, "Happify" for emotional well-being, and "Headspace" for meditation have limitations such as fees, lack of scientific methods, or single-focus, leading users to use multiple apps.

3.3 Games For Nutritional Education and Weight Management

Many serious games and gamified apps for better nutrition and weight management are available. This section gives an overview of the analyzed work.

> Note: A version of this whole section was published by Aigner et al. in [29].

3.3.1 Alien Health

"Alien Health" is a serious exergame developed by "Embodied Games for Learning, LLC," and a play study was published by Hermans et al. [187]. It can be played using a Microsoft Kinect sensor and targets children, especially those in elementary school. By feeding a foundling alien, everyday food's nutritional profiles and the five most important macronutrient functions are taught. The game has four modes: "Forced Choice," in which the player must choose the healthier option between two presented kinds of food in order to change the alien's state from exhausted to super fit; "Quick Sort," again, the player must pick the healthiest of two options but in this mode, the game ends if all pairs are sorted, or a countdown timer hits zero; "Build a Meal," a three-course menu must be composed by choosing food from given options, healthier choices award the player with bonus shields for the alien's ship; "Ship Runner," the player steers the spaceship by jumping left or right to avoid collisions, which reduce the shields collected in the game mode "Build a Meal" and to collect coins and seeds to win the level. An evaluation was done with 108 children, which indicated that playing Alien Health effectively improved the participants' knowledge in the short term but that the improvement did not last in the long term. Furthermore, no differences in eating- and consumption behavior emerged from playing Alien Health [187]. Figure 3.2 shows a screenshot of the "Alien Health" game interface.

3.3.2 Food Pyramid Games

"Food Pyramid Games" is a collection of different games, songs, and animations developed at Colorado State University by Serrano and Anderson [188]. It is based on the Theory of Intrinsically Motivating Instruction (TIMI) and intends to educate Latino youth living in the U.S. about general nutrition topics, especially the food guide pyramid (FGP). This project consists of six parts: "Super Sorter," a game in which food must be assigned its correct level within the FGP; "More or Less," a game in which it must be determined for different meals and menus, if one needs more or less from different groups of food; "The Food Guide Pyramid," a song describing the FGP; "The Food Adventurers" and "Variety," songs that encourage to try new kinds of food; "Infomercials," a set of animations that teach various topics, for example the importance of drinking water. Food Pyramid Games was evaluated with 115 participants. It was found that they enjoyed the games and songs

Figure 3.2: Screenshot of "Alien Health" [187]

and that these effectively strengthened their knowledge about nutrition and the FGP [188].

3.3.3 Snake and Ladder Game

"Snake and Ladder Game" is a computer-based game developed in 2018 at Shiraz University of Medical Sciences, Iran, published by Hassanzadeh-Rostami et al. [189] which is designed to enhance especially the nutritional knowledge of preschool children. Therefore, this game is based on the well-known and intuitive board game "Snake and Ladder," in which the player, depending on the reached field, can either climb a ladder to a more advanced field or slide down a snake to a past field. This concept is adopted by the authors by rewarding the children with a ladder if they reach a field containing healthy food and punishing them with a snake for reaching a field with unhealthy food inside. An evaluation with 48 children showed that the participants highly enjoyed playing the game, and their nutritional knowledge could be increased [189].

3.3.4 Swiss Foodquiz

"Swiss Foodquiz" teaches users nutritional facts by applying serious game principles and was published by Fuchs et al. [190]. The game simulates a supermarket shelve where two similar products are displayed. These products are locally available real-world products. The user has to select the one product with the higher content of a given nutrient, e.g., higher sugar. The idea was to increase the end-user's acceptance and interaction rate compared to contemporary health information systems. In total, 350 participants were involved, representing the average Swiss population in terms of BMI distribution. The prototype had a high acceptance and interaction rate, and it could be shown that the users had quantifiable gains in nutritional education [190].

3.3.5 Foodbot Factory

The mobile serious game "Foodbot Factory" is based on Canada's Food Guide, the Canadian national dietary guidelines. It targets Canadian school children and aims to increase their nutritional knowledge. The game was designed to be played for 15 minutes per day over a five-day period. Each day was based on a different learning module: drinks, whole-grain foods, vegetables and fruits, animal protein foods, or plant-based protein foods. Foodbot Factory is a story-based serious game using quizzes, catching food, and sorting food to enhance user interaction and engagement. A total of 73 children participated in the single-blinded, parallel, randomized, controlled pilot study. 39 children were using Foodbot Factory while the control group (34) played "My Salad Shop Bar," a control app from the Google app store. A significant increase in the overall nutritional knowledge could be observed in the Foodbot Factory group [191], [192]. Figure 3.3 gives an overview of the gameplay of "Foodbot Factory."

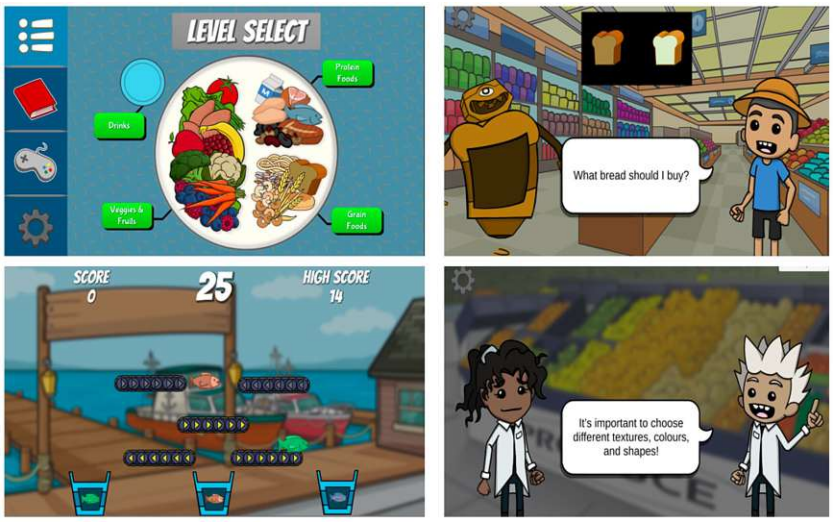


Figure 3.3: Screenshots of "Foodbot Factory" [192]

3.3.6 Fit, Food, Fun

A study conducted in Bavaria, Germany, by Holzmann et al. [193] compared the effectiveness of the serious game "Fit, Food, Fun" (FFF) to a classic lecture teaching nutritional knowledge to children and adolescents. Six guidelines were selected based on the guidelines of the German Nutrition Society for a wholesome diet. A total of 76 participants were divided into two groups. Group one (36 participants) played FFF for 15 minutes daily on three consecutive days, learning two daily guidelines. Group two (40 participants) were taught the same guidelines for 15 minutes using a blackboard and quizzes. The serious game takes the player on a European journey, where each country focuses on country-specific food items. Each country offers three different minigames: a quiz to compare nutrition in two food items, an estimation game for the content of

nutrients in one food item, and a physical activity unit, where the user packs a backpack with food and water to be sufficiently supplied. Successfully finishing all minigames from one country unlocks the next country. Both groups showed a significant improvement in nutritional knowledge [193].

3.3.7 Squire's Quest

"Squire's Quest" is a successful serious game in the field of nutritional education since it proved to have a positive impact on many students. It was published in 2000 by the Child Nutrition Research Center, evaluated in the work of Baranowski et al. [194], and was designed for fourth-grade students in elementary schools. The game consists of ten sessions, each of which lasts 25 minutes. It is about supporting the king and queen of the kingdom of "5Alot" as they are under attack. Their opponents want to destroy the kingdom's fruit and vegetable crops to weaken them. To prevent this from happening, the player supports the knights in their fight against the villains by preparing healthy meals from the fruits, vegetables, and juice in the kitchen. The game aimed to increase the consumption of fruits by the participants, which could be achieved. In an experiment involving 1578 students, it was observed that those who played Squire's Quest ate, on average, one portion more of vegetables and fruit. Due to its success, the sequel "Squire's Quest 2!" was released in 2009, which can be seen as an upgrade. The sequel mainly expanded the story and added more than 60 minutes of cut-scenes. Both games are based on the social cognitive learning theory [194].

3.3.8 Summary of Games for Nutritional Education and Weight Management

According to state-of-the-art analysis, it can be stated that most evaluated applications aim at a younger target group, ranging especially between 8 and 12 years of age. In contrast, the serious game Food Pyramid Escape presented in this thesis also intends to serve adolescent and adult users. Apart from this factor, most analyzed projects aim to achieve similar goals concerning nutritional education by raising awareness about a healthy diet and preventing nutrition-related diseases. The used strategies, however, turned out to be more diverse:

1. Most commonly, quizzes and selection exercises (" Choose the healthier option") were used. This strategy was also used in this work.

2. To convey more theoretical material, different, more innovative media types (songs, infomercials) were tested as a contrast to presenting material via a classical lecture or in a textual form as it is done in the game the authors propose.

3. Finally, existing and well-known games were analyzed and adapted to provide information about the intended subject (e.g., the snake and ladder game).

In summary, the strategies used in Food Pyramid Escape partly resemble the ones found in the state-of-the-art analysis but are also very innovative.

3.4 Applications for Food and Calorie Tracking

Note: A version of this whole section was published by Aigner et al. in [30].

A multitude of applications that aim to educate people about nutrition already exists in both the Google Play and Apple Store. However, in the author's opinion, there is a lack of applications that aim to motivate people to eat healthy foods that combat NCDs. Some examples are given below.

"Lifesum" is a popular health application to lose weight. The application includes a calorie counter, which displays the number of calories needed during a day according to the user's height, weight, and age. Moreover, the calories that have already been eaten and the calories that have already been burned are shown [195]. Figure 3.4 shows the calorie tracking page of the Lifesum app.

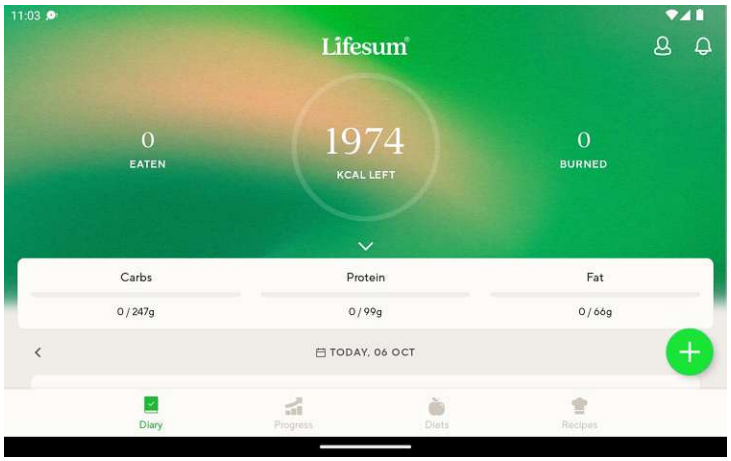


Figure 3.4: Screenshot of "Lifesum" [195]

"MyPlate" is a calorie tracker that helps people lose weight. It is possible to set up daily reminders for eating breakfast, lunch, and dinner. Moreover, the app can be connected to Google Fit to automatically add calories burned to MyPlate through different activities like walking, biking, or running [196]. Unfortunately, the "MyPlate" platform was shut down on July 9, 2023, [197].

"iEatWell" is a food diary that helps users eat healthier without counting any calories. Eating habits are logged through points. In the app, the daily awarded points are

displayed, and the user can add details about meals in the form of text or take a photo [198].

With "FoodSwitch," the bar code of a food product can be scanned. The app then provides detailed, easy-to-understand nutritional information about the product, such as fat and sugar percentages, and suggests healthier alternatives to the user [199].

The mobile application Nutrition Garden presented within this work centers specifically on food products that have already been proven effective against NCDs and were curated by nutritional experts beforehand. Furthermore, integrated gamification elements should keep users motivated, even for an extended period. In the author's opinion, these two aspects present a novel approach for a nutritional app in the mHealth space.

3.5 Applications and Games for Smoking Cessation

Numerous mobile health solutions for smoking cessation have already been published, and several are available to the public in various app stores. Some incorporate gamification elements or can be considered "full" serious games. Rajani et al. [200] conducted a study about smoking cessation interventions in the United Kingdom and reviewed 140 mobile apps. Their review showed that a high level of gamification is adopted only by a small minority of smoking cessation apps. However, they note a positive impact of gamification on psychological and behavioral outcomes [200]. Research has shown that incorporating gamification elements into smoking cessation apps may lead to a positive impact on psychological constructs such as self-efficacy and motivation to quit smoking [200]–[202]. Gamification features like badges, level advancements, and progress tracking can serve as motivational factors to aid in quitting [201].

3.5.1 Inner Dragon (Smoke Free)

White et al. [203] developed a game called "Inner Dragon" that was integrated into "Smoke Free," a smartphone app for proven smoking cessation efficacy that is available as a prescription in Germany, as part of the "DiGA" program [204]. The main game mechanic of "Inner Dragon" is the maintenance of an evolving pet dragon that hatches on the users' quit day and serves as a virtual avatar for the users' progress in quitting smoking by using traditional virtual pet retention mechanics, social features and options for customization and personalization. The user earns experience points by engaging in in-app activities with both "Inner Dragon" and the "Smoke-Free" app by playing minigames, feeding the dragon, completing a mission, or logging a diary entry. These points can then be used to unlock gifts and cosmetics to customize the dragon. Furthermore, the game uses "care meters" that users must work on to keep from falling low by taking care of them. These are calmness, nutrition, hygiene, and energy meters that can be influenced by engaging with the dragon differently, for example, feeding or petting it. The conducted trial showed that user satisfaction with the app was high overall. However, the authors

collected insufficient data to gauge the users' satisfaction with the "Inner Dragon" game in particular [203].

Super Smokey

Note: A version of this section was published by Aigner et al. in [31].

"Super Smokey" is a digital educational computer game aimed at educating its users about the impact of smoking on the human body since many people are not aware of the future consequences of smoking but rather focus on short-term positive effects. Therefore, wrong decisions are being made regarding one's smoking behavior. Super Smokey addresses this problem by offering users a game where they can see an image of their future selves to witness the future effects of smoking. For better identification, a personal avatar can be created with a photo taken by the user [205]. Figure 3.5 shows in-game screenshots with two different custom avatars using real-life photos.

(a) Male avatar (b) Female avatar

Figure 3.5: Screenshots of "Super Smokey" [205]

3.5.2 Cigbreak

Note: A version of this section was published by Aigner et al. in [31].

"Cigbreak" is a mobile application designed to assist with smoking cessation. It is based on theoretical, validated behavior change techniques and gamification elements. In the game, users are in a garden that they must cross to reach the "smoke-free end." Along the way, cigarettes fly towards them, which they must cut through by "swiping" or

"wiping" the screen. This activity is meant to distract from craving cigarettes. The app additionally includes the option to write diary entries and perform daily missions. Rewards are given when users manage smoking cessation in real life or when progress is made while playing the app. The behavior change techniques are realized through rewards, information about and highlighting risks and consequences, social support, and personal motivation [206]. Figure 3.6 gives an overview of the gameplay.

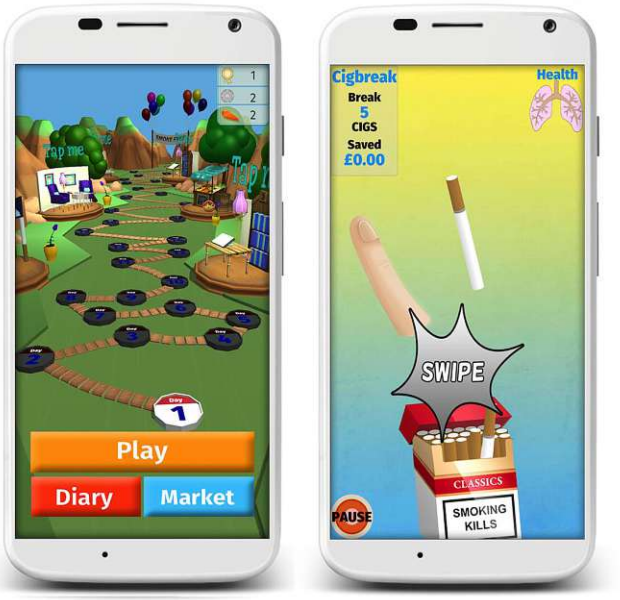


Figure 3.6: Screenshots of "Cigbreak" [206]

3.5.3 Inspired

"Inspired" is a mobile app for smoking cessation that uses game-based virtual goods as rewards for smoking abstinence and was assessed as part of a study by Raiff et al. [207]. The core game mechanic is set in a lush, vegetative environment and needs the player to swipe different colored pollen gems from a rotating queue into specific locations on lotus flowers to the left or right of the screen. Each level has an increased difficulty and was designed for five-minute playtime. Notifications, messaging, gifting, and social support were only available as mockups. Users have to record and present breath readings to a carbon monoxide monitor that influences certain parts of the game. However, specific rewards or the requirement to submit breath samples was not available at the time of the study [207].

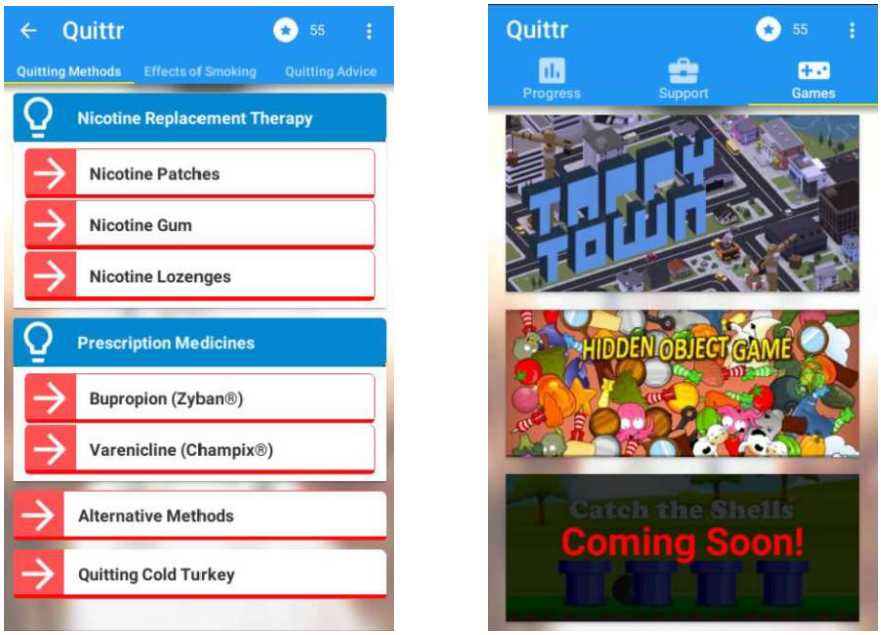
The study was conducted with 28 individuals. The findings suggest that the app has the potential to be an effective smoking cessation aid since 71% would play or recommend the game to other smokers who want to quit. However, at the time of the survey, the

application was incomplete and only available as a demo, needing the participants to guide them through the proposed intervention [207].

3.5.4 Quittr

Note: A version of this section was published by Aigner et al. in [31].

"Quittr" is a mobile app in which users should deal with given information and facts about smoking playfully. If they do so, they receive rewards in the form of advantages for integrated minigames. The app includes a tracker for smoking behavior with supporting information, playful elements, and a display of one's progress. This provides information on how many cigarettes have been avoided so far, how one's health has changed for the better, and illustrates one's successes, as well as financial aspects. This serves to motivate the user and to reflect on one's progress. Quittr is supposed to accompany a smoking stop for 28 days [208]. Figure 3.7 shows screenshots of the application.



(a) Information toolbox (b) Available games

Figure 3.7: Screenshots of "Quittr" [208]

3.5.5 QuitIT

Krebs et al. [209] proposed a serious video game that enables smokers to practice strategies for coping with smoking urges and maintaining smoking abstinence. The games

were designed with intertwining episodic stories in the form of flashback scenarios of in-game characters that reenacted their trigger situations without smoking. The player selects some of the character's thoughts and dialogue in each episode. Furthermore, players must match optimal coping strategies to each smoking cue. During the testing phase, the authors got feedback from five tobacco cessation experts and 20 current and former smokers, and the results showed a strong potential for a serious game to enhance skills for coping with smoking urges. The tested game, however, was only available in an early alpha phase.

3.5.6 Summary of Applications and Games for Smoking Cessation

Note: A version of this section was published by Aigner et al. in [32].

Most state-of-the-art applications center on one of the fundamental elements of smoking cessation: psychoeducational like "Super Smokey," offering distractions like "Cigbreak," or providing alternatives like "Quittr." However, BreathIn, the serious game proposed as part of this thesis, combines all three aspects, particularly emphasizing behavioral therapy elements. Consequently, its primary objective is to serve as a beneficial complement for individuals currently undergoing smoking cessation therapy.

3.6 Interoperability and Frameworks for Serious Games

Note: A version of this whole section was published as a journal paper by Aigner et al. in [35].

3.6.1 Serious Games Frameworks

Peters et al. [25] propose a framework for collecting health-related and game data from serious games and apps that cover the requirements to interpret data of various health- and game sources using a decision-support-system (DSS) based approach. The initial motivation for creating the framework was the "INTERACCT" project, a serious game for young oncological patients. The game world consists of a 2.5-dimensional adventure game where the player has to complete procedurally generated levels. The levels are filled with hidden treasures and hostile avatars. Before entering the game world, the user needs to enter some medical parameters. These parameters are defined by medical experts and represented as LOINC codes. The project also has a physiotherapy application for PCs using the Microsoft Kinect device. According to the authors, one of the significant insights during the development of the project above was that the definition, gathering, and evaluation of data parameters was very challenging. A huge part of the framework's

design is a decision support system (DSS) that calculates structured health scores based on medical and game data. Health data is processed via a clinical decision support system, and game data via a serious game decision support system. The score can be, for example, on a scale of 0-100 and include more details about how the score was formed. Even though standards like LOINC can define some health parameters, the authors say others are highly specific and subjective. The authors also stated that it was challenging to design a ubiquitous data model for serious games for health mainly because of the wide variety of possible games, mechanics, and medical topics. This observation shows the importance of well-made implementation guides focusing on well-defined medical areas, like NCD prevention, and using current standards like HL7 FHIR and SNOMED CT. Even though the framework suggests using HL7 FHIR over RESTful interfaces using secure transport layers only, in the author's opinion, an actual implementation guide needs yet to be designed and implemented.

Yusoff et al. [210] developed a conceptual framework for serious learning games. It combines learning and pedagogy theory with gaming requirements. The framework includes components like "Capability," which refers to the cognitive, psychomotor, and affective skills players develop in the serious game, instructional content, intended learning outcomes, game attributes supporting engagement, learning activities, reflection on these outcomes, genre, game mechanics, and achievements such as scores, resources collected, or time to reach goals.

The eAdventure platform is a tool designed to help create educational adventure games used in various domains, including health sciences. It uses the Sharable Content Object Reference Model (SCORM) to integrate into Moodle-like platforms but solely focuses on one particular type of video game [211].

Another example is the work of Stefan et al. [212], which proposes a multidimensional interoperability framework for serious games that integrates three key dimensions: the core components, the ecosystem, and external factors. According to them, the research on serious game interoperability should focus on standardization, which means the creation of functionally interchangeable items; interchangeability, which refers to identifying methods that would make game components interchangeable; standards adoption, which involves creating adaptable solutions; open systems architecture, which provides a modular design that defines key interfaces; and unique specifications and proprietary devices, which indicate that proprietary devices may be counterproductive but are often necessary to provide the needed functionality. The work focuses on serious learning games [212].

Cowan and Kapralos [213] focused on technical insight into serious game development by conducting an extensive literature review that examined frameworks and game engines, including a summary of their features. According to their study, the frameworks Second Life, Unity, Unreal, Flash, XNA Game Studio, and the Torque game engine were extensively used since they had the highest search results. They concluded that developers primarily use technical frameworks that were not originally designed for serious games but for commercial entertainment games.

3.6.2 Serious Games Interoperability

Digital health apps, especially mobile apps, can, as of January 2023, export their data in a semantically interoperable way into the German national electronic health record. The "DiGA Toolkit" project, currently released as version 1.1.0 [214], allows storing data in the electronic health record ("ePA - Elektronische Patientenakte") by using HL7 FHIR as part of the concept called MIOs ("Medizinische Informationsobjekte") [215]. A second MIO currently under evaluation is the "DiGA Device Toolkit" MIO, which will establish a standard for transmitting health data from medical aids and implants to DiGAs. This MIO provides DiGA and device manufacturers with a standardized framework for data transmission. The data transfer occurs between the device manufacturer's backend and the DiGA manufacturer's. The MIO "DiGA Device Toolkit" ensures compatibility with the MIO DiGA Toolkit. The integration of both MIOs offers the technical capability to transfer care-relevant measurement data from devices, such as aids or implants, in an interoperable manner into the electronic health record, making the pertinent information readable and understandable for healthcare providers in the primary system [216]. According to Mittermaier et al. [217], physicians can already prescribe authorized "DiGAs" to patients, which can be reimbursed by statutory health insurance. Mittermaier et al. also stated that "DiGAs" can support the field of internal medicine. Even though the "DiGA" profiles already define useful data structures for digital health apps, such as diary entries, questionnaires, and lifestyle factors, they currently do not focus on segments for serious games or gamification for health.

The German Institute for Standardization Registered Association (DIN) published a specification for serious game metadata in 2018. This specification aims to define a metadata format for serious games that enables developers and publishers to describe their games in a standardized manner, allowing potential users to find them more easily [132].

The "Sharable Content Object Reference Model" SCORM is a standard that can be used with learning games by defining a method for delivering e-learning content across various platforms [133].

3.7 Summary

This section summarizes the state-of-the-art analysis conducted on the relevant NCD-prevention domains, compares the highlighted games and apps, and provides an overview of the analysis performed in the field of serious game frameworks. Each developed application proposed as part of this thesis offers a novel approach to NCD prevention and behavior change in its respective clinical field. The interoperable framework designed on top of these applications serves as a novel best practice catalog for NCD-prevention game and app development, focusing on the interoperable exchange of relevant data.

3.7.1 Summary of Applications for NCD prevention

This section visually compares the analyzed applications in the fields of mental health for rehabilitation, nutritional education, food and calorie tracking, smoking cessation, and student mental health, see Table 3.1. The main comparison criteria included NCD risk factors, gameplay and engagement, learning aspects, the interoperable exchange of data, and the integration within the digital health environment, first and foremost, electronic health records.

Table 3.1: Comparison of state-of-the-art

Application	**NCD risk factors**	**Gameplay & Engagement**	**Learning aspects**	**Interoperable data exchange**	**eHealth integration**
Daylio [167]	Mental health	Badges, custom icons	None	CSV, PDF export, no interoperable exchange	Apple Health import
MindShift [168]	Mental health	Goals	Information and techniques about anxiety	Basic export, no interoperable exchange	None
Happify [169]	Mental health	Activities, games and challenges	None	None	None
MindDoc [170]	Mental health	None	Courses and educational aspects in the form of "insights"	Currently only PDF export	DiGA, potential to integrate with EHR but currently none
Wellpepper [172]	Mental health, rehabilitation	None	None	EMR integration, HL7 Continuity of Care Document (CCD)	REST API for programmatic access
Headspace [179]	Mental health	achievements, badges, colorful aesthetics, optional notifications, minimal text, animations, and social influence	Educational content about meditation and mental health topics, coaching	None	None
BetterHelp [181]	Mental health	None	Mental health advice on web portal	None	None
Ladakis et al. VR game [184]	Mental health	Relaxing VR environment	None	None	None
Carlier et al. Stress game [186]	Mental health	Minigames, experience points	None	None	None

Application	NCD risk factors	Gameplay & Engagement	Learning aspects	Interoperable data exchange	eHealth integration
Alien Health [187]	Nutrition	Exergame using "Microsoft Kinect"	Nutritional education	None	None
Food Pyramid Games [188]	Nutrition	Collection of games, songs and animations	Nutritional education	None	None
Snake and Ladder Game [189]	Nutrition	Digital board game	Nutritional education	None	None
Swiss Foodquiz [190]	Nutrition	Quiz, simulation of a supermarket shelf	Nutritional education	None	None
Foodbot Factory [191], [192]	Nutrition	Story-based serious game, quiz	Nutritional education	None	None
Fit, Food, Fun [193]	Nutrition	Minigames	None	None	None
Squire's Quest [194]	Nutrition	Educational multimedia game	Nutritional education	None	None
Lifesum [195]	Nutrition	Streaks	None	Nutrition program, recipies	Import/Export with Apple Health, Health Connect, and others
MyPlate [196]	Nutrition	Goals	Nutritional education	None	Google Fit Integration
iEatWell [198]	Nutrition	Rewards	None	None	None
FoodSwitch [199]	Nutrition	None	Nutritional education	None	None
Inner Dragon (Smoke Free) [203]	Smoking cessation	Virtual pet, minigames, missions, experience points	Educational content, chatbot	None	JSON/PDF Export (Smoke Free app, DiGA but currently no ePA integration)
Super Smokey [205]	Smoking cessation	Avatar, quizzes	Health education	None	None
Cigbreak [206]	Smoking cessation	Rewards, daily missions, swiping-game, minimap	None	None	None
Inspired [207]	Smoking cessation	Swiping-game, gifts, social support	None	None	None
Quittr [208]	Smoking cessation	Minigames, achievements, rewards	Smoking cessation education	None	None
QuitIT [209]	Smoking cessation	Episodic stories	Education on coping strategies and skills	None	None

The summary indicates that while most applications provide engaging game mechanics or gamification elements, only a few offer meaningful educational content. Most games and apps lack support for the interoperable exchange of medical data and do not integrate with digital health platforms. Two apps are classified as "DiGAs" in Germany, but they do not facilitate the exchange of relevant data into the German national health record (ePA).

3.7.2 Summary on Serious Games Frameworks

Note: A version of this whole section was published as a journal paper by Aigner et al. in [35].

The serious game framework proposed in this thesis outlines guidelines for designing and developing games and applications across six key domains. In addition to development best practices, organizational interoperability, usability, quality, and technical aspects, it emphasizes the semantically interoperable exchange of clinical and game data by incorporating state-of-the-art standards from the medical informatics domain, for example, HL7 FHIR.

Furthermore, the interoperable framework will predominantly focus on behavior change-driven games and gamified mobile apps to lower risk factors and thus help in the prevention of NCDs. Both are novel approaches within serious games and gamification in health. Even though rudiment framework approaches already exist, they either focus more on serious games for education or eLearning like the SCORM standard or general serious games for health and try to use DSS approaches without constructing actual implementation guides for the use within national or personal electronic health records and thus not allowing medical and game data to be further used for primary care or secondary use for scientific purposes.

Even though implementation guides for the interoperable exchange of medical data exist for mobile health apps, such as the "DiGA Toolkit" [214] or the "DiGA Device Toolkit" [216] in Germany, they do not specifically focus on serious health games or gamified health apps. They also do not currently use the latest version of HL7 FHIR, which includes newly added resources relevant to serious game data for NCD prevention.

CHAPTER 4

Methodology

As previously mentioned in Section 1.4 in the introduction of this thesis, the primary methodology was divided into five distinct phases, which are organized into a theoretical analysis and an applied stage. In the preliminary phase, a literature review, several brainstorming sessions with peer researchers in related fields, and a comprehensive state-of-the-art analysis of applications and games aimed at behavior change, particularly for NCD prevention, were conducted. This chapter delivers a detailed description of applied analysis phases 1 to 4, as seen in Figure 4.1.

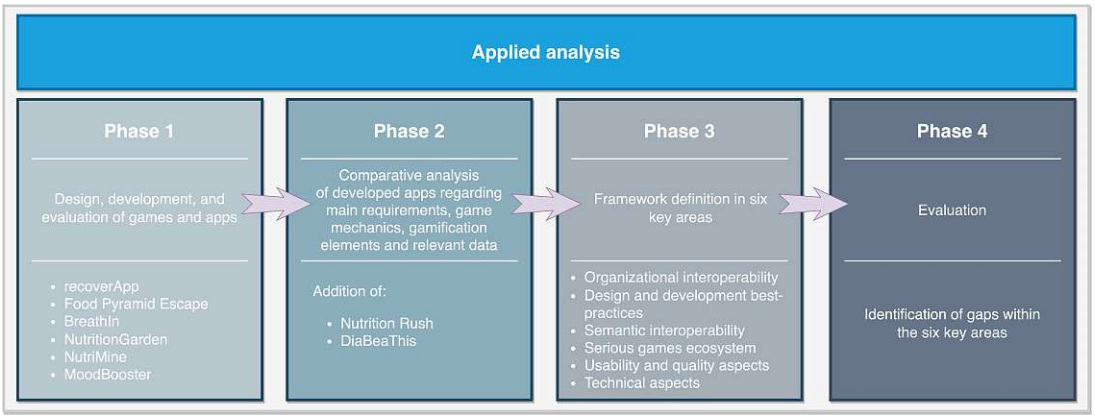


Figure 4.1: Detailed methodology of applied analysis stage

4.1 Phase 1 - Development of Games and Apps

The first phase involved designing, developing, and evaluating three serious games and three gamified mobile apps for NCD prevention. The following sections describe the

methodology for each in detail. The explanations were taken from relevant first-author publications and have been specifically prepared for this chapter.

4.1.1 Methodology of recoverApp

> Note: A version of this whole section was published by Aigner et al. in [28].

The methodology comprised a research, a design, and an evaluation phase. First, a basic literature review was conducted, followed by a brainstorming session with the research team. Relevant state-of-the-art applications were identified, evaluated, and categorized. The result of this phase was a comprehensive idea about a mobile application for supporting patients residing in stationary rehabilitation. At this early stage, the authors were already considering designing a web application for the therapist. The main requirements for both software parts were derived from these steps.

Table 4.1: recoverApp: Participants

Name	Age	Gender	Profession	Phase
P1	35	m	Therapist	Evaluation
P2	x	m	Therapist	Evaluation

The next phase consisted of finalizing the functional requirements for both the mobile app and the web application. The first visual prototypes were created and then shown to the two involved therapists. Their feedback was incorporated into the application design. Finally, the visual prototypes were refined, and the concept was finalized. Table 4.1 gives an overview of the involved participants.

4.1.2 Methodology of Food Pyramid Escape

> Note: A version of this whole section was published by Aigner et al. in [29].

The methodology used consisted of three phases - a research, a game design/implementation, and an evaluation phase. During the first phase, a profound literature review was conducted. This review was followed by a state-of-the-art analysis of relevant applications and serious games and an in-depth assessment of the nutritional situation in Austria.

The final requirements were defined in the second phase, and a comprehensive game design was created that included a design document containing a description of all planned seven

levels, the story elements and the riddles for each level, user interface elements, floor plans, and design studies of the main character and each of the non-player characters. After finishing the design, a fully functional prototype of the described serious game for the Android platform was developed by using the Unity game engine. All the required assets and graphics incorporated within the game world were drawn by hand.

Table 4.2: Food Pyramid Escape: Participants

Name	Age	Gender	Profession	Phase
P3	23	m	Student	Evaluation
P4	27	f	Employed Person	Evaluation

In the final phase, the game was playtested and evaluated by two persons from the target group, see Table 4.2. A qualitative interview followed up the playtest with both players. The playtest served both as a verification measure for the requirements and as an informal usability test of the game itself. The interview extended the usability testing aspect by asking usability-related questions but also focused strongly on questions on the general concept and potential application context of Food Pyramid Escape. The evaluation gave the authors valuable feedback, and its results were incorporated into the game by updating the intervention plan and refining the requirements.

4.1.3 Methodology of BreathIn

Note: A version of this whole section was published by Aigner et al. in [31] and [32].

For the first stage, the methodology used consisted of research and a design phase that took place in multiple iterations, as seen in Figure 4.2. First, a literature review (Iteration 0) was conducted to understand better the problem space and the associated state-of-the-art solutions regarding smoking, serious games, and motivational/behavioral aspects. Next, an online survey, distributed via multiple social media channels (Iteration 1), was conducted to get more detailed insights on how people could be motivated to stop smoking, together with knowledge of how nicotine affects the body and the different side effects of it. Afterward, semi-structured interviews (Iteration 2) were conducted to re-evaluate the online survey results and gain more insights into the target group. Subsequently, requirements were derived based on previous iterations. Based on these results, a concept (game elements, mechanics, and behavior) was drafted, and mockups were drawn. These mockups were shown to different participants, including a psychiatrist in Iteration 3. Finally, the results were discussed and concluded.

An additional survey on digital gaming behavior with 162 individuals was conducted as part of this particular research. Based on the preceding work and the survey results, a

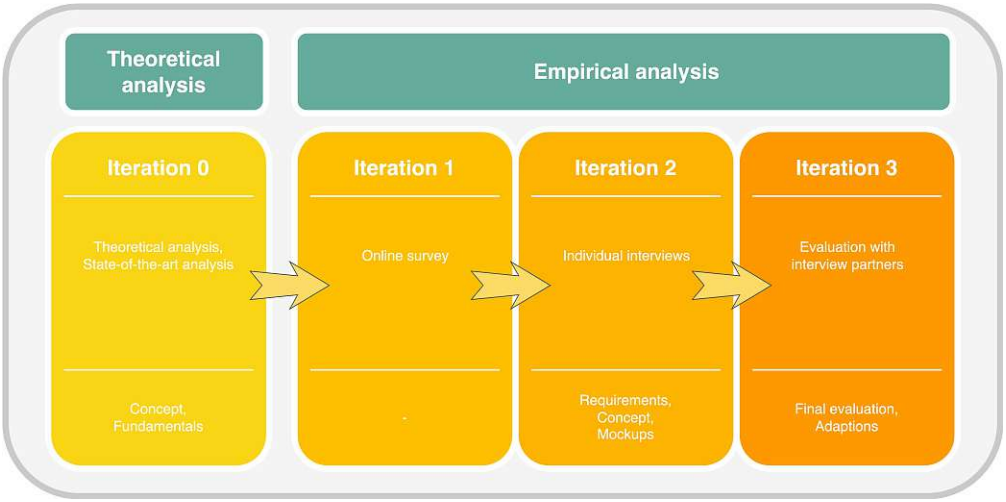


Figure 4.2: BreathIn: Methodology for the first stage of BreathIn [31]

Table 4.3: BreathIn: Participants

Name	Age	Gender	Profession	Phase
P5	25	m	x	Design
P6	55	f	x	Design
P7	27	m	x	Design
P8	57	m	x	Design
P9	70	f	x	Design
P10	23	f	x	Design
P11	24	m	x	Design
P12	24	m	x	Design
P13	61	m	x	Design
P14	x	m	Psychiatrist	Implementation
P15	19	f	Student	Evaluation
P16	24	m	Software developer	Evaluation
P17	28	m	Employed Person	Evaluation
P18	35	f	Employed Person	Evaluation
P19	37	m	Employed Person	Evaluation
P20	53	f	Employed Person	Evaluation
P21	57	m	Retiree	Evaluation

fully functional prototype was designed and implemented with the Unity framework [218] for Android as the target platform. A playtest with seven participants, three females, and four males, all between the ages of 19 and 57, was conducted to gain insight into the developed prototype. Each participant was handed a smartphone with a preinstalled

version of BreathIn, and instructions of what was expected were given. Table 4.3 gives an overview of all involved participants from all phases.

4.1.4 Methodology of Nutrition Garden

Note: A version of this whole section was published by Aigner et al. in [30].

The methodology used in this work comprises three phases: initial research, design/implementation, and evaluation.

Table 4.4: Nutrition Garden: Participants

Name	Age	Gender	Profession	Phase
P22	27	m	Computer Specialist	Design, Implementation
P23	23	m	Student	Design
P24	55	f	Accounting	Design, Implementation
P25	29	m	Nursing Assistant	Implementation
P26	76	f	Pensioner	Implementation
P27	58	m	Programmer	Implementation
P28	37	f	Nutritionist + Fitness Trainer	Consulting
P29	22	f	Student	Consulting

In the first phase, a literature review was conducted specifically about nutritional advice. Furthermore, a comprehensive state-of-the-art analysis was performed. Relevant applications and projects were identified, categorized, and evaluated as part of this phase.

The second phase consisted of an extensive design process involving a nutritional scientist and potential users from the target group of the proposed application. Together with the results of the research phase and interviews conducted with the participants during the design phase, user stories were identified, and the final requirements were derived and documented. Furthermore, based on these findings, mockups were created. Following up on that was the implementation of a prototype developed for the Android platform. A list of all participants and the phases in which they participated can be found in Table 4.4.

The final phase consisted mainly of comprehensively testing and evaluating the application designed and implemented during the second phase. Five participants from the target group were selected for this process. They all extensively tested the app and were interviewed afterward.

4.1.5 Methodology of NutriMine

Note: A version of this whole section was published by Aigner et al. in [33].

The methodology of this work consisted of four phases. First, a comprehensive literature review and state-of-the-art analysis were conducted to find current solutions and identify the baseline for the following steps. The second phase involved interviewing a nutritional expert to gather further information about healthy nutrition, especially obesity interventions. The interview partner was female, 53 years old, and a nutritional science and therapy expert.

In this phase, requirements were derived based on the interview, which were used for an initial concept. The third phase consisted of finalizing the concept and developing the prototypical modification for Minecraft. The final phase included an extensive playtest and evaluation of the prototypical modification. Table 4.5 gives an overview of all participants.

Table 4.5: NutriMine: Participants

Name	Age	Gender	Profession	Phase
P30	53	f	Nutritional expert	Design
P31	16-30	m	x	Evaluation
P32	16-30	m	x	Evaluation
P33	16-30	m	x	Evaluation
P34	16-30	m	x	Evaluation
P35	16-30	m	x	Evaluation
P36	16-30	f	x	Evaluation
P37	16-30	m	x	Evaluation
P38	16-30	m	x	Evaluation
P39	16-30	m	x	Evaluation
P40	45+	m	x	Evaluation
P41	16-30	f	x	Evaluation

To evaluate the Minecraft mod developed for this study, a select group of individuals played the mod and shared their feedback. Post-gameplay, they were asked to complete a survey covering various aspects, including demographic information, the mod's impact on their gameplay behavior, and any new learning or behavioral changes resulting from the mod. The survey used a Likert scale, with statements related to their experience with the Minecraft mod and changes in nutritional behavior. Participants were asked to rate their level of agreement on a scale of one (strong disagreement) to five (strong agreement).

A total of 11 individuals responded to the survey. Demographically, all but one participant was between 16 and 30 years old, with one participant being over 45. The group consisted of nine males and two females. Educational backgrounds varied: Five had completed high school, five held a bachelor's degree, and one had a master's degree. Dietary confidence scores ranged widely, with an average of 2.91. Six participants rated diet satisfaction a three out of five, while five rated it a four. Three participants reported experiencing mental or physical health issues related to nutrition. The average score for general video game experience was 3.82, with specific experience in Minecraft averaging 3.72.

4.1.6 Methodology of MoodBooster

Note: A version of this whole section was published by Aigner et al. in [166].

The methodology of this work consisted of four phases. In the first phase, preliminary research on student mental health was conducted, and gaps were identified. Afterward, a comprehensive state-of-the-art analysis of mental health apps and serious games was conducted. In the second phase, the design of the main application, which included mini-serious games, was conducted. Four game ideas were designed in total. The concept was prototypically implemented in the third phase, including two designed serious games: "Just Breathe!" and "Draw Your Stress Away." In the final phase, the finished prototype was evaluated by target group users using questionnaires and personal interviews. Table 4.6 gives an overview of the participants.

Table 4.6: MoodBooster: Participants [166]

Name	Age	Gender	Profession	Phase
P42	21-24	f	Student	Evaluation
P43	21-24	f	Student	Evaluation
P44	21-24	f	Student	Evaluation
P45	25-28	f	x	Evaluation
P46	29+	f	x	Evaluation
P47	29+	f	Student	Evaluation
P48	29+	m	x	Evaluation
P49	29+	m	x	Evaluation
P50	x	x	x	Evaluation
P51	x	x	x	Evaluation

4.1.7 Summary of Phase 1

Each application followed its own distinct methodology. In total, 51 people contributed to the design, development, and evaluation of the serious games and apps. Six of them were experts in the field, including therapists, a psychiatrist, and nutrition specialists. Additionally, 45 individuals participated in requirement analysis, evaluation of mockups, or playtests of prototypes or were involved in multiple phases. Furthermore, 466 individuals took part in online surveys.

4.2 Phase 2 - Comparative Analysis

For this phase, the six games and apps designed and developed beforehand, recoverApp, Food Pyramid Escape, BreathIn, Nutrition Garden, NutriMine, and MoodBooster, were compared with two more applications from the author's research group: NutritionRush, a platformer focusing on nutritional education, and DiaBeaThis, a web portal for tracking diabetes-related blood levels that also includes a card-based serious game. Four of them are considered serious games, and the other four are considered gamified applications.

These eight applications were compared based on the following criteria:

- Type of the application: Whether the concept can be characterized as a full serious game or an app with gamification elements.
- Platform: Whether they are designed for mobile operating systems like Android or iOS or are meant to run on a PC or the web.
- Main NCD risk factor: Whether the concept is related to smoking, nutrition, mental health, or other non-communicable disease risk factors.
- Secondary (clinical factors): Whether the game or app targets additional factors, such as well-being, nutritional education, positive psychology, depression rehabilitation, injury, or pain.
- Main requirements: Lists the main requirements of the analyzed concept.
- Game mechanics/Gamification elements: List the primary game mechanics if the concept is a serious game, or outline the key gamification elements if it is a gamified app.
- Relevant data: Define all pertinent data elements related to patient data, game data (game progress, achievements, badges, inventory), clinical data, engagement data, or lifestyle data.

The main comparison was primarily presented in tabular format to facilitate visual comparisons. It served as the foundation for a basic requirement catalog that defines the essential requirements that NCD-prevention games and apps should implement.

4.3 Phase 3 - Development of the Framework

Based on the comparative analysis conducted and the definition of basic requirements during phase 3, an interoperable technical framework for NCD-prevention serious games and gamified apps was developed that focused on the following six key areas:

- C1 - Organizational interoperability: Presents recommendations for care processes, app workflows, and government platforms while considering national and multinational health data spaces.
- C2 - Design and development best practices: Defines a requirements catalog that describes sets of functional and non-functional requirements while clarifying the use of game mechanics, gamification elements, BCTs, and configuration aspects.
- C3 - Semantic interoperability: Defines the interoperable exchange of clinical and game data.
- C4 - Serious games ecosystem: Includes best practices for using metadata, public app registries, and serious game appliances while also providing basic suggestions on regulatory compliance.
- C5 - Usability and quality aspects: Defines basic design guidelines and offers recommendations for conducting usability and clinical studies.
- C6 - Technical aspects: Includes APIs, the use of game engines, authentication and authorization, game analytics and telemetry, backend services, as well as data security and privacy.

The first step was refining the basic requirements extrapolated from the comparative analysis during phase 3. The requirement catalog was completely revised, and a category dividing it into functional and non-functional requirements, along with a level of fulfillment, was added.

Afterward, a prototypical implementation guide using HL7 FHIR and FHIR shorthand as the domain-specific language to define customizations was created. The outcome was a set of profiles, extensions, code systems, and value sets that were packaged as a navigable web page that also allows for the download of individual artifacts.

Based on the two technical artifacts, key areas C1-C6 were thoroughly defined and outlined visually and in textual form.

4.4 Phase 4 - Evaluation

During the final phase, the eight games and apps analyzed in the comparative study were briefly evaluated to identify any gaps. To this end, the prototypes' current state was compared with the six key areas of the framework, and their degree of fulfillment was determined. Three categories were defined for that purpose:

- Full: The game or app fully meets all recommendations of the specific key area.
- Partial (part.): The application partially meets the recommendations of the key area, but gaps still exist.
- None: The concept does not meet any recommendations of the respective key area.

After the evaluation, a conclusion for this thesis was drawn by thoroughly discussing all results and answering the three research questions stated at the beginning. Furthermore, potential limitations of this work were analyzed and documented, and aspects of future work were identified, some of which are already ongoing.

CHAPTER 5

Results

This chapter presents the results of this thesis by providing a comprehensive description of the designed and implemented serious games and gamified apps for NCD prevention. A total of six applications are described within this chapter that had been published as a first author beforehand. A frame box indicates that an entire section or paragraph was taken from such a publication and was adapted to the needs of this thesis. Based on these six applications and two more from the research group of the author, a comparative analysis was conducted that served as the basis for an interoperable framework that defines best practices for the design and development of NCD-prevention serious games and apps and places a large emphasis on the construction of an implementation guide for the semantically interoperable exchange of health and game data.

5.1 Development of NCD Prevention Games and Applications

The following chapter describes phase two of this thesis work, the design and development of six NCD-prevention serious games and gamified applications.

5.1.1 recoverApp - A Mobile Health Solution for Stationary Rehabilitation

Note: A version of this whole section was published by Aigner et al. in [28].

Prolonged stays in hospitals or rehabilitation facilities can have negative psychological and physical effects on patients. Possible symptoms patients are suffering from are depression, reduced cognitive performance, feelings of loneliness, anger, and aggressive behavior. The

aforementioned issues can affect the general healing process of medical conditions the patient was hospitalized for in the first place. Therefore, a concept for a mHealth solution entitled recoverApp, specially designed to support people in stationary rehabilitation, is proposed. Its core features are intended to support patients in overcoming certain psychological problems that occur during prolonged periods of recovery by using concepts and interventions of cognitive behavioral therapy (CBT). recoverApp was designed based on a comprehensive state-of-the-art analysis and incorporated feedback from therapists to further refine its main features. These include functions to track the patient's mood, tasks, challenges, and skills. It also provides the patient with a diary and an instant messaging feature to contact the treating therapist directly. The patient receives skill points by completing challenges and tasks or by simply entering diary entries. This gamification approach is used to enhance the engagement and acceptance of the mobile application.

Results

The following results depict an application framework specifically designed for use in stationary rehabilitation. The concept includes a mobile app that patients will use and a web application that their therapists will use. The main focus of this framework is the support and improvement of psychological care and a decrease of negative mental influence that can happen during prolonged stays in rehabilitation facilities, as well as psychological problems that can occur due to serious injuries. As stated in the introduction, patients in rehabilitation are at a greater risk of suffering from depressive disorders, anxiety, or other mental health issues. Such issues can have negative effects on the rehabilitation process itself.

The results consist of several requirements (outlined in subsection "Requirements"), a high-fidelity prototype (subsection "Designed Prototype"), and concludes with the evaluation of the developed high-fidelity prototype (subsection "Evaluation").

Requirements Table 5.1 depicts the functional requirements and the corresponding affected actors that were derived as a result of the state-of-the-art analysis and the gathered feedback from the participating therapists.

Designed Prototype

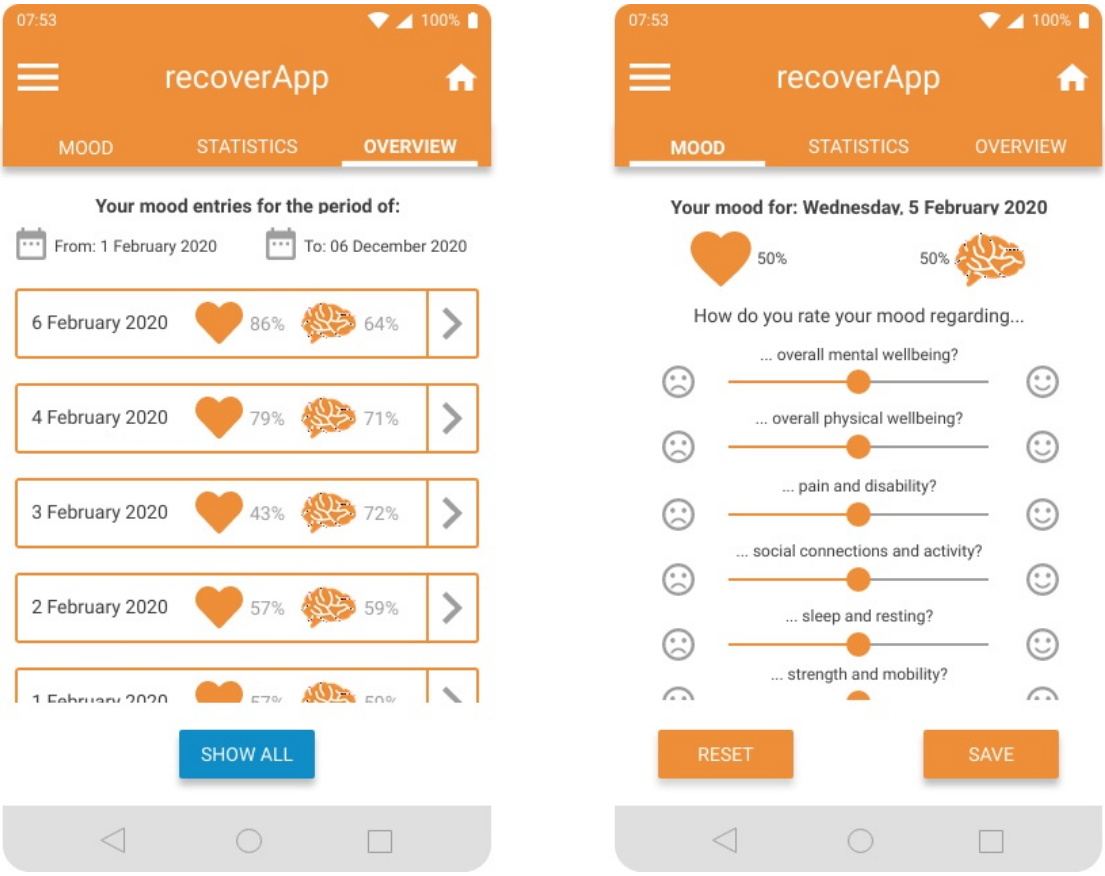
Mood Tracking The mood-tracking feature is split into mental and physical well-being categories. This feature is based on the "Day Reconstruction Method". The data entry should be conducted once per day. Users will be notified via a push notification and must answer five questions for each category. Each answer can be entered using a slider with a scale from 0 to 100 percent. An average of all entered values is computed and visualized in the form of a line diagram. Users can change the displayed timeframe and access all previously entered data. If values exceed predetermined limits, therapists will receive a notification. Figure 5.1 gives an overview of the mood-tracking feature within the app.

Table 5.1: recoverApp: Functional Requirements [28]

Req. ID	***Description***	***Affected actor***
R01	Create therapy task	Therapist
R02	Create private task	Patient
R03	Perform therapy task	Patient
R04	Perform private task	Patient
R05	Record mood data	Patient
R06	Access mood data	Therapist
R07	Derive mood trends	Therapist
R08	Create challenges	Therapist
R09	Perform challenges	Patient
R10	Create skills	Patient/Therapist
R11	Write diary entry	Patient
R12	Read public diary entries	Therapist
R13	Award skill points	Therapist
R14	Receive skill points	Patient
R15	Send messages via chat	Patient/Therapist

Diary The diary feature augments the mood-tracking function by allowing the user to track activities and events additionally. As with the mood tracking feature, the user should enter data on a daily basis. Scientifically, this requirement is also based on the "Day Reconstruction Method." The core of the diary is a free-text input field where patients are encouraged to record their perceived emotions, activities, experiences, and interactions with other people of the previous day. Adding pictures, videos, or voice recordings to diary entries can also provide a more vivid recollection of that particular day. The goal of keeping a diary is to help reinforce positive thoughts when looking at past entries and to promote self-reflection. Patients are also encouraged to record negative events as well so that they can reflect and learn from those past experiences. Patients can decide whether to share these entries with their therapists to use the information for future therapy sessions or keep them private - which is the default value. All data can be sorted weekly, monthly, and yearly and can be enhanced with statistical data. Figure 5.2 shows the diary feature within the app.

Tasks Tasks is a calendar feature that can be used for both therapy-related and private appointments. Users will be presented with an overview of their day so that they get a stronger feeling about being involved in the therapy process. An appointment should always contain information about a session's beginning and end time, the assigned therapist, and the room. Users should get a reminder via a push notification. Patients can add additional private appointments, e.g., planned visits from relatives. These custom appointments can also be marked as public so that the therapist can see them as well.

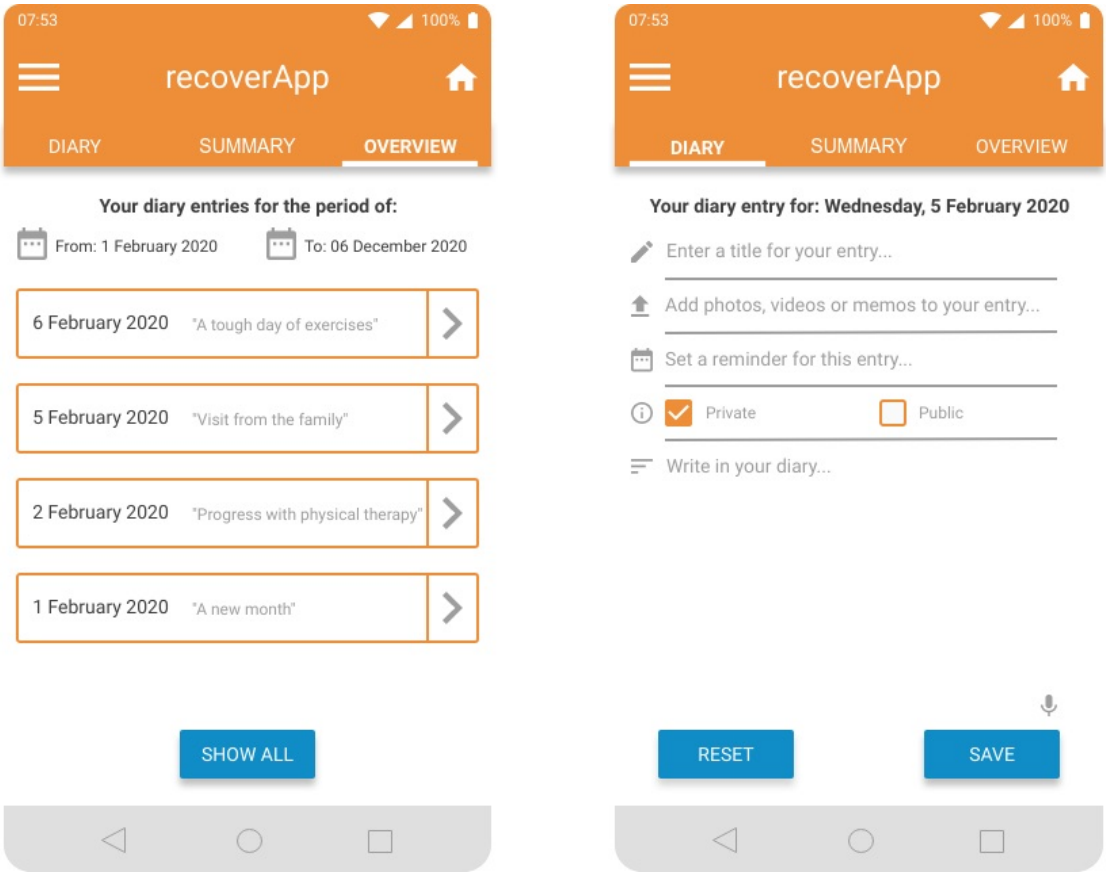


(a) Overview (b) Entry

Figure 5.1: recoverApp: Mood-tracking [28]

All therapy-related tasks are going to be added by the therapist. The app can display current, past, and future daily routines. Figure 5.3 shows the schedule feature and how to add a new task within the app.

Challenges A major problem for patients suffering from depressive disorders is increased anergia, which, in turn, can cause more negative thoughts, which can lead to a downward spiral [219]. Challenges are designed to be short tasks that patients can perform to increase their activity level and promote positive emotions. The app displays a list of tasks that users can choose from. These challenges can be based on mental or physical activities. They can be related to the therapy or completely unrelated, technology or socially based, and should help to improve certain skills of the patient. Usually, these challenges will be short and easily solvable. Some examples are taking a walk, solving a crossword puzzle, conversing with a fellow patient within the rehabilitation facility, relaxation exercises, meditation, or simply reading an article about depression. All the above-mentioned challenges should be helpful in increasing mental and physical

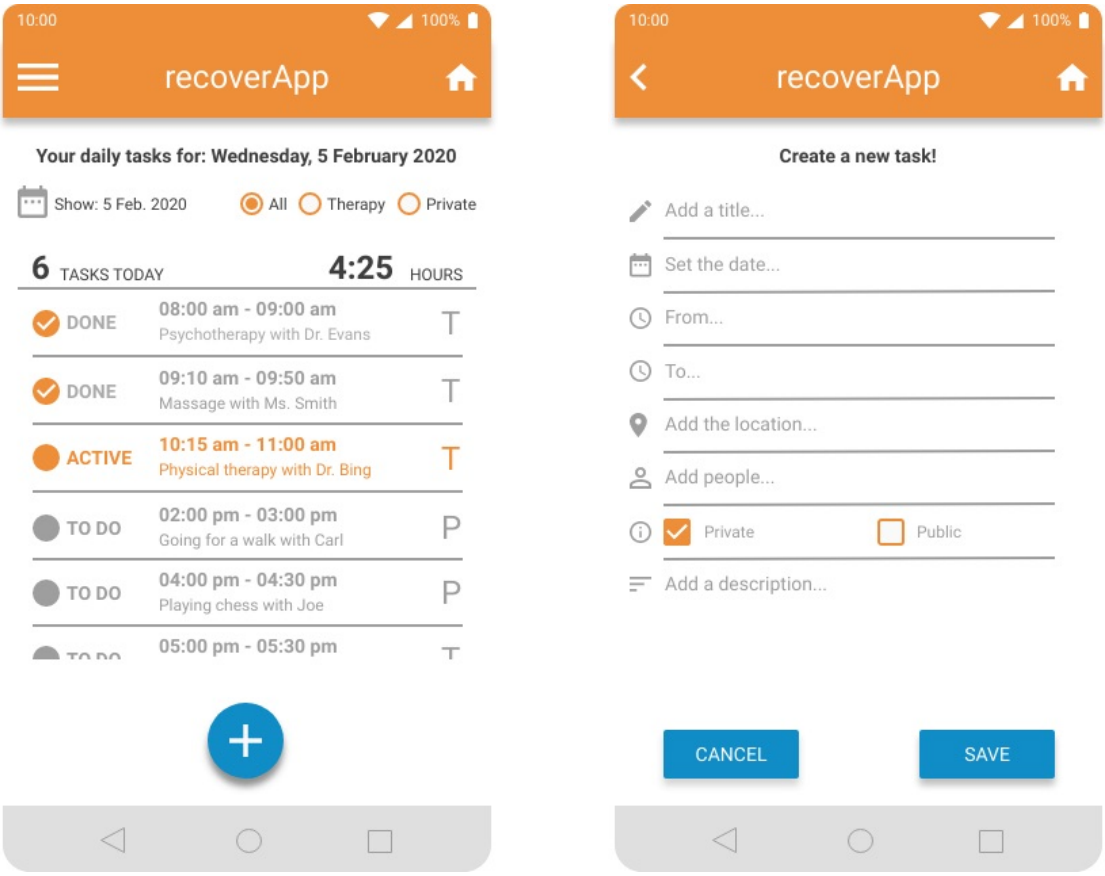


(a) Overview (b) Entry

Figure 5.2: recoverApp: Diary [28]

activity, enhancing social interaction with peers, learning coping skills, and increasing psychological education.

Skills recoverApp depicts the goals set in a patient's therapy plan as part of the skills feature so that they can be more easily achieved. A skill can be an ability like coping with a situation or a quality like being robust or self-assured. Skills can also concern the improvement of the physical constitution to progress within the physical therapy, for example, improving motor skills. Users can collect skill points by successfully completing challenges to improve the aforementioned skills. The skill points will be assigned to one or more skills upon completion of a challenge. The amount of points for a challenge depends on its content and goal. The therapist can define and enter the number of skill points for a particular challenge in the web application. The app will provide the patient with the distribution of the points on all available skills. Skills may be created by therapists or by patients themselves. Figure 5.4 shows the app's skill chart and challenges overview.

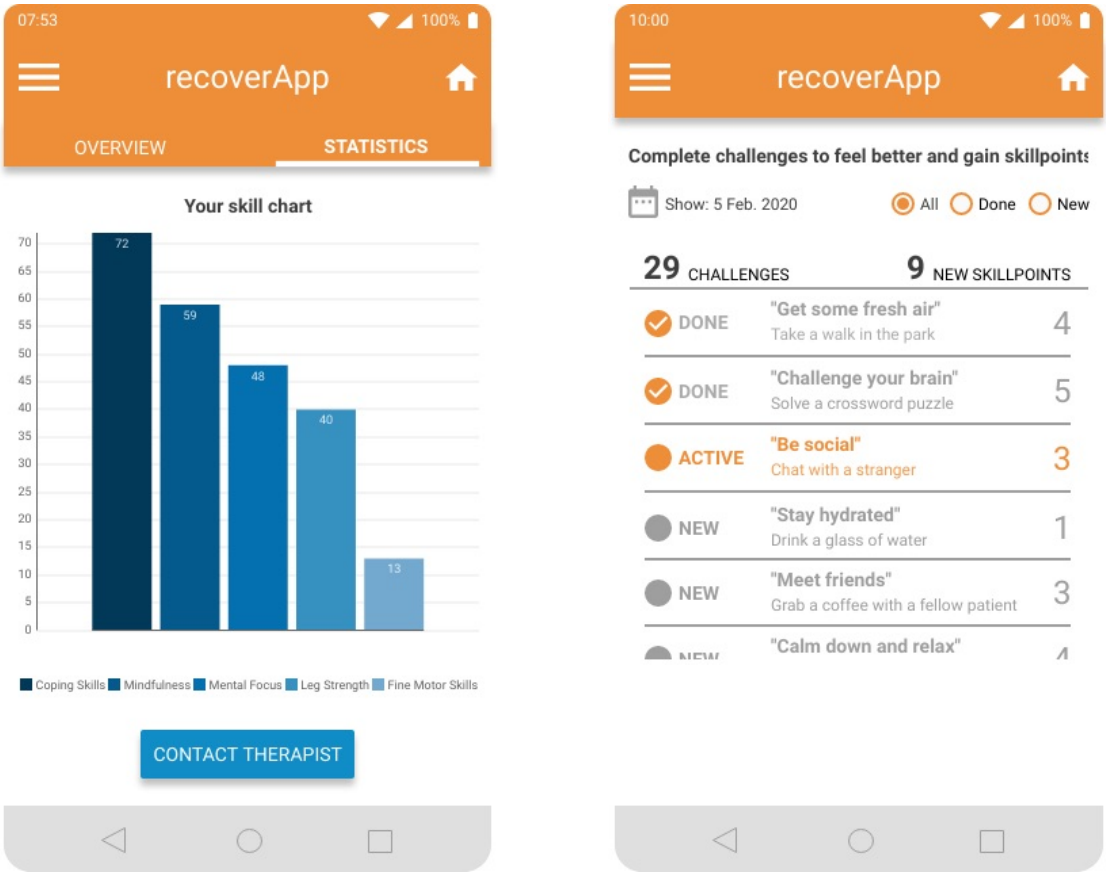


(a) Schedule (b) New Task

Figure 5.3: recoverApp: Tasks [28]

Chat The chat function is an instant messaging feature that patients can use to communicate with other patients within the same rehabilitation facility or with their therapists. The app will provide different channels for users to talk about specific topics. This feature should increase social interaction and connect patients facing similar problems, conditions, or interests. That particular feature should soften initial social barriers between strangers.

Web application for Therapists The web application for therapists incorporates all administrative functions that correspond with the features of the mobile application. The web app displays an overview of all supervised patients. By choosing a patient from the list, the details of that particular patient are shown. Therapeutic personnel can access basic claim data, mood tracking entries and visualizations, shared diary entries, existing tasks, completed challenges, and skills. Therapists can also use the chat feature to communicate with their patients.



(a) Skill chart (b) Challenges overview

Figure 5.4: recoverApp: Challenges/Skills [28]

The web application enables them to react to gathered patient data, for example, directly, certain negative events that require immediate counseling, low mood, or certain diary entries about suicidal tendencies. Patients should feel supported and receive more targeted help through those interventions. Therapists should also react to positive events by awarding skill points for successfully completed challenges. These measures should introduce a feedback system to enhance the therapeutic relationship and increase the patient's motivation for their therapy. Figure 5.5 gives an example of the patient overview screen.

Evaluation The application design was presented to a group of two therapists in the form of mockups and corresponding technical descriptions. These therapists work in a facility that specializes in oncology care. One of them is the head of the therapy department, and the other is the site manager. They are currently not using any technology that assists the therapy process. However, they note that their colleagues from occupational therapy are using serious games.

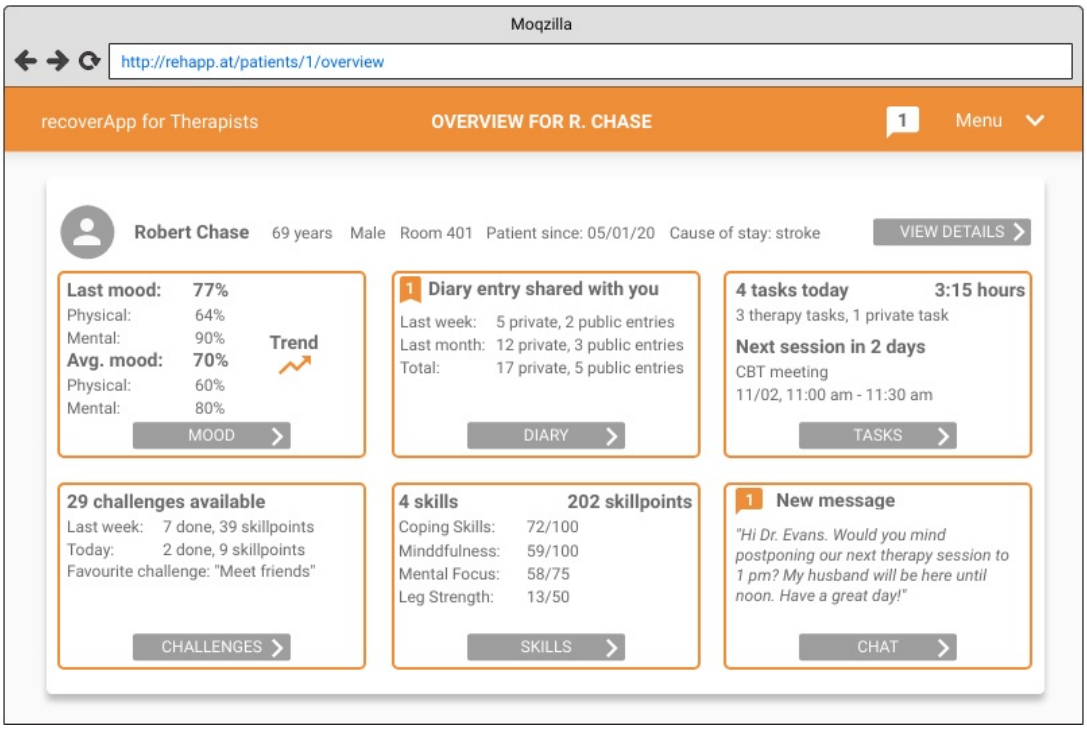


Figure 5.5: recoverApp: Overview of the web application [28]

According to the involved therapists, mood data should be recorded at the same time daily so that the results do not get distorted due to disremembering or suppression of negative incidents or emotions. For the visualization, the focus should lie on positive trends since mentally impaired patients lean toward negative emotions and thoughts.

According to the involved therapists, the diary feature can lead to a shortage of therapeutic resources. Doctor-patient relationships can suffer if therapists do not have enough time to read through all diary entries. Patients can, therefore, feel neglected if they cannot acknowledge that therapeutic resources can be limited. According to the therapist, such a diary feature could be more beneficial to non-stationary treatment.

Both therapists think that the task feature could be beneficial. They wish for an import function to integrate appointments from existing systems.

Challenges are especially suitable for therapy-related tasks on weekends. These supplementation tasks could help therapists with their workloads and may also benefit the patient's recovery. A predefined catalog of challenges and skills therapists could choose from would be especially beneficial since therapeutic resources are very limited. The involved therapists also stated that the gamification approach for skills could induce "child-like" feelings in patients, further enhancing their motivation to solve therapy-related tasks.

Both therapists expressed skepticism about the chat function, fearing that it could lead

to more work for them.

Discussion

The proposed rehabilitation framework, recoverApp, comprises a mobile app for patients and a web platform for therapists. It presents a novel approach for supporting patients suffering from mental health issues caused by prolonged stays in rehabilitation facilities. This platform should benefit patients and therapists.

The state-of-the-art analysis conducted by the authors has shown that mobile apps can be effective in treating the mentioned problems and can be applied very flexibly. Some of them are already widely used. Incorporating the needs of therapists by designing an integrated platform represents a novel approach, in the author's opinion, and should support both patients and therapists with their needs during prolonged stays in rehabilitation facilities.

Summary and Next Steps

The design for an app framework presented here is intended to support patients in overcoming certain psychological problems that occur during prolonged periods of recovery in special facilities. The design is based on initial brainstorming and state-of-the-art analysis that was consequently improved by valuable feedback from the two involved therapists. Although only two experts gave feedback, the work presented here is still considered a very good starting point for further research.

The next steps will be the prototypical implementation of the innovative solution presented here to support people in stationary rehabilitation. Afterward, a bigger evaluation will be conducted in a participating rehabilitation facility to gather more data on the benefits for patients and therapists. These results should give a better indication for further in-depth activities to support people in stationary rehabilitation, ideally helping them through their daily activities and eventually helping them get well as soon as possible.

5.1.2 Food Pyramid Escape - A Serious Escape Game for Nutritional Education

Note: A version of this whole section was published by Aigner et al. in [29].

Food plays an important role in everyday life. It keeps the human metabolism up and running and can also hugely affect personal health. Despite the many food options people can choose from nowadays, some still tend to prefer unhealthy food. Such malnutrition can lead to severe medical problems like metabolic syndrome, diabetes mellitus, and cardiovascular diseases. Many people seem to lack nutritional knowledge and, therefore, often make poor food choices. Health promotion, which strives to empower people to care for their health, aims to take effective countermeasures for the aforementioned problems.

Currently, most Austrian health promotion interventions only rely on information material and workshops and are mostly aimed at specific target groups (e.g., minors or the elderly). Therefore, a serious game called Food Pyramid Escape, which has the potential to aid health promotion in Austria and beyond, is proposed. Food Pyramid Escape is a serious escape game that conveys nutritional knowledge by wrapping it into a coherent story with diverse riddles and mini-games. It is targeted to a wide audience. The game can be used as a standalone nutrition intervention measure or together with additional information material and workshops for larger-scale intervention plans.

Results

A mobile serious game named Food Pyramid Escape was developed as a standalone nutrition intervention for the Android platform. The target group was determined to be 18-to-50-year-old omnivores with limited health literacy. Seven levels were designed based on the Austrian Food Pyramid and nutrition recommendations, allowing the user to explore their nutritional knowledge.

Requirements Following the methodology described in the subsection "Methods," 18 requirements were identified throughout the overall process. These requirements were derived from the state-of-the-art analysis, and feedback was gathered during the evaluation phase. The requirements are depicted in Table 5.2.

Designed Prototype The following section describes the developed prototype. Starting with the game's general structure and continuing with a more detailed description of the implemented features according to the derived requirements.

The idea for the game is based on the Austrian food pyramid, which consists of seven layers. Each layer represents a certain food group. More details on the different categories can be found in the paragraph "Levels." The different layers of the food pyramid are the foundation for each game level. Therefore, seven levels were designed, each representing one layer of the food pyramid. Each level consists of multiple rooms. At every level, knowledge from the specific category is transcribed to the player whilst playing the game. The content of the game contains information on all classes of nutrients, their purpose, sources, deficiencies, toxicity symptoms, and recommendations on physical activity.

At the start of the game, the player is located in a pyramid, where riddles need to be solved to progress to the next room and ultimately complete the game. The player can move freely through the pyramid and talk to different objects and food items. By interacting with these items, the player gains nutritional knowledge that helps solve the riddles. Non-player characters are crucial to the gameplay as they serve as an interface between the learning content and the player. The underlying story unfolds by maintaining dialogues and reading additional notes that are collected throughout the game. Other items are placed in the level and can be collected by the player to solve different riddles. The player can interact with these items via an interaction menu (as seen in Figure 5.6, which shows various options. The player can interact with the item, which, in this case,

Table 5.2: Food Pyramid Escape: Requirements [29]

Req. ID	***Description***
R16	Represent the seven levels of the Austrian Food Pyramid
R17	Communicate subject matter using riddles in the game
R18	Solving the riddles contributes to reaching the game goal
R19	Each finished level unlocks the next one
R20	Finished levels can be revisited
R21	The game status can be resumed after leaving and restarting
R22	The instructional goal is well defined by a curriculum
R23	The subject matter is summarized in an encyclopedia
R24	The player can interact with the game environment
R25	A riddle's progress is communicated using feedback
R26	The riddles' difficulty increases linearly with the player's knowledge
R27	The taught knowledge is correct and taken from respectable sources
R28	Recommendations are suitable for Austrians, age-specific, and for omnivores
R29	Emphasis lies on teaching information to help shift dietary shortcomings
R30	Deepening knowledge is available but not game-relevant
R31	No foreknowledge on nutrition, chemistry or biology is necessary
R32	The nutritional knowledge is taught one section at a time to avoid an information overload
R33	Food-based intake recommendations are used

is a glass of water, by adding it to the inventory, viewing its content, or drinking it. The menu on the right gives the player additional options, such as to pause the game or access hints (more detailed information on hints can be found in paragraph "Hints"), open their current inventory (see Figure 5.7), or browse the encyclopedia (see Figure 5.12).

Riddles A core feature of the game is the aforementioned riddles. They are solved by using nutritional knowledge earned while playing the game. The different types of riddles, their descriptions, and where they are used within the game can be found in Table 5.3.

Unsolved riddles are marked with a question mark. If the player has already started solving them, the state changes to "in progress," and they are marked with three dots. Once a riddle is solved, the state is visualized with a green checkmark. Figure 5.10 shows the visualization of the three different states of riddles.

Levels According to the intervention plan described in the previous chapter, the levels are based on the food groups defined in the Austrian food pyramid. The content of each

Figure 5.6: Food Pyramid Escape: Interaction menu [29]

Table 5.3: Food Pyramid Escape: Types of riddles [29]

Riddle	***Type***	***Description***	***Usage***
RI01	Fetch and bring	The player must fetch certain items and bring them to a character (using the inventory of the bag, which can be seen in Figure 5.7)	Level 1 (Room 1) Level 1 (Room 4)
RI02	Moving objects	The player must move objects into a specific area to open a door	Level 1 (Room 2) Level 2 (Room 2)
RI03	Quiz	The player must pick the correct answer of two options; see Figure 5.8	Level 1 (Room 3)
RI04	Category-quiz	The player must assign items to their correct category	Level 2 (Room 1)
RI05	Food bounce shooter	The player must shoot items fulfilling certain criteria, see Figure 5.9	Level 2 (Room 3)
RI06	Count-riddle	The player must count items fulfilling certain criteria	Level 2 (Room 4)

level is based on the food group of each layer from the food pyramid. An overview of the layers can be found in the chapter "Theoretical Foundation."

Figure 5.7: Food Pyramid Escape: Player's inventory [29]

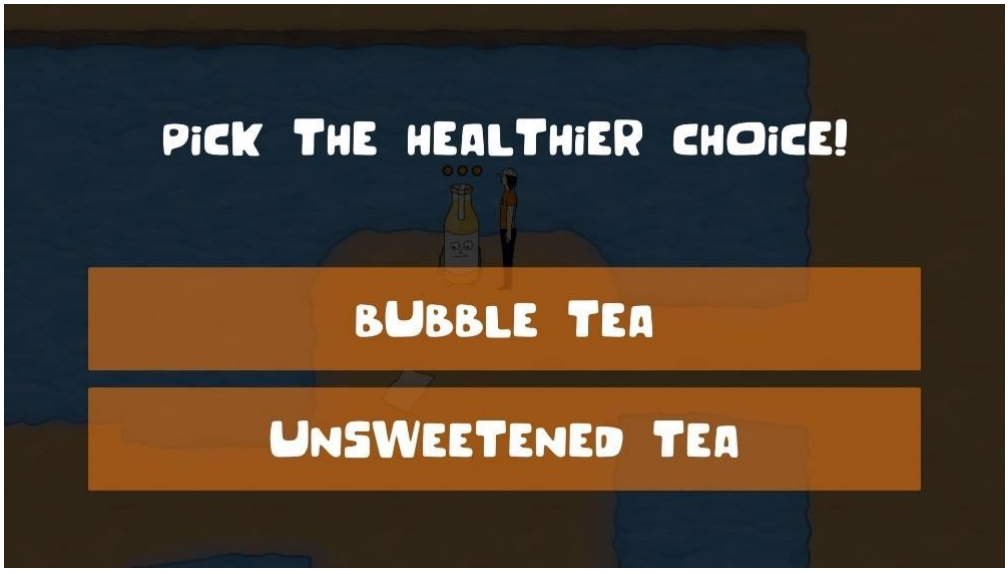


Figure 5.8: Food Pyramid Escape: Quiz view [29]

Within the scope of this research, the first two levels were implemented to serve as a proof of concept. The basic mechanics remain the same throughout the game, but the gameplay varies from level to level to avoid boredom. The first level is named "Waterway," and the theme is a desert. That was chosen because liquid is a rare commodity in the desert, and thus, it should teach the player the importance of liquid. The topics covered are non-alcoholic drinks and general nutritional knowledge. The second level is called "Vitamin Forest" and focuses on the difference between water-soluble and fat-soluble

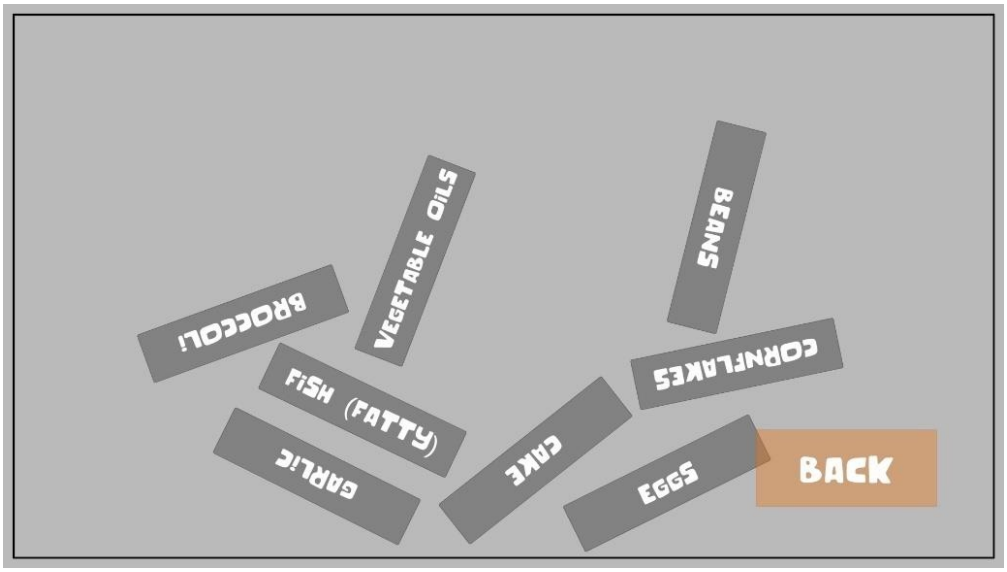
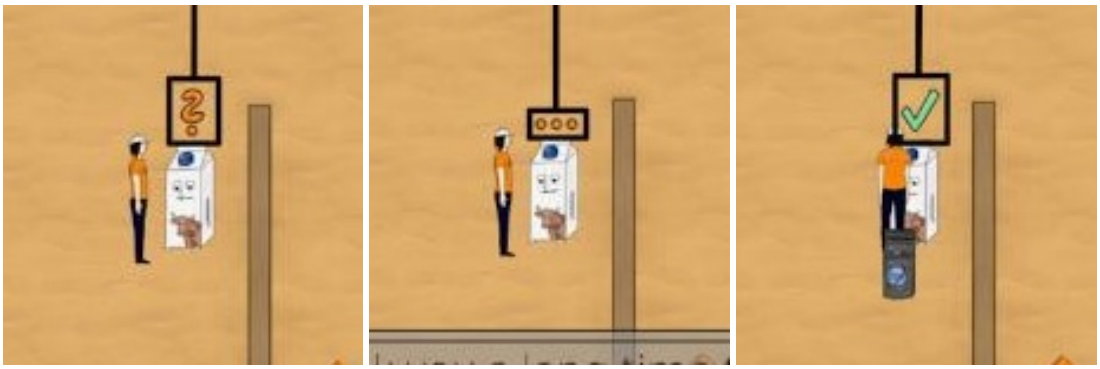


Figure 5.9: Food Pyramid Escape: Food bounce shooter [29]



(a) Unsolved riddle (b) Riddle in progress (c) Solved riddle

Figure 5.10: Food Pyramid Escape: Different states of riddles [29]

vitamins.

Four riddles were designed for the first level. The curriculum content covers different types of nutrients, the average needed food intake, factors that influence energy requirements, and the recommended daily intake of water.

The player starts in an anteroom and is welcomed by a talking door and a bookworm that explains the encyclopedia function. More detailed information on the encyclopedia can be found in the paragraph "Encyclopedia." When the door is passed through, the first level begins, and the following rooms have to be mastered:

- Room 1

  - Subjects: What types of nutrients exist? How much energy (in kcal) from foods does the average man/woman need daily, and which factors influence the energy requirements?
  - Riddle: Collect and bring the correct amount of energy (in kcal), representing the average calorie requirement for a human, in the form of astronaut food, to the room's character. Then, more information about energy consumption is described by the character.

- Room 2
  - Subjects: What does the human body need water for? What influences the water demand of humans? How much percent of the human body is water?
  - Riddle: Move the correct amount of water in tanks to a weighing area.

- Room 3
  - Subjects: What are healthy thirst quenchers? Of what beverages should one consume less?
  - Riddle: Solve a quiz (see Figure 5.8) provided as a dialogue with the room's character, in which the healthier food choice must be ticked. The correct answers provide the order of a numeric code that must be extracted from the answers' representations in the encyclopedia.

- Room 4
  - Subjects: What is the recommended daily intake of water? What are the consequences of excess water intake? What are the consequences of insufficient water intake?
  - Riddle: Collect and bring the correct amount of water, which a human should drink daily, in the form of glasses to the room's final door that leads to the next level.

Encyclopedia The encyclopedia is the in-game representation of the curriculum and, thus, one of the game mechanics that convey the nutritional knowledge in the game. It is separated into chapters and sections. Each chapter contains the subject matter for one level, and each section contains the content of one encyclopedia page that can be found in the game. The encyclopedia's pages are spread over the levels' maps and must be collected by a player to form the final and complete book. Figure 5.11 shows how the player can find a loose page of the encyclopedia, and Figure 5.12 gives an example of the content of a collected encyclopedia page. It serves two purposes: Mainly, it is a knowledge base where all relevant information is collected in more detail than in the game itself. It can be accessed at any time by clicking on the book at the level's menu (see Figure 5.6) and is a good starting point to get deeper into the subject if one is interested.

Figure 5.11: Food Pyramid Escape: Page to collect (active hints) [29]

Moreover, the encyclopedia holds hints and information that are needed to solve some riddles; for example, some words contain numbers (e.g., "orange7juice"), which form a numeric door code when put into the correct order. Thus, also players who are not particularly interested in gaining some extra knowledge are encouraged to take a look at the encyclopedia from time to time and, therefore, expand their knowledge even further.

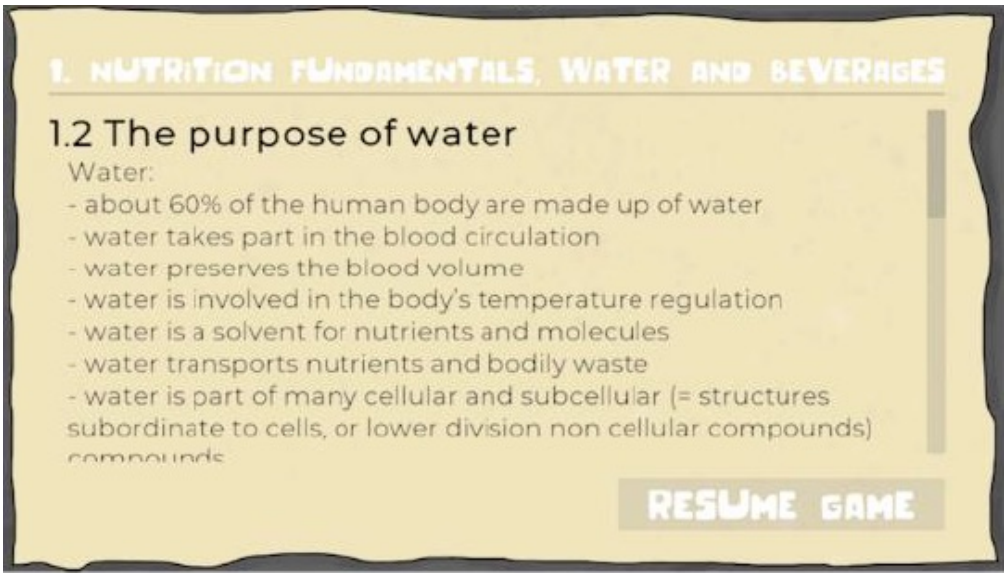


Figure 5.12: Food Pyramid Escape: Encyclopedia page [29]

Hints Hints are an in-game helping mechanism that ensures help is accessible anytime. They can be activated via the options that can be accessed by pushing the "Pause" button that can be seen in Figure 5.6. Hints contain two types of effects:

- Exclamation marks highlight important objects for solving the current quest.
- The total number of encyclopedia pages at the current level is shown together with the number of pages already collected.

Both hint mechanisms can be seen in Figure 5.11.

Evaluation The final prototype was presented to two people with different prior knowledge and nutritional education backgrounds. The diverse prior knowledge helped the authors gain a wide range of feedback despite the small group of participants. The participants were asked to play the game and interviewed both before and after their playtest to evaluate the prototype. The participants are described in more detail in the following:

- P1: A 23-year-old who possessed some basic knowledge about nutrition, acquired in school and from friends, but was not particularly interested in nutritional knowledge.
- P2: A 27-year-old whose nutritional knowledge was above average and originated from being a subject during the person's master's study and from personal interest and motivation due to a vegan lifestyle.

The overall impression the participants had was a good and positive one, especially since the game's design, characters, and storyline were highlighted positively. The major criticism on which both participants agreed was that some of the riddles felt lengthy, complicated, and, at times, confusing and frustrating. Concerning the intended educational purpose of the game, both stated that a learning effect could be observed (i.e., they learned something new). However, the scope and amount of theoretical information (particularly the encyclopedia and its contents) were sometimes perceived as quite overwhelming. Finally, the game was rather seen as one part of an intervention since this app alone was not recognized to be suitable for raising awareness about healthy nutrition and lifestyle.

Based on these results, the following major updates of the intervention plan and the game itself were worked out:

- Additional learning material should be created to extend the existing intervention plan, such as an information booklet or workshops.
- The encyclopedia should be split into smaller sections, contain pictures and more headings and paragraphs to be understandable more easily and not put off the player from reading it.

- The single riddles should be split into smaller steps and should be generally reworked to be easier, more intuitive, and include the subject matter.

Discussion

The research proposed as part of this thesis presents a novel approach for a serious game called Food Pyramid Escape for nutritional education that can be used as a standalone intervention or as a specific measure in a nutrition intervention concept for larger target groups in the context of the Austrian health promotion and beyond. Food Pyramid Escape is a serious escape game that conveys nutritional knowledge by wrapping it into a coherent story, diverse riddles, and mini-games. Its development was achieved in three phases: a research, a game design/implementation, and an evaluation phase.

State-of-the-art analysis has shown that most work targets specific target groups (e.g., minors or the elderly). Food Pyramid Escape, on the other hand, is targeted to a wider audience.

The game was well received by the playtesters. The story, visuals, and character-building aspects were especially praised. However, some riddles were perceived as too complicated, and the subject matter presented in the game was too extensive. The prototype presented only implemented the first two levels, but the additional five levels were already designed as part of the research work.

Even though only two people participated in the evaluation, the authors think this work represents a solid foundation for further game improvements and more comprehensive trials with larger test groups.

Summary and Next Steps

Food Pyramid Escape incorporates a very intuitive gameplay and is, therefore, easy to use. Playtests of the game have shown that the subject matter presented in the game was too extensive. This observation led to an adaption of the requirements concerning the subject matter. It should be presented more visually appealing and in smaller portions of information at a time. Further changes concerning the usability of the game were noted. In general, all found requirements were validated as necessary; however, not all were found to be implemented in a way that satisfied the user's expectations.

In the authors' opinion, Food Pyramid Escape and serious games in general are most efficient as single measures in larger-scale interventions. The greatest potential for Food Pyramid Escape is seen in the combination of information material and workshops that can also cover more practical aspects of nutrition, such as choosing healthy foods and applying intake recommendations in everyday life. This way, the game could contribute more efficiently to new or existing Austrian nutrition interventions.

The next step in this work will be implementing the remaining five levels to map all seven pyramid layers to actual levels in the game and make them more applicable as intervention measures. The next iterations of the game should also include further

challenges and goals, various difficulty levels, additional audio and video content, the incorporation of multiplayer modes, and even AI approaches for the level design.

The pretesting stage group was rather small, containing only two participants. Therefore, a bigger evaluation is planned in collaboration with a nutritionist, an educator, and more playtesters.

5.1.3 BreathIn – A Serious Game For Smoking Cessation

Note: A version of this whole section was published by Aigner et al. in [31] and [32].

Smoking is still a worldwide phenomenon and a big health issue that needs to be combated. Smoking cigarettes is linked to many serious illnesses and causes an estimated six million deaths per year. Tobacco users are more likely to quit if they have better knowledge of specific health risks caused by their tobacco consumption. Overcoming this addiction caused by nicotine is often very difficult both on a physical as well as a psychological level, and most smokers fail to stop, especially on a long-term basis. It has been shown that the success rate of stopping smoking increases when smokers use some form of further assistance. Therefore, a novel serious game called BreathIn is suggested to support the process of smoking cessation. An iterative design study was conducted after a comprehensive literature review and a state-of-the-art analysis. During a total of three iterations, responses from 304 participants with the help of an online questionnaire and nine additional interview partners were collected and ended up in the definition of 12 final requirements, which were used for the definition and design of the serious game (low-fidelity prototype). The prototype was then subsequently evaluated by six users and one psychiatrist in the third and final iteration.

Afterward, a high-fidelity prototype for the Android platform was constructed. The subsequent playtest with seven people, which consisted of a short introduction, a playing phase, and a feedback round containing a predefined questionnaire, offered insights into this approach's effectiveness and highlighted improvement areas by extracting 12 suggested adaptions, ultimately contributing to the ongoing discourse on leveraging technology to combat the global smoking epidemic and subsequently help prevent NCDs.

This serious game was published in two parts at two separate conferences. The two parts were merged and edited for readability and clarity.

Results

This section describes the results from the three iterations of the first stage and also the prototypical implementation and playtest of the second stage. The questionnaire from the first iteration was filled out by a total of 304 participants (171 identifying as female, 130 identifying as male, three identifying as other or gender was not specified), of which 75% (n=228) have smoked at some time or are actively smoking. The questionnaire

was separated into different types of questions. There were general questions (e.g., age, gender), questions about smoking behavior, questions about serious games, and an optional quiz to evaluate the participants' knowledge about smoking. The most noteworthy results of the questionnaire are summarized subsequently.

The questions about smoking behavior showed that 51% (n=155) want to quit smoking in the future. It was found that younger participants in the age group of 18 to 30 were more willing to quit. The top three reasons to quit smoking were personal health, saving money, and the wish from other people for them to quit. 73% (n=222) of all participants, currently smoking, tried at least once to quit smoking before. On average, they tried two to three times without success. 20% (n=61) also used some form of medical aid, nicotine replacement products, professional help, or digital support. The reasons why the attempt to quit smoking failed for some participants were a lack of motivation, reasons to keep going, withdrawal symptoms, or social settings. 45% (n=137) of currently active smokers would use a mobile application for support, and 67% (n=204) would rather use a mobile application instead of seeking professional help to get support with quitting smoking.

The participants were asked if they knew what serious games were, but only 9% (n=27) had heard of these types of games. As part of the questionnaire, they also got a short description and a definition of serious games. Afterward, 23% (n=70) said they would consider using a serious game to support them with smoking cessation, and 57% (n=173) said that they were not sure yet and would need more information about it. The preferred device to play a serious game, which was also questioned, should be a smartphone or tablet with 80% (n=243), followed by a computer with 16% (n=49) and a gaming console with 4% (n=12).

The last part of the questionnaire was a quiz to determine the current knowledge about the effects and consequences of smoking. Overall, there were 12 questions with different answer possibilities. This part of the questionnaire was optional, and 157 people participated. These participants were aware of the dangers of smoking and did not know about health consequences like cancer. A lack of knowledge was found on the impact of nicotine as a neurotoxin, addiction, withdrawal symptoms, and the effect of smoking on the human body. They were unaware of the impact on health, and the risk of developing a disease from smoking was underestimated.

In the second iteration, 9 participants were interviewed (6 identified as male and three identified as female). To have a variety of opinions, participants were selected with different gender, ages, and smoking behavior. The participants were categorized by their smoking behavior: active smoking, successfully stopped smoking, and never smoked. The interview questions were prepared for each group individually. Former smokers and active smokers were asked about their motivation to start and quit smoking and the use of any aids (medical or technical). At the same time, people who never smoked were asked about their motivation not to smoke and their view on aids to support smoking cessation. All groups were asked about their knowledge of serious games and the health consequences related to smoking.

In total, two non-smokers were interviewed as part of the first group. They had the most awareness of the risks and consequences of smoking. For the second group, people who successfully quit smoking, a total of 3 people were interviewed. Health was the biggest impact for them to stop smoking. They also stated that they probably would have stopped earlier if they had known more about the consequences. The interviewed participants also stated that goals and motivation were important factors in successfully quitting smoking. Another important factor is to change routines. Smoking is often psychologically linked with certain activities (e.g., partying), and these links need to be severed. The third group consisted of people who were actively smoking. A total of 4 participants were interviewed within this group. They mentioned that they lack the motivation to quit smoking and that withdrawal symptoms are stronger than the positive aspects of quitting. It could be found that they have a lack of risk awareness compared to the other groups. People who actively smoke also think that health-related issues will not affect them personally.

Based on these findings of the questionnaire and the individual interviews, requirements for the serious game were identified. These requirements are listed below in Table 5.4 with a description of how they were integrated with the design of the serious game.

Table 5.4: BreathIn: Requirements [31]

Req. ID	**Requirement**
R34	The user defines the personal reasons and goals to quit smoking. These are permanently present in the application so that the user is frequently confronted and, therefore, remembers the personal goal.
R35	To create new routines and provide an alternative behavior to smoking, the serious game needs to be played every day. With challenges or levels, the game animates the user to interact with the application regularly. Therefore, a new behavior is trained.
R36	Health and strength of the avatar mirror the health of the user. The health of the avatar is improving as the user keeps being abstinent. Therefore, the avatar's health symbolizes the positive effects of not smoking. By tracking the last smoked cigarette and reporting any relapse, the user is monitoring one's behavior and is more motivated to stick to the goal. With the avatar getting stronger, new challenges and levels are unlocked.
R37	Negative consequences in-game: The game continuously reminds the user of the negative consequences of smoking through specific challenges where the avatar is persuaded to smoke a cigarette. The user needs to decline the offer; otherwise, the avatar is weakened. Another idea is a game where the user must avoid cigarettes that are thrown toward the avatar.

Req. ID	Requirement
R38	Negative consequences triggered by real-world events: If the user smokes a cigarette, the days since the last cigarette are reset to zero, and the avatars' strength is also set back to the initial strength. This action is supposed to show the user the negative consequences of smoking.
R39	The design and graphics are selected to represent the progress. In the beginning, the avatar is visualized with dark colors, and the stronger the avatar gets - with continuous abstinence from the user - the brighter and more colorful the avatar will become. This is also true for the environment around the avatar to visualize that smoking is also affecting the surroundings.
R40	To keep the user interested, the game should have a story. The avatars' goal is to reach the user-defined goals. On the path, the avatar is followed by enemies who are trying to persuade him or her to smoke a cigarette. The user must throw cigarettes at these enemies. The enemies will smoke those cigarettes and get too weak to catch up with the avatar. On the path, the avatar can rest on checkpoints where he or she is saved from enemies. Mini bosses need to be defeated to reach a checkpoint.
R41	Riddles should be included in the serious game to offer some form of distraction to the user. They are either part of a level or can be solved spontaneously to distract the user from the urge to smoke. These riddles are built like quizzes where the user answers facts on smoking and smoking cessation. This also increases the user's knowledge and the motivation to protect one's health.
R42	Achievements and positive feedback. The serious game tracks the last smoked cigarette. Every day the user opens the application, he or she is reminded of the days that have passed since the last smoked cigarette and gets positive feedback (motivational quotes). The application also reminds the user of the progress towards self-defined goals. For every completed week of smoking abstinence, the user gets a special achievement with newly unlocked items that can be used within the game. These items can be clothes to outfit the avatar or give the avatar a health boost.
R43	Social support: To enable social interaction, events from the game can be shared on social media. The user can share achievements and milestones that have been reached. This enables positive feedback from family and friends.
R44	Music and sound effects are used for different interactions. When the avatar moves through the scene, background music is played, and the music changes when an enemy appears. For successfully unlocked achievements, the sound effects should be happy and motivational. This helps the user perceive information and match interactions to resulting actions accurately.

Req. ID	Requirement
R45	The game should be played for a period of six months. There must be enough levels so that users can achieve their goals within those six months. A level itself should last for about five minutes.

Based on these requirements, mockups were created with the online tool Figma [220]. The game was designed with the device held in landscape mode in mind. The main color that was chosen for the mockups was green because that color is associated with life, nature, and health [221]. The illustrations were acquired from unDraw [222].

When the user starts the application for the first time, they will be greeted by onboarding screens. These will collect information about the user and explain the gameplay. First, the user will be asked for some personal data (name, age, gender, smoking status). This information is used to calculate the achievements to quit smoking. After that, the user will be asked to define three personal goals, which can be monetary or health-related. The user can also upload images to visualize these goals better. After that, the user will be asked to name the date of the last smoked cigarette. This will start the time tracker and will calculate the corresponding achievements. The user is also given additional motivation on this screen with facts about health improvements after quitting smoking. After that, users can customize and name their avatars. This is important so that they can identify with their avatars. When the avatar is customized, the next screen will describe the avatar's skills and how not smoking will increase the health and strength of that avatar. This is followed by screens that describe the gameplay. Enemies will try to persuade the avatar to smoke, and the user needs to resist the temptation. Each level has an end boss. The user has two possibilities to avert the temptation, either by solving a riddle about facts on the topic of smoking or by playing a mini-game, where they throw cigarettes at the enemy to win. After defeating the enemy, the user gets to a checkpoint and can continue to the next level. In case the player loses the level, he or she must play it again. Another important fact about the gameplay is that the user must reach a checkpoint at least 5 days per week. If this is not done, the user cannot unlock new checkpoints within the next week and can only play the already unlocked levels.

When the application is opened again, the onboarding screens are skipped, and the user gets to the map view directly. This view tells users their current progress. Levels marked in blue are already unlocked, whereas levels marked in red need to be mastered. The user also sees at which level he or she is currently, and at the top of the screen, the bars show the avatar's energy and health. The map icon in the top left corner brings the user to exactly this view. The menu icon in the top right corner will open the menu.

Figure 5.13a shows the platformer core game mechanic. The player must run away from the enemies, who symbolize smoking skeletons. While running away, the avatar can throw cigarettes at them. The avatar must also jump over obstacles to get away from the skeletons. When a skeleton gets to the avatar, it loses strength and becomes slower; after being caught by three enemies, the avatar becomes too slow and must restart the level. The avatar can be controlled by on-screen buttons. Each level ends with an end-boss,

as seen in Figure 5.13b. The user must correctly answer a single-choice question. If the answer is correct, the next level will be unlocked. Otherwise, the avatar loses energy and strength and must replay the level.

(a) Mockup of the platformer game play

(b) Mockup of the encounter with the boss

Figure 5.13: BreathIn: Screenshots of low-fidelity prototype [31]

When reaching milestones, the user receives achievements, showing the user the progress towards the personal goals and the time that has passed since the last cigarette. Through the menu, the user can report a relapse. When the user cannot resist smoking a cigarette, the user can enter the date when it happened. This resets the energy and strength of the avatar to the initial level. The menu also enables the user to change settings or share achievements on their social media accounts.

In the final iteration, the mockups and designed gaming elements were shown to a group of six people, who were chosen from the group of iteration 2 and a practicing psychiatrist. Overall, the game idea was received very positively. The game was interesting to use, seemed fun to play, and the concept was easy to understand. Two older persons over the age of 50 had problems with the interface and the controls. The psychiatrist, who

works at the University Clinic for Psychiatry in Vienna, Austria, agreed that a playful approach can be a good intervention method for smoking cessation. In his opinion, the game could effectively supplement ongoing therapy. He also stated that losing should be an integral part of the game since patients should be confronted with the negative aspects of smoking.

Online Survey As part of this research, a consecutive online survey on digital gaming behavior was conducted in which 162 individuals participated, of which 90.2% (n=146) completed the entire survey. People from various backgrounds and all age groups were chosen, including smokers, non-smokers, and ex-smokers. 51.3% (n=82) of the participants identified as female, 48.1% (n=77) identified as male and 0.6% (n=1) preferred not to disclose. The average time taken for completion was approximately 02:36 minutes. 74.5% (n=114) are playing video games on a smartphone. Only 11.76% (n=18) did mention not to play any video game at all. 53.3% (n=80) believe that a serious game can benefit smoking cessation, even though 78% (n=117) have not heard of serious games beforehand. The survey also showed that the participants prefer puzzle games, platformers, and the smartphone as the medium.

Prototype The prototype was constructed with Unity 3D [218] because of platform independence and because many assets, objects, and sound files are publicly available. The authors also created many game assets themselves. Figure 5.14 shows two screenshots of the high-fidelity prototype.

When starting the game, a menu with different options is shown. Various data must be entered when the game starts for the first time, and an overview of the goal, rules, and mechanics is given. During this onboarding, the name, gender, cigarette consumption, number of cigarettes per pack, and price can be entered. Within the next step, players can set themselves three goals. In the third and last step, the date of the last smoked cigarette can be entered as free text. All this data is used within the game and its personalization. Within a statistics view, it is possible to view statistics about the game and habits ("not smoking since," "money spent," "not smoked cigarettes," "won lifetime," and a reminder about the set goals). An additional achievement view containing 16 different achievements was also included. If someone starts to smoke again, another view allows them to adapt and set a new date to start over.

The game is controlled with a touch joystick and buttons displayed on the smartphone. Players must reach the target zone when the game starts by jumping, running, and shooting cigarettes. On their way, different enemies and obstacles need to be avoided. Enemies are also following the player. When an enemy is hit, the player's energy bar decreases. When it is empty, the game must be restarted from the beginning. This bar fills up again if, for some time, no enemy is hit. To slow down or remove enemies, the player can shoot cigarettes at them (they start smoking them, and their energy decreases). If three cigarettes hit the enemy, it vanishes. In addition, it is not allowed to fall into holes. Some areas within the gaming area can only be reached after some time without

(a) The platformer game play

(b) Encounter with the boss

Figure 5.14: BreathIn: Screenshots of high-fidelity prototype [32]

smoking in the real world (i.e., entering this information into the game), as can be seen in Figure 5.15. By doing so, the avatar can jump higher and run faster. That mechanic works in conjunction with an open-world concept, where the player is motivated to return to previously played parts to reach new hidden areas (where additional cosmetic items can be collected), further explore the game, and thus continue not to smoke. At the end of the level, a boss must be defeated by answering four different smoking-associated questions. They all need to be correct to win the game - otherwise, the level restarts from the beginning.

Figure 5.15: BreathIn: Level overview including hidden area [32]

Playtests The conducted playtests lasted between 5 and 24 minutes and showed that the serious game was very well received but needed to be improved within different areas. Twelve suggested adaptions (abbreviated with "A") were extracted. The movement with the joystick needs to be improved (A01). Enemies were too near after jumping on the first platform (A02), and trees in the hidden level were hard to pass (A03). In addition, it was argued that a checkpoint is needed (A04) to not start from the beginning again. The overall system of shooting was also too complex (A05). The movement speed of the avatar was also posed to be too fast after 15 days without smoking (A06) - which was simulated during the playtests. According to the participants, the general dialog system and its options needed to be bigger to be selected (A07). From a design point of view, the user would like to have different jumping animations (A08). In terms of enemies, it was argued that they should have the possibility to jump to make the game harder (A09), and they should block the way after giving them three cigarettes (A10). The ramp at the end of the level was also found to be too challenging (A11), and the difficulty of the boss as well (A12).

All participants reported having fun navigating their avatars through the level and defeating the mini-boss at the end. The players felt very positive, especially about the different methods that are supposed to help quit smoking. They were also of the opinion that these methods could help stop smoking. Participants P3 and P4 will use the finished serious game to support them if they want to quit smoking.

Summary and Next Steps

In this work presented here, an analysis and a design study were carried out to identify essential elements and concepts for a serious game to stop or reduce smoking. In the beginning, the basics of smoking and smoking cessation, as well as their physical and psychological consequences, were investigated. Afterward, a comprehensive state-of-the-art analysis was conducted that has shown that mobile serious games can be effective in helping patients with smoking cessation. Subsequently, the serious game was designed in a total of three iterations involving multiple users of the target group and a psychiatrist. The result is that BreathIn, a serious game for smoking cessation, has shown to be a valuable assistance to people who want to stop smoking and are also already involved in some form of treatment.

The subsequent prototypical implementation as an Android app showed that integrating

identified requirements within a serious game is feasible, which was also verified by executing a playtest with seven users. Combining a jump-and-run-like game with puzzle elements led to entertaining gameplay and helped educate the users by including quizzes about the negative aspects of smoking cigarettes. These findings were also backed up by the online survey conducted beforehand and show that the author's approach can fit the needs of potential users. The participants played only the first and the 15th day during the playtest. Playing all days within the game consecutively as part of a real-time test should be incorporated into future work to get a better sense of the user's smoking cessation journey. Although the presented results were promising, a few things need to be addressed in future work. A more extensive evaluation with more smokers is one of the most prominent aspects that needs to be done. Since the game is designed to be played for an extended period of six months, long-term playtests must be conducted. This evaluation might also be encapsulated within a clinical trial that finds significant results in terms of usage, especially compared to classic aspects of trying to stop or reduce smoking.

The proposed solution could also be used in conjunction with other domains. Therefore, it is planned to consider the possibility of using these mechanics together within a diabetes diary and an already-established serious game [223]. In addition, other gameplay-related topics should be addressed in future work. Besides more levels and increasing difficulty, the avatar's personalization should also be considered. The current version also does not contain a point system, which might be included by adding collectibles. Shooting cigarettes was also not perceived as an ideal gameplay mechanic. Therefore, this approach should be looked into in more detail as well. Finally, music, sound, and graphical elements like sprites can also be improved to provide an even more immersive and entertaining experience by playing the serious game. Overall, the presented solution should pose a beneficial and easy-to-use starting point for additional and further research possibilities.

5.1.4 Nutrition Garden - A Gamified App For Motivating People to Eat Healthy

Note: A version of this whole section was published by Aigner et al. in [30].

Many people are struggling with making decisions about changing and, more importantly, maintaining their eating habits even though information about this specific topic is very widespread in current media. Choosing the right nutrients for a healthy diet is vital for preventing non-communicable diseases (NCDs) like diabetes or cancer. A large number of applications are available to smartphone users around the world, including mHealth apps (mobile health applications). Part of this mHealth application space are also apps that aim to educate people about nutrition and help them change their eating habits as part of a healthy diet. However, in the author's opinion, state-of-the-art applications still lack the ability to motivate people to eat healthy foods, especially for combating

NCDs by delivering specific food information. Therefore, Nutrition Garden, an app that was created together with the help of field experts and users of the target group, is proposed. It is a mobile application that motivates, supports, and encourages people to eat healthy by consuming a diet rich in fruits, vegetables, nuts, seeds, and fish oils to prevent NCDs and tighten up the knowledge of nutritional science for its users. Together with using gamification elements to help users stay motivated over an extended period and simultaneously focus on curated food items, it provides, in the author's opinion, a novel approach for a mHealth application in the domain of nutritional science.

Results

As part of this work, a mobile application for the Android platform was developed, specifically designed to support people who are willing to change their behavior and live a healthier life. The application itself was implemented with Java using Android Studio. A 3-Tier Architecture was chosen, and an SQLite database was used to persist data.

Requirements As described in Chapter 4, a variety of methods were used to gather the final requirements, such as a literature review about nutritional science (with the assistance of a nutritional expert) and interviews. This resulted in a total of 21 requirements. See table 5.5 for a list of these identified requirements. However, due to their low relevance for this prototype, two requirements (R58 and R59) were not implemented in this work.

The corresponding features were derived from the identified requirements. Features were seen as certain functionalities offered to the user that satisfy specific requirements.

Prototype The following section describes the implemented prototype in more detail. It explains the game mechanics and implemented features. This overview is structured to correspond to the application's views, and the implemented requirements are mentioned.

On first use of the app, the user has to register (R46); therefore, personal information is entered into the application. Multiple people can use the application on the same mobile phone. For the registration, input validation was implemented to avoid incorrect input and to prevent security-related problems. After users have successfully registered and/or logged in (R47), they get redirected to the home screen. Throughout all screens of the application, a bar at the top and the menu are visible. This bar should create a consistent look and feel. The bar at the top of the screen shows daily points, total points, and rewards (R56). Since this is visible on every view, the user can keep track of the current progress. At the bottom of the screen is a menu with corresponding icons. This menu allows the user to navigate through the application. Menu items are Home, Foods, Statistics, Garden, and Account. The currently active view is highlighted in green. The color green was mainly chosen for the application because it is generally associated with nature and should represent a healthy lifestyle. In the home view, which is the default start view, the user sees an overview of today's consumed foods (R52, R53) as well as a nutrition fact (R65). The facts about nutrition are scientifically proven and relevant to nutrition. When the user consumes food, it can be added to today's consumed foods

Table 5.5: Nutrition Garden: Final identified requirements [30]

Req. ID	***Description***
R46	The user should be able to register for the application
R47	The user should be able to log in to the application
R48	The user should be able to log out of the application
R49	The user should be able to show a simple list of foods
R50	The user should be able to select the food consumed from the simple list of foods
R51	The user should be able to add the selected food to the food diary
R52	The food diary with all the day's consumed foods should be shown to the user
R53	Each food in the food diary should contain a photo, name, points, and the amount of the food
R54	The user should be able to show detailed information about the food
R55	The user should be rewarded with points for each nutritional food he or she consumed from the food list of the application
R56	The user should have an overview of the daily and total points, as well as other achievements, like the gathered fruits
R57	The user should be able to show the weekly progress diagram
R58	The user should be able to show the monthly progress diagram
R59	The user should be able to show the yearly progress diagram
R60	Scientific nutritional facts should be shown on the home screen
R61	The user should be able to buy tree seeds on the market if he or she has enough points
R62	The user should be able to show the tree and water it
R63	The user should be able to harvest the tree if it carries fruits
R64	The harvested fruits will be recognized as additional achievements
R65	The user should be able to show account details
R66	The user should be able to update account details

(R51) by clicking the add button, which is symbolized as a '+.' After clicking the Add button, a dialog opens. Here, users can choose the type of food from a predefined list of foods as well as the amount that they have consumed (R49, R50). After adding a food item, users get points (R55) and are then redirected back to the home screen.

The second item on the app menu is food. This item offers a detailed list of all available foods that are currently available in the application (R54). The list contains a picture of the corresponding food item, its name, the reward points, and, additionally, the specific health benefits of consuming that particular food item. For the prototype, only five different food items were added to the application. There is, however, no feature that

allows users to add additional food items because users could add items that are not scientifically proven to prevent NCDs. When the user selects a food item from the list, more detailed information about that specific item is displayed (R54).

The next menu item is statistics. This item shows a line plot of how many points users collected every day during a week (R57). This view helps users to visualize their progress. On days when users are not able to collect more points, the graph will, of course, also be higher. Figure 5.16a shows the statistics view.

Within the menu item garden, users can overlook the garden; see Figure 5.16b. This is where they can buy a tree (R61), seed and water the tree (R62), or harvest its fruits (R63). If a certain action is currently not possible, the corresponding button is disabled. Buying a tree will subtract 30 points from the user's total points. After buying the first tree, it can be watered once a day. After fifteen times, the tree will grow to its next, bigger stage. Watering the tree will decrease the total points by two. Once the tree is fully grown and carrying fruits, it is time for users to harvest them (R64). These reward users in the form of virtual apples.

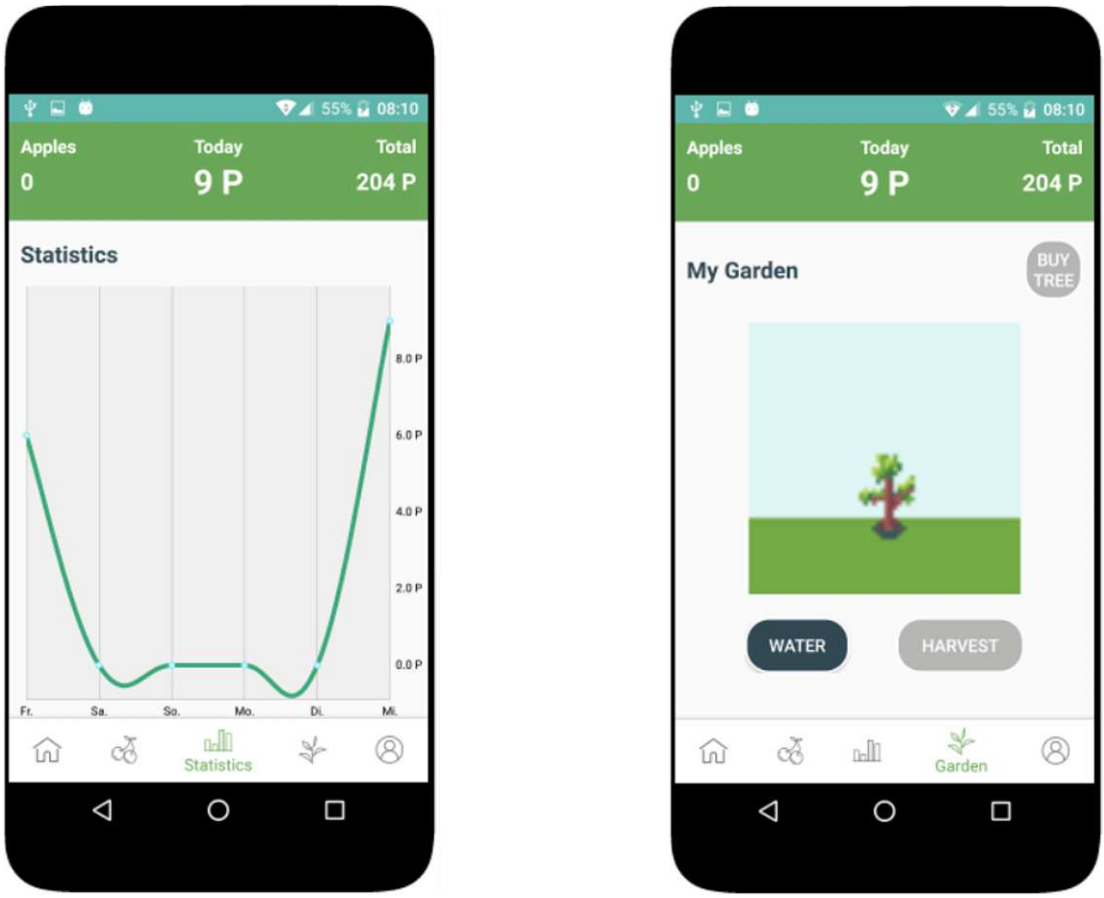
By selecting the menu item Account, users can select different account settings, such as the currently active profile, settings, adding another account, or logging out (R48). In the profile view, user information can be shown and updated (R65, R66). Settings were not yet implemented in the scope of this prototype.

Evaluation Five potential users tested the application and were interviewed afterward to evaluate the implemented prototype. Each interview lasted 20-30 minutes. Open-ended questions were constructed so that the play-testers could answer them freely and for the authors to gather as much information as possible.

Participants were asked if they knew of and used mobile apps about healthy eating. Three of the participants knew of applications, and two were using them only on occasion. Nutrition Garden differs from these applications in that it focuses more on curated food items and the particular health benefits they bring. Also, the gamification elements were seen as unique to Nutrition Garden.

When asked what they like best about the current iteration of the Nutrition Garden app, users mentioned the nutritional facts and health benefits the app teaches about different foods. They also mentioned the fact that unhealthy meals are not punished as an appealing factor. The integrated gamification elements were also mentioned as a very positive and useful feature.

When asked about the application's shortcomings, the participants mentioned that a custom threshold could be added to the statistic, which would represent a personal goal for a particular user. The participants stated that they would be interested in using the application further if more foods and motivational factors were added.



(a) Stat. overview of points within the last week

(b) Growing a garden by using collected points

Figure 5.16: Nutrition Garden: Screenshots of the application [30]

Discussion

The research proposed as part of this thesis presents a novel approach for a mobile application called Nutrition Garden, using gamification elements to motivate people to eat a healthier diet. Adding a point system and achievements rewards the user's healthy food choices. The Nutrition Garden app focused on integrating food items whose preventive effect against NCDs has been proven in studies and on the gamification elements.

Features include a simple food list, a food diary, statistics, and a food overview. In the overview, for example, the user receives information about which food categories specifically can prevent diseases or have benefits to the body. On the other hand, points can also be collected in the app, which can be used to buy seeds to grow a tree. With the harvested fruits, it is possible to get additional rewards. Statistics represent a feature

of already mentioned apps. Goals and rewards are two of the important elements Berger and Jung [224] described in their study.

Some already-established concepts of motivation and gardening were used within this publication. Despite being rewarded with points, the users are also rewarded by the garden concept itself because the garden atmosphere (although virtual) might provide relaxation and satisfaction [225], which is also important in urban areas, where there could be a lack of trees [226]. Furthermore, the garden concept can bring users to think more about eco-response and sustainability [226] and perhaps educate them to eat more natural foods "picked up directly from the garden" and avoid highly processed food.

An analysis of state-of-the-art applications has shown that many apps do not focus specifically on food products that have already been proven effective against NCDs. Furthermore, not all apps integrate gamification elements to keep their users motivated over an extended period. A paper by Suleiman-Martos et al. [227] describes the positive effect of gamification elements on nutrition. In the paper, a systematic review and meta-analysis were conducted. It was found that gamification interventions that provide food information can positively impact food choices in children and adolescents. For this reason, gamification could help to improve knowledge about healthier eating habits. The Nutrition Garden app, therefore, specifically includes such elements.

Five users tested the herein-proposed mobile application. The evaluation showed that users generally liked the idea of the application. However, testing it in a prototypical stage meant that they also admitted that it would need some refactoring work. One of the features that were liked the most was the "food facts," where the users stated that they learned new facts about foods and how their consumption could help them prevent certain diseases. The food diary, in general, was also well-received to keep track of consumed food items. The participants also mentioned the statistics and the gamification elements as being helpful for their motivation. With the inclusion of gamification elements and the focus on specific curated food items, Nutrition Garden provides a novel approach for a mHealth application that focuses on nutritional science.

Summary and Next Steps

The Nutrition Garden App has proven effective in imparting specific nutritional knowledge to users and keeping them motivated for an extended period. The focus on behavior change techniques and gamification elements is particularly relevant to applications in nutritional science. Therefore, it should also be the main focus of future endeavors of this work.

The next step for this project will be the implementation of the remaining features. This includes adding more food items, consulting additional nutrition experts, and conducting more studies about the health benefits of each food item, as well as adding those references to the detail-view of each food item so that users receive more information about the health benefits of the particular food items. Also, the remaining statistic functions should be integrated as this could be a motivating factor for friends who want to compare

themselves. Furthermore, extending the reward system should be implemented, for example, by giving the user extra points for using the app every day for a month. It could also be interesting to add challenges, like "Eat fruit at least every day." If users accomplish the challenge, they will get extra rewards, like a golden fruit. Then, users can compare their rewards with those of their friends. This could further improve motivation to use the application and eat healthy.

Another idea for the future is expanding the app to allow data exchange between the patient and the nutrition expert, which would promote communication between them. A nutrition advisor could create individualized food items for patients based on possible food intolerances and inspect the patient's progress remotely with the app.

Finally, the authors of this work also identified an overhaul of the app's visual design and notification system during the final phase, which will be part of the next iteration. A huge part of future work will be a playtest with a larger test group. The author would like to include additional nutritional scientists for the larger evaluation phase.

5.1.5 NutriMine - A Serious Game Modification To Support a Healthy Diet

Note: A version of this whole section was published by Aigner et al. in [33].

The escalating issue of obesity, a huge risk factor for contracting non-communicable diseases (NCDs), in industrialized countries necessitates innovative intervention strategies. Serious games designed to impart educational and transformative experiences have emerged as a potential solution. This research identifies the critical elements required for serious games to effectively influence behavioral change, specifically through a novel medium: a serious game developed as a modification for the popular video game "Minecraft." This modification was constructed based on requirements identified by a nutritional expert through a qualitative interview. Furthermore, a preliminary evaluation was performed in a pilot study with eleven users. The results revealed a reasonable level of engagement with the serious game. On a scale of one to five, participants rated their diet confidence at an average level of 2.91. Satisfaction with their diet was generally average, with most participants rating it between three and four. Notably, a few participants acknowledged experiencing mental or physical health issues due to their diet. The participants' familiarity with video games, particularly Minecraft, was relatively high, with mean values of 3.82 and 3.72, respectively. These findings suggest that the novel serious game, implemented as a modification for the video game" Minecraft," has the potential to influence behavioral change and thus help prevent NCDs.

Results

The state-of-the-art analysis and the interview with a nutritional expert led to a handful of requirements that were part of implementing a successful behavior change serious game. These included providing fun and challenging game mechanics, clear goals, rewarding desired behavior, giving players cues on their behavior, and simulating the consequences of healthy and unhealthy diets. These requirements were then transformed into a prototype of a modification for the popular computer game "Minecraft." Within that game, the player controls a character from the first-person view placed in a fully interactive 3D world of blocks created using a special retro pixel art style. Core game mechanics include collecting resources and crafting objects out of them, e.g., wood can be harvested and later used in preparing wooden tools and weapons. A second major game mode is "survival." In this mode, there is a day-night cycle. At night, hostile creatures will spawn that attack the player, who must defend themselves using weapons crafted from the abovementioned resources. A food strategy is already built into the core game, a "hunger system," where the player needs to consume various food items to survive. However, as it is a very rudimentary nutrition model, the authors believe it should include essential aspects of diet and health. It does pose a challenge for the player but does not educate the player about nutritional information nor aims to improve dietary behavior. The "hunger system" within Minecraft is one of the major aspects this work is trying to improve.

The developed modification for Minecraft incorporates the following core features:

- Adding relevant food items and nutritional data.
- Grouping food items according to the German food pyramid.
- Tracking of food consumption from the food groups.
- Calorie and weight tracking (abstract weight classes within the game were also defined).
- Adding positive and negative in-game effects from consuming specific food items within the game (e.g., gaining +1 health when consuming vegetables and fruits or decreasing movement speed when the game character becomes overweight).
- Improvements in the difficulty system of Minecraft.

The finished prototype was evaluated by a group of 11 participants between 16 and 45 of age. The mean time of playing the modification was about 70 minutes. Even though a substantial change in nutritional behavior could not be observed after one session, all participants stated that they believed the modification could change their dietary behavior over an extended period. The mod helped most participants to think about their diet more actively, and many learned some new aspects about how nutrition can impact the human body.

Requirements As described in the section "Methodology," different methods were used to identify the requirements for the initial concept. Eight requirements have been determined through a comprehensive literature review and an interview with a nutritional expert. The derived requirements can be seen in Table 5.6.

Table 5.6: NutriMine: Requirements [33]

Req. ID	***Description***
R67	Is an adaptation of an existing game
R68	Does not interfere with base game mechanics excessively
R69	Provides fun and challenging game mechanics
R70	Provides clear goals
R71	Rewards desired behavior
R72	Is not overly complex
R73	Gives players cues on their behavior
R74	Simulates consequences of healthy/unhealthy diet

Game Concept The following section describes the concept for the developed Minecraft modification, starting with an explanation of Minecraft's nutritional model and continuing with a detailed explanation of changes made to promote a better diet among adults and adolescents.

The serious game developed is based on the popular Minecraft, which has been modified to support behavior change. In general, Minecraft's hunger and food system is not intended to provide nutritional information or to improve behavior, as it ignores essential aspects of a healthy diet. For example, players can survive by only eating cakes in the game or eating foods that would lead to severe poisoning in real life (e.g., raw meat). Therefore, the nutritional concept of the game has been modified. The focus was laid on preventing weight gain and supporting overweight individuals. The player's in-game diet now has a significant impact on the game. If a player consumes excessive calories on an in-game day, the unhealthy nutrition causes the avatar to gain weight. It leads to various in-game effects, such as decreased movement speed. However, it is not only the number of calories that is decisive. In order to maintain a healthy diet, the quality of the food consumed and its nutrients play a significant role, which is why the nutritional values, as well as the calories of the consumed food items, are monitored.

The German food pyramid is used to evaluate the player's diet. The reason the German food pyramid was chosen is that the interviewed nutrition expert favored the German version over the Austrian one, as the role of oils and fats is more comprehensive in the German food pyramid. The pyramid consists of seven food categories, to which the Minecraft food items were assigned based on nutritional attributes. For the state of simplicity, every food item was assigned to one food group only. Additionally, food items that do not help to promote responsible dietary habits and do not exist in real life, except

sweet berries, were removed from the list of consumables. Furthermore, a new food item, pecan nuts, was created and added to the game since no food item suitable for the pyramid category "fat and oil" existed. An overview of the food items used in the game can be seen in Table 5.7.

Throughout an in-game day, the system keeps track of how many food items from each of these seven categories have been consumed and provides an overview of the players eating behavior at the end of each in-game day. Players can see their consumption rates for each food group in the newly implemented GUI, as shown in Figure 5.17.

Table 5.7: NutriMine: Food classification [33]

Category	***Food***	***kcal/100g***	***Portion (g)***
Drinks	Water	0	250
Animal Products & Alternatives	Cooked Chicken	204	300
	Cooked Cod	105	300
	Cooked Mutton	309	300
	Cooked Porkchop	265	300
	Cooked Rabbit	197	300
	Cooked Salmon	206	300
	Rabbit Stew	121	300
	Cooked Beef	306	300
Bread, Grain & Sides	Baked Potatoe	93	150
	Bread	245	100
Dairy	Milk	60	300
Extras	Cake	323	1000
	Cookie	487	50
	Honey Bottle	314	20
	Pumpkin Pie	210	200
Vegetables & Fruits	Apple	52	150
	Beetroot	43	150
	Beetroot Soup	43	300
	Carrot	40	150
	Dried Kelp	200	50
	Melon Slice	30	150
	Mushroom Stew	56.6	300
	Sweet Berries	68.5	150
Fats & Oils	Pecan	691	60

Adhering to the recommended consumption of essential foods positively affects the players, while excessive or insufficient consumption of certain food groups leads to negative effects. Positive applied effects would be "Haste" (increased mining speed), "Strength" (greater attack damage), and "Absorption" (four permanent health points). Additionally, five new

Figure 5.17: NutriMine: Newly implemented GUI overviewing the eating behavior [33]

in-game effects have been implemented, as shown in Table 5.8. The "Veggie and fruit rush" effect will be applied if the player consumes the fifth food from the "vegetables and fruit" group of the food pyramid. The added effects will come into force if the player reaches the BMI classifications overweight or obesity type I-III. Some of the new in-game effects applied to the avatar can be seen in Figure 5.18. The player moves up a weight class if a calorie surplus is detected. Conversely, if a player reduces his calorie intake, his weight class is reduced by one class. The weight class with which the player starts the game depends on the selected start mode. Minecraft's inherent difficulty system has been adapted for three different starting scenarios. If the player chooses the hard mode, the game starts with a weight class of eight (BMI category: obesity type I), the normal difficulty level starts with a weight class of four (BMI category: normal), and the peaceful mode sets the player's weight class to zero (BMI category: normal).

Table 5.8: NutriMine: New In-game effects [33]

Effect name	***Description***
Overweight	20% decreased movement speed
Obesity type I	30% decreased movement speed
Obesity type II	40% decreased movement speed
Obesity type III	50% decreased movement speed
Veggie and fruit rush	30% increased movement speed, and 30% increased attack for five minutes

Figure 5.18: NutriMine: Applied "Overweight" and "Veggie & Fruit Rush" effects [33]

Prompts have been implemented to provide feedback to the players on their diet behavior of the previous day. These notifications are displayed in the chat window, as seen in Figure 5.19. The prompts provide information on the food pyramid categories in which the amount consumed was too much or too little. In addition, compliments are made if the player adheres to a healthy diet.

Figure 5.19: NutriMine: Prompts on feedback on the player's diet of the previous day [33]

Evaluation In the playtesting phase, participants engaged with the mod for an average of 70 minutes, ranging from 30 to 120 minutes. Generally, players found it straightforward to manage their character's hunger. The modification influenced their resource management strategies, emphasizing farming and food preparation. Preferences emerged

for certain foods, with apples, carrots, and other fruits and vegetables being favored by eight participants, while steak, bread, and milk were less popular. Conversely, foods like cookies, meat, and cake were often avoided.

The average enjoyment rating for the mod's added complexity was 4.18. This complexity also prompted reflection on dietary habits, as indicated by an average agreement score of 4.09 to the statement, "The mod made me think about my diet." While a direct change in nutritional behavior was not immediately evident, with an average score of 3.09, all participants believed in the mod's potential for long-term behavioral change.

Participants reported learning new aspects of nutrition, such as the benefits of good nutrition, the need for reduced meat consumption, and appropriate food portion sizes. Game mechanics like the veggie and fruit rush effect, the caloric system, and the diet user interface were noted for their positive influence on behavior. However, some aspects were considered cumbersome or impractical, such as the need to drink liquids, rapid weight gain, difficulty losing weight, and the inability to consume raw meat.

Discussion

The presented research as part of this thesis proposes a novel modification for the popular game Minecraft that supports people's adherence to a healthy diet and lifestyle. A key outcome of the study is that the mod enhances the Minecraft gaming experience by introducing enjoyable game mechanics, indicating its potential for voluntary play in an informal, serious game context. Additionally, participants believe that extended gameplay could positively impact nutritional behavior. The most effective game mechanic for behavior change was the positive reinforcement of healthy choices, particularly through the veggie and fruit rush effect. Another notable aspect was the improvement in the character's health when adhering to dietary guidelines, further emphasizing the mod's effectiveness in positive reinforcement.

Beyond influencing behavior, the serious game prompted many players to reflect on their dietary habits. This reflection is a significant achievement, as considering and evaluating one's diet is crucial for better nutrition. The authors believe the modified version could be quite effective since Minecraft is a very popular game due to its "sandbox" nature, low entry barrier, and focus on entertaining the player. In contrast, more traditional serious games like Food Pyramid Escape were designed as supplement measures and should normally be played as part of a therapy or intervention [29].

Summary and Next Steps

The study suggests that further research with a larger, more diverse group over a longer period and a more detailed questionnaire is needed to fully assess the mod's effectiveness in altering nutritional behavior. Enhancing the mod with more content and mechanics, such as a wider variety of food items and additional consequences for dietary choices, could increase its impact. Adjusting the mod's difficulty level to provide tailored feedback and information could also improve its effectiveness.

However, the study's limitations, including a small participant pool and short duration, must be considered. Most participants did not report adverse dietary effects on their health, limiting insights into the mod's impact on such issues. Despite these limitations, the study indicates the mod's potential to make players more mindful of their diet and nutrition, especially if used over longer periods and with other interventions. Further development and testing are necessary to confirm its actual behavioral influence.

5.1.6 MoodBooster - A Gamified App to Support Stress Reduction in Students

Note: A version of this whole section was published by Aigner et al. in [166].

Mental health has become an important topic in recent years and can be considered a risk factor for contracting non-communicable diseases (NCDs). These diseases, especially cardiovascular diseases, cancers, chronic respiratory diseases, and diabetes, are not spread through infection or other people but are caused by unhealthy behaviors. This work focuses on mental health for university students. Studies have shown that this target group can be particularly susceptible to stress and stress-related symptoms because they have to deal with academic pressure, separation respectively, individuation from their families, work, and tight financial situations. Therefore, the authors of this work propose "MoodBooster," an application to support stress management for university students. It includes features like tracking stressful events, educational content, and several mini-serious games, two of which were prototypically implemented to help with stress reduction. Serious games are games that also serve purposes other than pure entertainment and have been shown to be successful with behavior change in their users. The prototype was evaluated within the target group, and the feedback was mostly positive. Players especially found the included serious games helpful for stress reduction, entertaining, and easy to grasp.

Results

The main result of this work was the design and development of a mobile application to help with student mental health. The app was developed for the Android platform and comprises a main application for tracking current mood and stress-related symptoms, as well as minigames that can be started directly from the app.

Design and development of the main application When starting the mobile app, users are presented with the home screen, as shown in Figure 5.20. This screen includes shortcuts to all the major features of MoodBooster. These are, "Information," "Akut," "Mini Spiele," "Jetzt Testen" and "Prävention." Since the application was built with a German-speaking audience in mind, all textual information, including buttons and labels, was presented in German. The "Information" feature serves as an educational hub

covering various topics related to stress symptoms and stress's physical and cognitive impacts on the body. It also gives the student further information about how to deal with symptoms, how proper diet and physical activity can affect mental health, and how this information can be used in stress management or psychotherapy. The "Akut" feature was designed to help with imminent stressful situations. It contains special questions about the current stress level and possible causes. "Mini Spiele" leads the user to the developed serious minigames, which will be described in detail in the forthcoming subsection. "Jetzt Testen" can be seen as a main feature of MoodBooster. It leads the student to a questionnaire that tests their current stress level. There are four categories of questions: Health, emotional, study-related, and personal. In the current state of the prototypes, these questions are still placeholders and will be developed with therapists in the next iteration. "Prävention" is a feature designed to provide users with stress relief guides, e.g., for breathing exercises, back exercises, and yoga. This feature was not implemented in the final prototype of this phase. The app also features a profile page, where personal adjustments can be made, a calendar, and a note-taking feature. These features can also be considered mockups in the current prototype and will be fully implemented in the next phase. The profile view is further divided into statistics, showing the stress diary entries, badges, achievements of the included minigames, and settings to customize the app to the users liking.

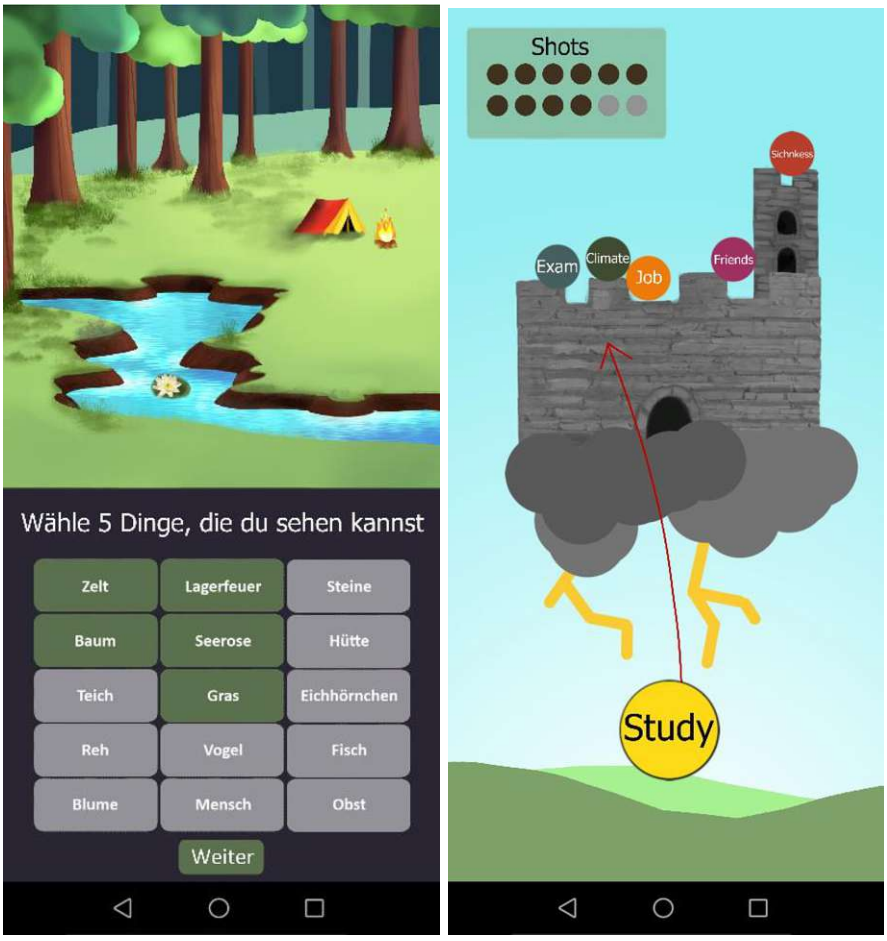
Design and development of the serious minigames MoodBooster aims to include games that align with evidence-based relaxation techniques, each focusing on reducing stress. Four serious games were designed, namely "Just Breathe!", "Draw Your Stress Away," "Wipe Out Worry," and "Mind Your Senses." "Just Breathe!" and "Draw Your Stress Away" were prioritized for their focus on calming distractions to soothe the mind and were prototypically implemented. "Mind Your Senses" was centered around concentration exercises. In contrast to the other games, "Wipe Out Worry" was designed to provide a more engaging gaming experience to offer an alternative to a more gaming-oriented audience. Furthermore, initial ideas for a game aimed at encouraging physical activity were explored, adding to the comprehensive approach to stress management.

The game "Just Breathe!" is centered around focused breathing exercises. During the game, the user controls a hot-air balloon and has to fly it over a series of mountains while collecting gemstones and avoiding birds. The user must breathe in to climb the hills, pause at the top, and breathe out when the mountain range flattens. In the prototype, this can be achieved by using the slider on the right side of the screen; see Figure 5.23. In future work, a sensor should be used instead. In the middle of the screen, additional information is shown about the current phase of the breathing cycle: inhale - pause - exhale. The game offers different breathing patterns to incorporate different breathing volumes. The game includes green gemstones, which the user has to collect to increase a built-in score, and birds the user has to avoid, not to lose one of the three lives that are indicated by the heart bar at the top of the screen to provide them with an actual challenge, see Figure 5.23.

Figure 5.20: MoodBooster: Main application screen [166]

The basic idea of "Draw Your Stress Away" is to provide users with a digitalized coloring book to offer relaxation in times of stress or anxiety. After starting the game, the user receives a randomly generated mandala (a Sanskrit word referring to a "circle" or "discoid object") to color. Mandalas were chosen because of their prior usage as a therapeutic tool in stress-anxiety-depression syndrome [228]. The top pop-up menu gives the user the ability to change the color. Clicking on an empty field within the mandala fills out that particular field with the chosen color. Different-sized brushes and an eraser can also be selected to add and modify the background. The button to generate a new mandala is located at the bottom of the screen labeled in German as "Nächstes," which means next in English; see Figure 5.22.

"Mind Your Senses" was developed as a psychological concept based on mindfulness [229]. It uses the five-point method of anxiety [230] to achieve a serious implementation of the game. The player has to acknowledge the following in the game: Five things the player can see, four things the player can touch, three things the player can hear, two things the player can smell, and one thing the player can taste. The method involves shifting attention from stress factors to the five senses, thereby distracting from feelings



(a) "Mind Your Senses" (b) "Wipe Out Worry"

Figure 5.21: MoodBooster: Two of the designed minigames [166]

of anxiety. The player is shown a picture for each category and has to click on the correct terms corresponding to the current category, as shown in Figure 5.21a.

"Wipe Out Worry" is a modified serious game that uses a similar game structure as well as some design ideas from the popular commercial game "Angry Birds" [231]. The inquiry-based stress reduction (IBSR) that uses specific questions to help people recognize stressful thoughts was applied to the game [232]. Before the game begins, users are asked to enter up to six terms corresponding to their negative thoughts or current stress factors. Examples such as "exam," "deadlines," "relationship," or similar are listed for reference. In addition to the respective negative thought, a possible countermeasure to the stress factor can be entered as input in an additional field. This field is displayed under the sentences "Can I currently actively do something about the problem?" and "How would I currently feel without this problem?". The latter is based on IBSR [232]. This input allows users to reflect right at the start of the game on whether their situation is as

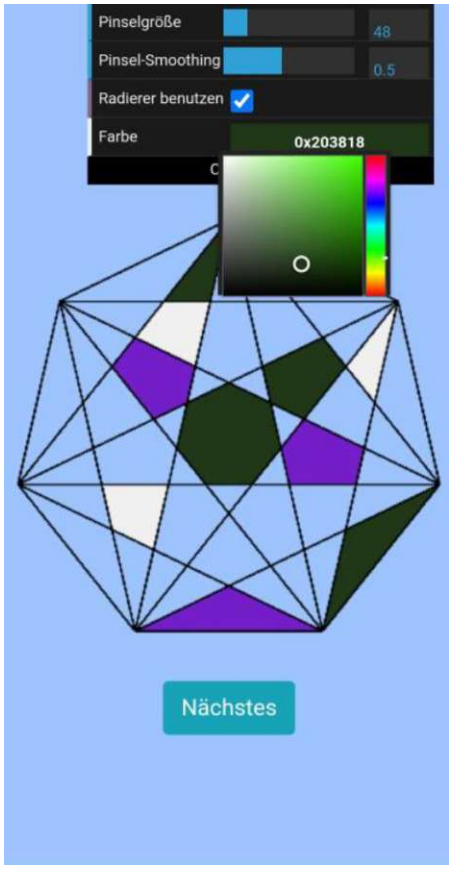


Figure 5.22: MoodBooster: "Draw Your Stress Away" minigame [166]

hopeless as it seems. Up to two countermeasures are possible for each negative field. The game can be started with fewer terms if there are fewer stress factors. The game aims to destroy the castle loaded with predefined negative thoughts, as shown in Figure 5.21b. The player can do this by shooting balls with predefined countermeasures. The movement of the fingers on the touchscreen determines the direction and intensity of the thrown ball. In the top left corner, the player can see the remaining shots.

Evaluation Ten participants evaluated MoodBooster in two parts. Part one covered general questions about the application and usability topics, and part two focused on the in-app serious minigames. Seven individuals from the target group participated in the first part and four in the second part. In addition, three participants were given the app independently and interviewed afterward. They did not fill out the survey.

Seven participants were handed the app as an installable file for their smartphone and access to an online form they were supposed to fill out after experiencing the application as part of the first survey. The user interface was perceived well, even though some disliked the light variant's color scheme of the app. Some participants mentioned that

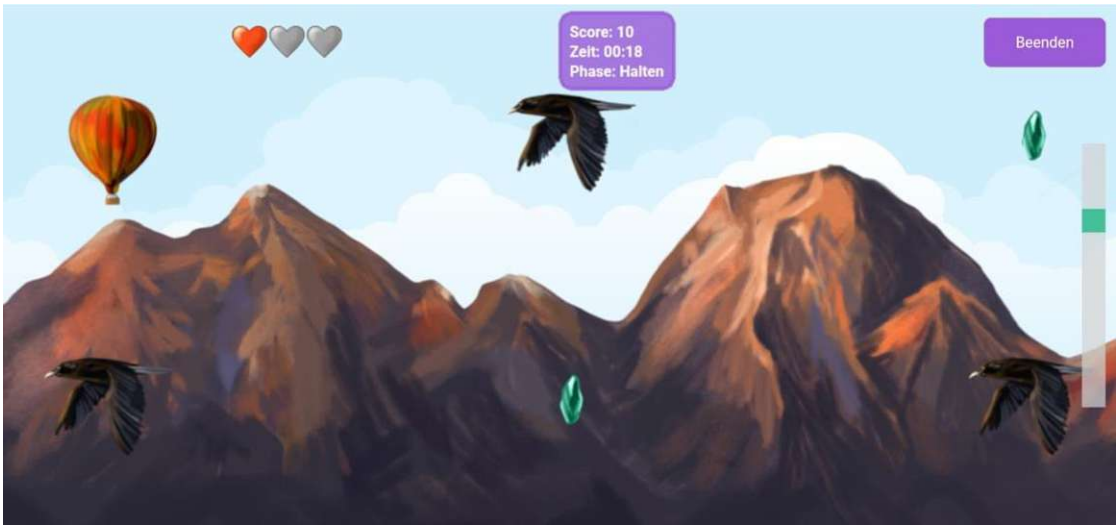


Figure 5.23: MoodBooster: "Just Breathe!" minigame [166]

the navigation could have been more straightforward, and some features might have needed to be easier to find. Also, participants noted that there was no information about controlling the included minigames and that they were not intuitive. The participants provided mostly positive feedback overall. The users found the games entertaining, and the design was functional and mostly intuitive.

The second part of the survey focused on the four designed serious minigames. Four users participated in this part. "Draw Your Stress Away" was perceived positively by the participants. The description of the game was sufficient, and the gameplay was intuitive. The users found that it was fun to play and also relaxing. Therefore, the authors concluded that this game can reduce stress. One drawback in the current implementation is that the generation of new designs can lead to the same previous arrangement, which should be corrected according to the participants. Users also would like to add their own color palettes. Overall, "Just Breathe!" was less entertaining than "Draw Your Stress Away" for some participants. The users also needed clarification about the stress relief the game should provide. The game's description was sufficient, but overall, the game could have been more intuitive. The badges that can be earned for both games were received positively. Users wish to leave the badges feature as is, however.

Discussion

The evaluation of MoodBooster has shown a promising outcome, as did the feedback from the target group's users. The two prototypically implemented serious games helped relax and relieve stress in some participants, even though some usability issues were mentioned that the authors would address in the next iteration of the prototype. Since the app does not use backend components, user data will remain on the respective device. It can be distributed free of charge, which is especially beneficial for younger students

with less-than-perfect financial situations. Overall, the users gave valuable feedback that should be incorporated into the next iteration of the developed prototype.

Summary and Next Steps

The authors of this work propose a mobile application called MoodBooster, which has serious minigames for stress relief and management among university students. Two of four serious games were incorporated into the prototype. It was tested and evaluated by target group users, who gave valuable feedback and showed that the application could benefit student mental health.

The next steps in this work are incorporating the comprehensive feedback from the evaluation into the prototype's subsequent iteration and implementing the two remaining serious minigames, "Wipe Out Worry" and "Mind Your Senses." Designed features like the calendar, the notes function, and the prevention feature, called "Prävention" within the app, must be incorporated into the next stage of the prototype. The "Akut" and "Jetzt Testen" feature questionnaires are currently placeholders and must be implemented in cooperation with therapists.

Furthermore, the authors plan to add social media features to the application so that students can communicate with each other. They also intend to rework the badge system. Additionally, a larger assessment with the improved prototype and more students is planned to gain more insight into playful stress management.

5.2 Comparative Analysis of Developed Games and Applications

Note: A version of this whole section was published by Aigner et al. in [34].

The following section depicts a comparative analysis of serious games and gamified apps for NCD prevention, leading to a series of requirements classes. The basis for it was the developed apps and games described in the previous sections. Additional work that was published within the author's research group was also used for the comparative analysis. This analysis leads to a definition of classes of requirements for NCD-prevention games and apps. Table 5.9 gives an overview of the analyzed concepts, their used platform, and main and secondary risk factors. In addition to the work described within this thesis, the game NutritionRush and DiaBeaThis were included as well.

The foundation for the comparative analysis presented in this work was eight applications, four serious games, and four gamified mobile health apps. These will be described in further detail within this section. Table 5.10 visually compares all analyzed applications.

Table 5.9: Framework: Summary of the comparative analysis [35]

ID	Work	Type of the application	Platform	Main NCD risk factor	Secondary (clinical) factors	Ref.
G1	BreathIn	Serious Game	Android	Smoking	well-being	[31], [32]
G2	Food Pyramid Escape	Serious Game	Android	Nutrition	well-being, nutritional education	[29]
G3	Nutrition Garden	Gamified mobile application	Android	Nutrition	well-being, nutritional education	[30]
G4	NutritionRush	Serious Game	Android	Nutrition	well-being, nutritional education	[233]
G5	NutriMine	Serious Game (modification)	PC	Nutrition	well-being, nutritional education	[33]
G6	recoverApp	Gamified mobile application	Android, PC	Mental health	depression, rehabilitation, injury, pain	[28]
G7	MoodBooster	Gamified mobile application	Android	Mental Health	well-being, positive psychology	[166]
G8	DiaBeaThis	Gamified web application	Web (PC and mobile)	Hyperglycemia	well-being	[223]

BreathIn is a serious game designed to facilitate smoking cessation by introducing a novel concept where the user's progress in quitting smoking is integrated into the gaming experience, using gamification aspects to enhance motivation and provide real-time feedback. It runs on the Android platform, and its main NCD risk factor is smoking. Its secondary clinical factor is well-being. The game was designed as a platformer where the player has to reach the target zone and avoid enemies and obstacles [31] [32].

Food Pyramid Escape is an educational escape game that teaches about nutrition through a compelling storyline, various puzzles, and minigames. It runs on Android, and its main NCD risk factor is nutrition. Its secondary clinical factors are well-being and nutritional education. It can be used as an independent tool for nutrition intervention or combined with other informative materials and workshops for larger-scale interventions [29].

Nutrition Garden is a mobile health (mHealth) application that supports, motivates, and encourages people to consume a healthy diet rich in vegetables, nuts, fruits, seeds, and fish oils to prevent the risk of contracting NCDs. It also tightens nutritional knowledge by utilizing gamification elements to help users remain motivated over time. It runs on the Android platform, and its main NCD risk factor is nutrition. Its secondary clinical factors are well-being and nutritional education [30].

NutritionRush is a serious game developed with a nutritionist that offers an educational digital library containing information about nutrients, nutritional values, and daily energy intake, and a platformer-like game where the user is encouraged to employ its knowledge to complete specific missions. It runs on the Android platform, and its main NCD risk factor is nutrition. Its secondary clinical factors are well-being and nutritional education [233].

NutriMine is a modification for the popular video game Minecraft. It was developed

as a serious game with requirements gathered with the help of a nutritional expert. It runs on PC, and its main NCD risk factor is nutrition. Its secondary clinical factors are well-being and nutritional education. NutriMine utilizes game progress data only.

recoverApp is a mHealth solution designed to support people in stationary rehabilitation using concepts and interventions of cognitive behavioral therapy (CBT). It includes gamification elements such as skill points that can be acquired by finishing challenges and tasks to enhance engagement and acceptance. The app for patients runs on Android, while the therapist view is a web application best used on a PC. Its main NCD risk factor is mental health. Its secondary clinical factors are depression, rehabilitation, injuries, and pain [28].

MoodBooster is a mobile gamified application that supports good mental health for university students. The prototype runs on the Android platform. The app tracks mood and stress-related symptoms and includes an educational hub covering information on symptoms and the physical and cognitive impact of stress on the human body. The hub also gives students information on how to deal with stress-related symptoms, proper diet, and physical activity. The app also includes features for stress relief, including exercise guides. Furthermore, the app consists of serious minigames. These are "Just Breathe!", centered around focused breathing exercises "Draw!", a digitalized coloring book to offer relaxation; "Wipe Out Worry," where the player needs to destroy a castle of predefined negative thoughts, and "Mind Your Senses," focusing on the psychological concept of mindfulness [166].

DiaBeaThis is a web portal accessible via mobile devices or computers. Upon logging in, users can create diary entries that record their current blood glucose levels and track instances of hypoglycemia and hyperglycemia, carbohydrate intake, insulin injections, and physical activities. Each new diary entry contributes to the accumulation of experience points. These points directly affect the gameplay of the included game, a card game based on "War." Two players face each other in multiple rounds and have to present cards. Cards with higher values lead to a win. By gaining experience points, the player levels up and gets access to higher-value cards, thus achieving advantages within the game. DiaBeaThis includes achievements and a leaderboard, which ranks all patients currently registered within the portal [223].

Table 5.10: Framework: Details of the comparative analysis

ID	Main requirements	Game mechanics/Gamification elements	Relevant data
G1	• Onboarding (Smoking behavior) • Platform game • Statistics	• Player navigates through various levels in the third person. • Player must reach target zone by jumping, running, and shooting cigarettes at enemies • Enemies and obstacles need to be avoided • Energy decreases with hits from enemies • Character gets stronger when the player continues not to smoke • Open world - stronger characters can reach new hidden areas • "Boss fight" including riddles	• Patient data • Cigarettes consumed per day • Amount of cigarettes per package • Current price of a package • Individual goals • Exact date of stopping smoking • Achievements
G2	• Seven levels that represent the Austrian food pyramid • Educational aspects with riddles and progress within the game	• Player moves to various levels in the third person. • Riddles need to be solved to make progress • Interaction with NPCs • Collection of items (inventory) • Encyclopedia that conveys nutritional knowledge • Hint system	• Game progress data • Engagement data
G3	• Show a list of foods • Select consumed food from the list and add it to the food diary • Overview of daily points and achievements • Progress diagrams	• Users will be rewarded with points for each tracked food • Scientifically validated nutritional facts • Buy tree seeds for points • Show the tree and water it • Harvest fruits from the tree • Get achievements for harvesting	• Patient data • Food diary • Game data (state of the garden) • Achievement data

ID	Main requirements	Game mechanics/Gamification elements	Relevant data
G4	• Jump 'n' Run game • Digital library of nutritional information on daily energy intake, nutrients, calories, carbohydrates, and body mass index (BMI) • User profile, including weight and height • Calculation of BMI and recommended daily intake based on user profile	• Player can choose different levels to play (mission overview) • User needs to complete different missions by collecting food items • Mission is complete if all defined sets of food items are collected • Player needs to avoid obstacles, like a flying dog • Player can collect coins (high score, achievements)	• Patient data • Weight, height, body mass index (BMI) • Game progress data
G5	• Modification of the sandbox game Minecraft • Adding relevant food items and nutritional data to the game • Grouping of food items according to the German food pyramid • Calorie and weight tracking • Improvements to the difficulty system of Minecraft	• Positive and negative effects in-game from consuming specific food items • Prompts that contain feedback on the player's diet	• Game progress data

ID	Main requirements	Game mechanics/Gamification elements	Relevant data
G6	• Mood tracking • Diary • Tasks, challenges, skills • Chat • Web app for therapists	• Challenges (short tasks to increase activity level and promote positive emotions) • Skills (collection of skill points by completing challenges)	• Patient data • Mood tracking entries • (Shared) diary entries • Existing tasks • Completed challenges • Skills (skill points)
G7	• Mood tracking • Tracking of stress-related symptoms • Minigames	• "Just Breathe!" minigame • "Draw!" minigame • "Wipe Out Worry" minigame • "Mind Your Senses" minigame • Badges • Achievements	• Patient data • Mood tracking data • Stress level questionnaire entries • Notes • Badges
G8	• Diary • Blood sugar curve • 7-day trend • Daily, weekly, and yearly overview • Card game "War"	• Mini game, played by two participants, six cards, six rounds • Cards with a higher value wins the round • Special action cards like swap, double, and block • Achievements • Leaderboard	• Patient data • Blood glucose level • Amount of carbohydrates consumed • Insulin dosage • Physical activity duration and description • State of mind via an emoji • Additional notes

5.3 Development of the Interoperable Framework

Note: A version of this whole section was published by Aigner et al. in [34]. The second part was published as a journal paper by Aigner et al. in [35].

This chapter provides thorough insights into designing and developing an interoperable framework for NCD-prevention games and applications. The framework defines best

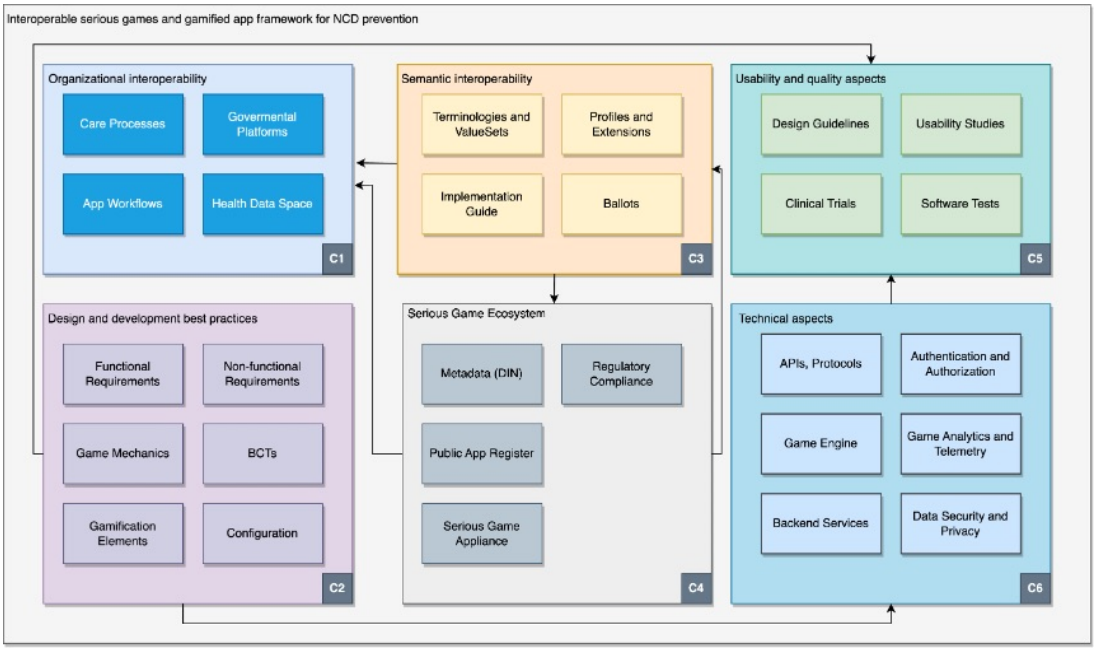


Figure 5.24: Framework: Overview of the defined framework [35]

practices and design guidelines and provides an implementation guide for the meaningful exchange of medical and game data.

The comparison study and the definition of basic requirements were the first steps in a process that combined a series of best practices into a framework focusing on the design, development, ecosystem, and interoperability of NCD-prevention games and apps. The overview (Figure 5.24) shows the six key areas C1-C6 of the envisioned framework.

The framework is separated into six major, interconnected components. The first component (C1), organizational interoperability, depicts recommendations for care processes, app workflows, and governmental platforms and considers national and multinational health data spaces. The second component (C2) focuses on best practices for designing and developing games and apps by defining a requirement catalog, describing sets of functional and non-functional requirements, and clarifying the usage of game mechanics, gamification elements, BCTs, and configuration aspects. These best practices strongly connect to usability and quality aspects. The third component (C3) focuses on semantic interoperability and, thus, the interoperable definition and exchange of clinical and game data. It includes the definition of value sets and the meaningful usage of medical terminologies, defines technical profiles and extensions, and suggests a basic ballot process for the participation of serious games and app developers. The serious games ecosystem component (C4) describes practical guidelines for the target group to find games and apps and use them easily. It includes best practices for using metadata, public app registers, and serious game appliances and also tries to give basic suggestions on regulatory compliance. The fifth component (C5) covers usability and quality aspects

by defining basic design guidelines and offering recommendations for executing usability and clinical studies. The final component (C6) covers technical aspects of serious game development, including APIs, game engine usage, authentication and authorization, game analytics and telemetry, backend services, and data security and privacy.

C1 - Organizational Interoperability

This subsection examines aspects of organizational interoperability related to care processes, clinical workflows, and the utilization of government platforms and health data spaces.

Care Processes and App Workflows Games and apps must be integrated into the care process to support patient behavior change effectively. Healthcare workers need information about the availability of apps, their intended use, and guidelines for how patients can use them. Therapists and clinicians should be able to prescribe games and apps to patients who could benefit from them. For example, in Germany, applications can already be prescribed as digital health apps [234], a concept named "DiGAs." This possibility should be extended to serious games for health. Also, other countries must adapt so that more patients can benefit from similar opportunities. Patient care plans should determine at which stage of the treatment the application should be prescribed.

App workflows are very important. BreathIn, for example, should be used as part of an ongoing smoking cessation therapy rather than as a standalone intervention. Food Pyramid Escape, on the other hand, was designed as a learning app that can be used anytime to teach patients better nutrition and encourage them to change their eating behavior. NCD-prevention games should always come with detailed instructions for clinical personnel so that apps can be perfectly integrated into the clinical daily routine.

Therefore, as part of the best practices defined within this framework, developers are strongly encouraged to collaborate with clinicians to define instructions, processes, and workflows during and after development. Since this framework promotes semantically interoperable data extraction into public and personal health records, it is also important to actually use the data after patients have finished playing a game or using an app. This data can then be used within future steps in patients' care plans.

Governmental platforms Governments should develop platforms to make NCD-prevention games and apps available to a wide audience and integrate them into national health promotion and prevention campaigns. This will contribute to NCD prevention and reduce the risk of contracting NCDs.

Health Data Space Health data space initiatives should include interoperable NCD-prevention games and apps to promote the exchange of medical data across national borders. This gives patients greater control over their data and facilitates the secondary use of clinical data for research, innovation, and policymaking [235]. An example is the EU

initiative European Health Data Space (EHDS), which is currently being developed [24]. This framework proposes integrating NCD-prevention games and apps into such health data spaces, especially since it encourages data exchange in a semantically interoperable way.

C2 - Design and Development Best Practices

The following subsection outlines best practices for the design and development of NCD-prevention games and apps by establishing a requirement catalog and guidelines regarding game mechanics, gamification elements, BCTs, and configuration aspects.

Requirement catalog The comparative analysis served as the foundation for deriving a catalog of requirements classes that can be seen as a baseline for serious games and gamified apps for NCD prevention. Comprehensive best practice guides and frameworks for NCD prevention games and gamified apps should include these requirements classes. Table 5.11 overviews all the identified requirements that were categorized into functional and non-functional and include a fulfillment level. For the level of fulfillment, the definition from RFC2119 was used [236].

Game mechanics should be based on behavior change techniques (RF01). The core aspects of NCD prevention serious games should be playful elements that motivate the players to change their behavior in practice. For example, BreathIn uses a game mechanic that strengthens the game character the longer the player stops smoking in real life, thus giving players access to new paths and areas within already explored levels and, in turn, motivates them to continue not smoking. The game mechanic is more detailed in Figure 5.25, showing jumping height differences on day one versus day 15 of not smoking. Another important aspect is to avoid negative feedback and embrace positive feedback, meaning the player should not face unfair or specifically hard game mechanics just because behavior change is not consistent or lasting. Otherwise, players might lose interest in the game.

For gamified apps, gamification elements should be specifically designed to attempt to change the user's behavior (RF02). Successfully implemented gamification elements that should be included are achievements, challenges, quizzes, and scores. Gamification elements should incentivize users to use the app's core features. For example, Nutrition Garden lets the user collect points and achievements, and recoverApp includes short challenges and lets the user collect points as well.

Learning and educational aspects (RF03) are vital for NCD prevention games. Users should be able to learn about good nutrition, good mental health, and the health hazards of smoking, drinking alcohol, and low physical activity while playing a game. For example, BreathIn includes quizzes about smoking as part of the boss battle at the end of a level. In Food Pyramid Escape, the user has to solve riddles about nutrition to progress further in the game. NutritionRush includes a whole educational library about nutrition. Nutrition Garden presents scientific nutritional facts to the user.

Table 5.11: Framework: Requirements

ID	Description	Req. Level	Req. Type
RF01	Integration of behavior change techniques as core game mechanics	MUST	Functional requirement
RF02	Integration of engaging gamification elements for gamified applications	MUST	Functional requirement
RF03	Learning and educational aspects	SHOULD	Functional requirement
RF04	Emphazing good interaction design and usability	SHOULD	Non-functional requirement
RF05	Usage of appealing game graphics	MAY	Non-functional requirement
RF06	Integration of music and sound effects	MAY	Non-functional requirement
RF07	Considering suitable game genres	MAY	Non-functional requirement
RF08	Applying intuitive control	MUST	Non-functional requirements
RF09	Integration of social support and interaction	MAY	Functional requirement
RF10	Make games and apps readily available	MUST	Non-functional requirement
RF11	Games and apps should come at low cost for users	SHOULD	Non-functional requirement
RF12	Suitable hardware platform for low entry barrier	SHOULD	Non-functional requirement
RF13	Inclusion of therapists and clinicians	MUST	Non-functional requirement
RF14	Ability to extract data in a semantically interoperable way	MUST	Functional requirement

Serious games and gamified apps should emphasize good interaction design and usability (RF04) and thus be easy to play. Specific platform design guidelines like "Material Design" [237] should be used whenever possible. Appealing game graphics (RF05) respectively, music, and sound effects (RF06) should be used whenever possible but should not heavily increase the system requirements of the hardware the game is running on.

Suitable game genres should be considered when designing new serious games for NCD prevention (RF07). The authors suggest platformers and role-play, respectively, adventure

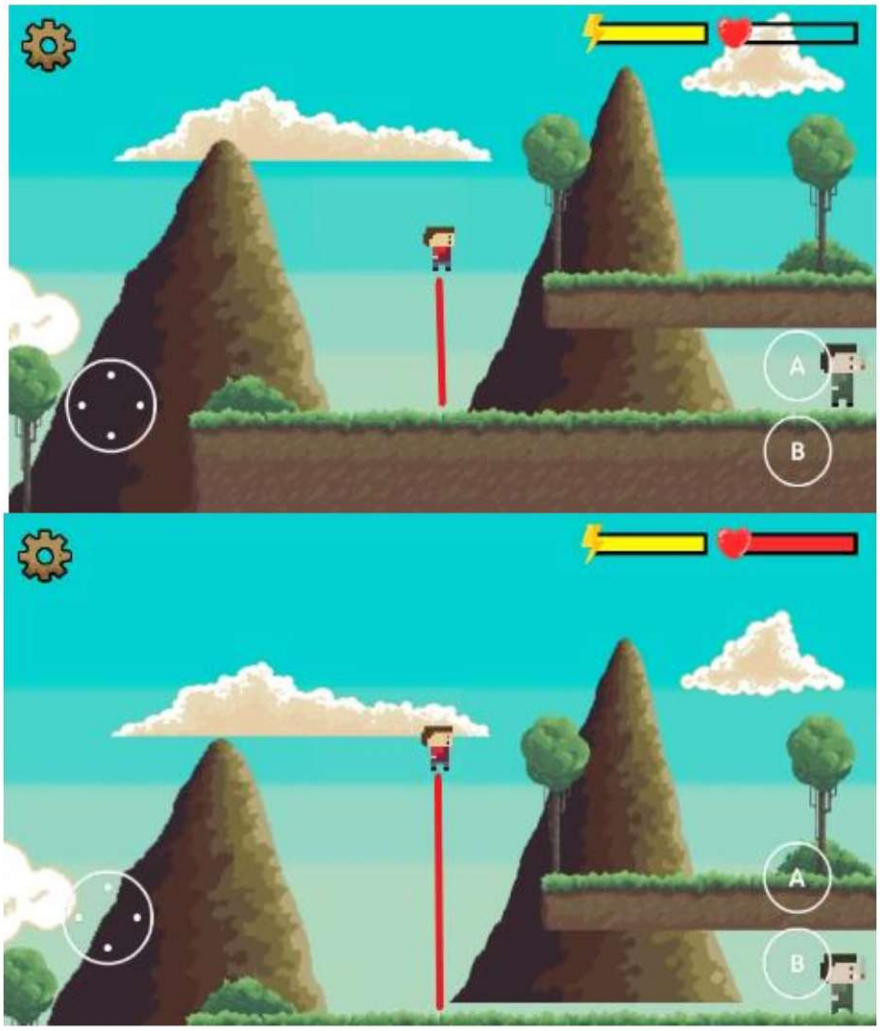


Figure 5.25: Framework: BreathIn - Jumping height differences [32]

games since they are easy to develop with modern frameworks and normally have low hardware requirements.

Controls should be intuitive, and no special game controllers should be required (RF08). Most of the analyzed serious games could be played with touch control. NutriMine, the Minecraft modification, can be played with a keyboard or gamepad.

Social support and interaction features can be beneficial (RF09). For example, recoverApp included an instant messaging feature that patients could use to contact therapists or other patients, even allowing chatrooms for specific topics.

NCD prevention games and gamified apps should be readily available. For example, they should be listed in public directories and include certain metadata (RF10). They

should be of low cost for the user (RF11). For example, this requirement can be achieved by making them prescribable by doctors, like "DiGAs" in Germany. Supported game platforms should be widely available, like "Google Android" or "Microsoft Windows" (RF12). This requirement ensures that many users can access NCD prevention games. Games and apps should also be cross-platform.

Medical personnel, such as doctors, nurses, and therapists, should be incorporated into the design of games and apps (RF13). For example, with recoverApp, the authors developed a web application for therapists that incorporates administrative functions, allows direct communication with patients, and provides an overview of all supervised patients.

A really important requirement is the semantically interoperable tracking and export of patient, medical, and game data (RF14). Except for Food Pyramid Escape, all analyzed apps store at least some game and patient data. Certain datasets must be included if data is going to be exported meaningfully into an electronic health record (EHR).

Game Mechanics and Gamification Elements Four concepts included in the comparative analysis were applications with gamification elements instead of full-serious games. These apps primarily offer non-gaming features, like a nutrition tracker in Nutrition Garden, blood sugar level tracking in DiaBeaThis, mood tracking in recoverApp and MoodBooster, and gamification elements. Features like badges, achievements, challenges, and rewards were used successfully and should be implemented by novel gamified apps.

Some game mechanics are more effective for NCD-prevention games than others. For instance, BreathIn and NutritionRush employ a traditional side-scrolling platformer as their main gameplay. This approach is straightforward to grasp, as it draws from concepts popularized in the early days of video gaming during the '70s and '80s. While touch controls on mobile devices function adequately, attention should be given to them, as confusing controls could detract from the gaming experience. Food Pyramid Escape presents an adventure-like game where players directly navigate the main character with an on-screen directional pad. It also employs an inventory and an encyclopedia. NutriMine, a modification for Minecraft, is the only first-person game in the analysis. It was designed to work with the Java version of Minecraft for PC, making it easier to control than the mobile version using a mouse and a keyboard.

Overall, platformer and adventure-type games are best suited for serious NCD-prevention games since they are easily accessible and can be controlled intuitively, even on small smartphone screens. In particular, 3D and first-person games may be more challenging to access and control on mobile devices, so they are not encouraged for NCD-prevention games and apps.

BCTs Serious games can effectively use behavior change techniques (BCTs) to help with actual behavioral changes in their users. The BCT categories used within this

framework came from the BCT Taxonomy (v1), which describes 93 hierarchically clustered techniques [21]. For example, the BCT "Information about health consequences" was implemented by all analyzed apps except recoverApp and DiaBeaThis, whether it was information about good nutrition, the hazards of smoking, or the various effects of bad mental health and how to achieve good mental health. Other important BCTs used by all games except Food Pyramid Escape and NutritionRush were the "Self-monitoring of behavior" and "Feedback on behavior" BCTs. They were mostly used for tracking cigarette consumption, food diaries, calorie tracking, blood sugar levels, and mood and stress tracking.

MoodBooster, recoverApp, Nutrition Garden, DiaBeaThis, and BreathIn used the "Incentive (outcome)" BCT. It was mostly used in the form of achievements, badges, and (skill) points. Additionally, recoverApp used the BCT "Social support" by providing a chat feature and the BCT "Graded tasks" by implementing the task feature, allowing the therapist to enter therapy-related tasks for their patients to perform. DiaBeaThis uses the BCT "Social comparison" since its included game "War" requires two players facing each other.

Overall, the BCTs "Information about health consequences," "Self-monitoring of behavior," and "Feedback on behavior" should be implemented in novel games and apps and are therefore recommended as part of this framework since they were successfully implemented and have shown to be useful. The "Incentive (outcome)" BCT is a good addition and, depending on the game, should be strongly considered when designing new NCD-prevention games and apps. Social BCTs like "Social support" and "Social comparison" can be successful, but they strongly depend on the app's target group.

Configuration Configuring certain aspects of serious games and gamified apps can be very beneficial, and this framework encourages this. This includes setting certain game or level settings like speed, time, the player's life count, achievements, and overall difficulty [238], as well as the general possibility of turning certain features on and off. Configuration options can be important regarding social features since some players can be negatively affected by them, especially if they involve social comparison, e.g., a leaderboard, high scores, badges/achievements, as was shown.

C3 - Semantic Interoperability

The ability to exchange data from NCD-prevention games and apps meaningfully is one of this framework's key aspects. Using the data within public electronic health records and personal health records can be very beneficial for patients to archive and record their data, help with ongoing treatment and therapy, and therefore helpful for clinicians as well. It can also be used anonymously for scientific purposes as part of secondary use. This section describes the developed implementation guide that defines a set of profiles, extensions, and value sets using HL7 Fast Healthcare Interoperability Resources (FHIR), a standard for exchanging electronic healthcare data created by the HL7 International organization [150]. The standard was chosen for its popularity and increasing adoption

within the medical informatics community [26]. The defined profiles encourage the usage of current medical terminologies such as SNOMED CT for general clinical terms [239] and Logical Observation Identifiers Names and Codes (LOINC) [156] for medical laboratory observations.

Implementation Guide The developed implementation guide, a collection of profiles, extensions, value sets, and code systems, defines the structure of documents, which are the units of exchange. It represents all relevant data from a specific serious game and gamified app for NCD prevention using HL7 FHIR. Extensions can be used for additional data elements not defined in the standard. Valuesets represent actual elements from one or more code systems.

A "FHIR Document" is an immutable bundle with an attested narrative that serves as the unit of data that is exchanged between systems and persisted in health records [240] by using integration profiles like Cross-Enterprise Document Sharing (XDS) defined in the IT Infrastructure (ITI) technical framework by Integrating the Healthcare Enterprise (IHE) [241]. XDS is widely used, for example, within ELGA, the Austrian national health record, and ePA, the national health record in Germany, and provides a standards-based specification for the registration, distribution, and access of medical records [242].

Technically, a FHIR document is a FHIR resource of type "Bundle" that starts with an FHIR "Composition" resource and contains various other resources of a set version that are referenced within that "Composition." The HL7 FHIR standard defines a large set of resources that can be used for various clinical and administrative use cases. To further customize them, HL7 FHIR defines profiles that specify acceptable codes, contain new elements in the form of extensions, and specify constraints on existing elements and data types [243].

The collections of profiles, extensions, value sets, and code systems were designed using FHIR shorthand (FSH). Shorthand is a domain-specific language for defining FHIR profiles. The first full version was released in March 2020. Many FHIR community projects, including the National Health Record Initiative in Austria (ELGA) [244], adopted FSH.

The transpiler "Sushi" was used to process the defined FSH files and transform them into FHIR artifacts [245]. The HL7 FHIR IG Publisher [246] was used to create a standardized FHIR implementation guide. This exact combination of tools was chosen since the alternative would have been using complex Excel spreadsheets or a graphical tool called "Forge," which is only free-of-charge for single users and only available for Microsoft Windows [243]. FHIR shorthand has many advantages: it is concise, readable, and understandable, and changes can be made via text operations; since it is text-based, it is suited for source code version control, has error checking, and incorporates best practices [243]. The basic requirement for an FSH/Sushi setup is a recent computer with at least Java 17 and NodeJS 18 installed.

Furthermore, the FHIR IG publisher, written in Java, uses the Jekyll Framework to render complete implementation guides as web pages. The actual shorthand files were created using VisualStudio Code since it offers very useful plugins for HL7 FHIR, like FHIR Tools [247] and FHIR Shorthand language support [248]. Version 5.0.0 of FHIR is used, which includes new resources that are of particular interest for this IG, such as the NutritionIntake and NutritionProduct resources.

Each FSH file has the same structure. The first block contains the definition of the profile. The second block defines the parent resource, the title, and the resource description. Finally, the third block represents all the rules the profile should include. Elements can be marked as "must support" (MS) or limited in their cardinality. The profile can also restrict references to specific other profiles. For example, within the NCD patient resource, the reference to the attending physician was limited to the "NCDPractitioner" profile.

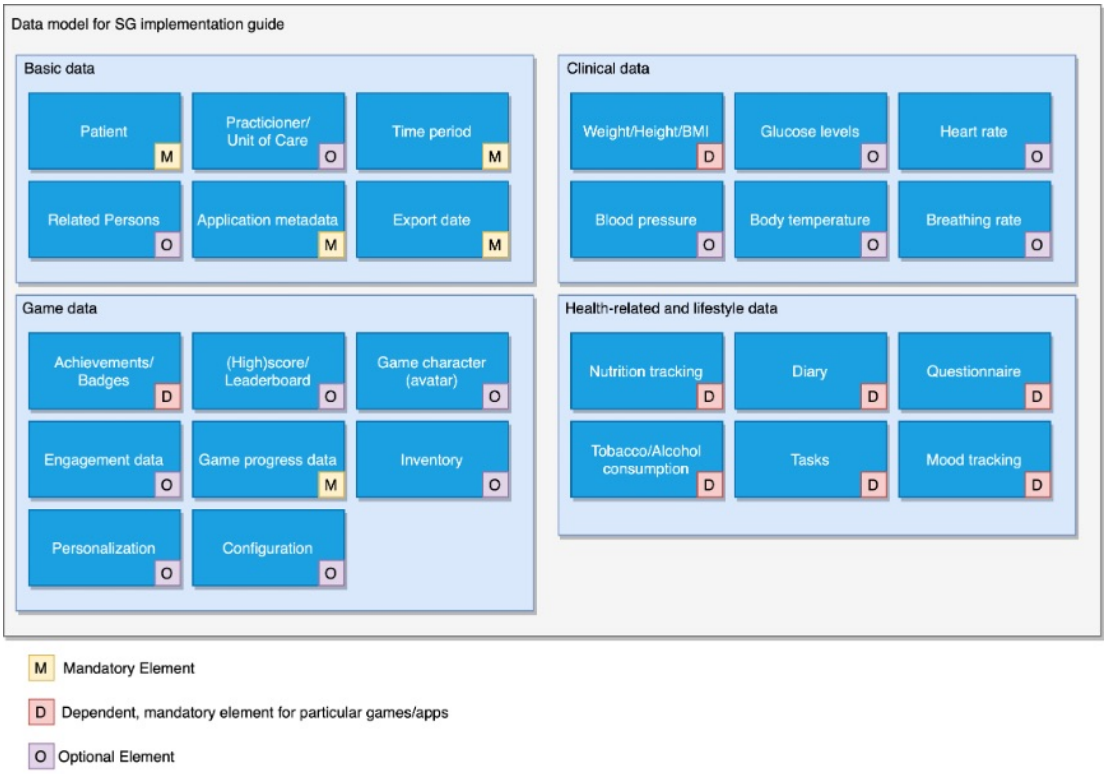


Figure 5.26: Framework: Data model of the implementation guide [32]

Figure 5.26 overviews the defined data model. All relevant data elements together form the FHIR document, which is technically represented as a FHIR Bundle resource. Each component was translated into a HL7 FHIR profile using FHIR shorthand.

The main element is the "NCDBundle," which contains the "NCDComposition" as its first element. The "NCDComposition" comprises three extensions: the time period of the

exported data with "date" as the datatype, the export date, also of type "date," and a free text field for metadata containing the DIN-specified metadata for the game with "string" as the underlying datatype; see section "Serious Games Ecosystem." The profile also includes slices for linking the practitioner and related persons. It contains three compositions that comprise clinical data, game data, and health-related and lifestyle data, as depicted in Figure 5.26 and shown as a web rendering in Figure 5.27. Two code systems, respectively value sets were created: "NCD Gamedata," which codes the different types of game data, contains seven concepts and has the URI "https://www.inso-world.com/fhir/ncd-prevention-games/CodeSystem/NCDGamedataCode," and "NCD Lifestyle data," which encodes the various types of lifestyle data, contains four concepts and has the URI "https://www.inso-world.com/fhir/ncd-prevention-games/CodeSystem/NCDLifestyledataCode," see Table 5.13.

In total, 32 FHIR profiles were designed and defined with FHIR shorthand for the implementation guide, which can be seen in Table 5.12. Profiles were defined on the FHIR resources "Observation," "Bundle," "Composition," "InventoryItem," "NutritionIntake," "Organization," "Patient," "Practitioner," "Questionnaire," "RelatedPerson," and "Task."

Table 5.12: Framework: FHIR profiles

Profile	**Description**
NCD Achievements Observation	The Observation resource for achievements
NCD Alcohol consumption Observation	The Observation resource for alcohol consumption
NCD BMI Observation	The Observation resource for BMI
NCD Blood pressure Observation	The Observation resource for blood pressure
NCD Bodyheight Observation	The Observation resource for body height
NCD Body temperature Observation	The Observation resource for body temperature
NCD Bodyweight Observation	The Observation resource for body weight
NCD BreathingRate Observation	The Observation resource for breathing rate
NCD Bundle	The Bundle resource which is used to represent the FHIR document
NCD Character Observation	The Observation resource for game character
NCD ClinicalData Composition	The Composition resource representing the clinical data of the document
NCD Composition	The Composition resource representing the main FHIR Document
NCD ConfigurationData Observation	The Observation resource for configuration data
NCD Diary Observation	The Observation resource for diary entries
NCD Engagement Observation	The Observation resource for engagement data

Profile	Description
NCD GameData Composition	The Composition resource representing the game data of the document
NCD GameProgress Observation	The Observation resource for game progress
NCD Glucose Observation	The Observation resource for glucose
NCD Heartrate Observation	The Observation resource for heart rate
NCD Highscore Observation	The Observation resource for high scores
NCD InventoryItem	The InventoryItem resource to use for game-related inventory data
NCD LifestyleData Composition	The Composition resource representing the health-related and lifestyle data of the document
NCD Mood Tracking Observation	The Observation resource for mood tracking
NCD NutritionIntake	The NutritionIntake resource to use for NCD IG
NCD Organization	The Organization resource to use for NCD IG
NCD Patient	The Patient resource to use for NCD IG
NCD Personalization Observation	The Observation resource for personalization entries
NCD Practitioner	The Practitioner resource to use for NCD IG
NCD Questionnaire	The Questionnaire resource to use for NCD IG
NCD RelatedPerson	The RelatedPerson resource to use for NCD IG
NCD Task	The task resource to use for NCD IG
NCD Tobacco-use Observation	The Observation resource for tobacco usage

Code listing 5.1 shows the declaration of the main FHIR bundle, which represents an exchangeable document in the form of an FHIR shorthand file. The first block, the declaration, states the profile by giving it the name "NCDBundle." The second block declares that the parent profile is the HL7 FHIR Bundle resource. The third block contains all necessary rules and constraints.

Listing 5.1: Declaration of the "NCDBundle" profile [32]

```
// (1) Declaration
Profile: NCDBundle

// (2) Keywords
Parent: Bundle
Title: "NCD Bundle"
Description: "The Bundle resource which is used to represent the
              FHIR document"
```

```
// (3) Rules
* type = #document (exactly) //type must be a FHIR document
* type MS

* entry 1.. MS
* entry.link ..0
* entry.fullUrl 1.. MS
* entry.resource 1.. MS
* entry.search ..0 //only necessary for search results
* entry.request ..0 //only necessary for operations
* entry.response ..0 //only necessary for operations

* timestamp 1.. MS //creation timestamp must be included
* total ..0 //only necessary for search results
* link ..0 //links are not supported for this document
* signature ..0 //signature is not needed

Invariant: compositionInvariant
Description: "Must contain one NCDComposition."
* severity = #error
* expression = "entry.where(resource.meta.profile=
                'http://inso.tuwien.ac.at/ncd-prevention-games/
                StructureDefinition/NCDComposition').count()=1"
```

The IG publisher rendered all profiles, code systems, and value sets as a webpage. The webpage includes an artifact summary page that overviews all defined resource profiles, extensions, value sets, and code systems. All artifacts can be exported as comma-separated-values, Microsoft Excel spreadsheets, or Schematron files.

Ballot process If changes to the NCD-prevention implementation guide need to be made, all stakeholders must be involved, especially serious game and electronic health record implementers. They should be able to give feedback and comment on proposed changes before publication. Therefore, the framework suggests implementing and following the HL7 Balloting process, which is defined as follows [249]. First, the stakeholders must sign up to participate in the ballot process. Then, the stakeholders review the proposed specification, provide feedback as ballot comments, and mark their comments as "negative" or "affirmative." After that, all comments are reviewed, and a decision is made about which changes to the specification will be incorporated. Stakeholders have the opportunity to "retract" or "withdraw" their "negative" comments. Agreed changes to the specification will then be applied. Afterward, a final determination is made as to whether the specification has passed the ballot or needs additional changes. Finally, a recirculation ballot can be necessary in some cases. The ballot process has yet to be implemented, as the current stage of the applications and framework remains in a prototypical phase.

Table 5.13: Framework: Used valuesets

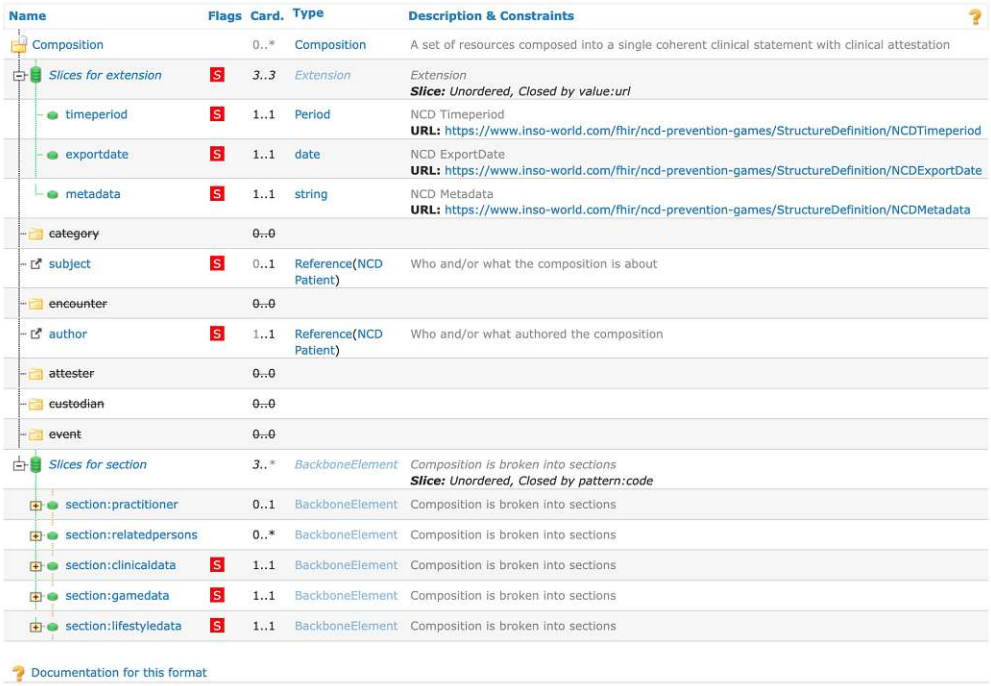
Code	Display
Codesystem: NCDGamedataCode	
achievements	Game Achievements
highscore	Highscores
avatar	Game Character/Avatar
engagement	Game Engagement Data
gameprogress	Gameprogress Data
personalization	Game Personalization Data
configuration	Game Configuration Data
Codesystem: NCDLifestyledataCode	
mood	Mood tracking
alcohol	Alcohol consumption
tobacco	Tobacco use
diary	Diary entry

C4 - Serious Games Ecosystem

The following subsection focuses on aspects of serious game ecosystems, such as metadata, public registers, serious game appliances, and regulatory compliance aspects.

Metadata (DIN) Every NCD-prevention game or gamified application should incorporate a metadata definition following the DIN standard established by Goebel et al. [132]. The metadata is part of the FHIR document; see chapter "Implementation Guide." This data helps categorize applications and makes them easier to find. Potential users can also check the suitability for their needs beforehand. The DIN norm defines three levels of descriptive elements. In this case, level 1 (core) is the minimum that needs to be supported. The preferred option would be compliance with Levels 1 and 2, which contain supplementary descriptive elements. Additional application profiles (level 3) are not required and, therefore, optional.

Public register Clinical personnel must be able to find appropriate applications they can recommend or prescribe to patients; see chapter "Care Process and App Workflow." This is only possible if public registers of accessible games and apps are available. The framework, therefore, proposes providing public registers that healthcare professionals can use to search for particular games and apps. Each application must provide specific metadata so that it can be easily found; see chapter "Metadata (DIN)." Non-profit organizations, governmental entities, or international entities are encouraged to host such registers.



Name	Flags	Card.	Type	Description & Constraints
Composition		0..*	Composition	A set of resources composed into a single coherent clinical statement with clinical attestation
Slices for extension	S	*3..3*	*Extension*	*Extension* ***Slice:** Unordered, Closed by value:url*
timeperiod	S	1..1	Period	NCD Timeperiod **URL:** https://www.inso-world.com/fhir/ncd-prevention-games/StructureDefinition/NCDTimeperiod
exportdate	S	1..1	date	NCD ExportDate **URL:** https://www.inso-world.com/fhir/ncd-prevention-games/StructureDefinition/NCDExportDate
metadata	S	1..1	string	NCD Metadata **URL:** https://www.inso-world.com/fhir/ncd-prevention-games/StructureDefinition/NCDMetadata
category		~~0..0~~		
subject	S	0..1	Reference(NCD Patient)	Who and/or what the composition is about
encounter		~~0..0~~		
author	S	1..1	Reference(NCD Patient)	Who and/or what authored the composition
attester		~~0..0~~		
custodian		~~0..0~~		
event		~~0..0~~		
Slices for section		*3..**	*BackboneElement*	*Composition is broken into sections* ***Slice:** Unordered, Closed by pattern:code*
section:practitioner		0..1	BackboneElement	Composition is broken into sections
section:relatedpersons		0..*	BackboneElement	Composition is broken into sections
section:clinicaldata	S	1..1	BackboneElement	Composition is broken into sections
section:gamedata	S	1..1	BackboneElement	Composition is broken into sections
section:lifestyledata	S	1..1	BackboneElement	Composition is broken into sections

Documentation for this format

Figure 5.27: Framework: Web rendering of the main FHIR composition [32]

Serious Games Appliance Serious game appliances can incorporate NCD-prevention games and apps. These are specific technical environments for serious games that can run on PCs, smartphones, or specialized hardware. They feature dedicated launchers to streamline game access and overall usability.

Regulatory Compliance Approval for NCD-prevention games to be used in clinical settings can be necessary. For example, digital health apps in Germany can be licensed as DiGAs [250], which requires a fast-track procedure according to § 139e SGB V [234]. These apps must not currently be used for primary prevention and must be recognized as medical products. This framework encourages developers to undergo certification processes for games and apps in specific healthcare scenarios. Digital health app programs like DiGAs in Germany should also include games and apps for primary prevention in the future.

C5 - Usability and quality aspects

This subsection focuses on design guidelines, usability, and quality aspects, including clinical trials and software testing.

Design Guidelines and Usability Studies Design guidelines should be followed to offer consistent user experiences. Android and Apple publish official guidelines for mobile

applications that are recommended to follow. For web applications, W3C guidelines should be used. Specific design guidelines provided by game engines or technical frameworks should be followed for games in general.

Clinical Trials Clinical trials are needed to fulfill certain certification requirements and provide valuable insight into the effectiveness of games and apps beyond smaller evaluations within respective target groups. Therefore, it is highly recommended that NCD-prevention app developers participate in clinical trials.

Software Testing Rigorous software testing methods are highly endorsed as part of this framework's best practices. NCD-prevention games and apps can only be effective if they run well without noticeable errors and have concise user experiences.

C6 - Technical aspects

This section focuses on the technical aspects of NCD-prevention games and apps, including APIs, protocols, game engines, game analytics, telemetry data, the use of backend services, and security and privacy considerations.

APIs, protocols, authentication and authorization HL7 FHIR specifies not only how the various data elements are structured but also how they should be exchanged using an Application Programming Interface (API). The implementation guide, which was developed, also includes a capability statement that specifies exactly how to interact with the FHIR API. It consists of a specification in the "openAPI" standard [251] that developers can directly use. Figure 5.28 shows an overview of the HTML rendering of the FHIR capability statement that is part of the prototypical implemented FHIR implementation guide.

However, if games use proprietary backend systems, this should also be allowed and will not be further specified by the implementation guide. Communication should still be based on common standards like Representational State Transfer (REST) web services and adhere to state-of-the-art security and privacy practices.

Game engine The analyzed games BreathIn and Food Pyramid Escape use the cross-platform game engine Unity [218]. Nutrition Garden, NutritionRush, recoverApp, and Moodbooster were developed as native Android apps. The minigames in Moodbooster were developed with JavaScript. NutriMine, a Minecraft mod, was created with Minecraft-Forge [252]. DiaBeaThis and the therapist application for recoverApp were implemented as web applications. Various engines and frameworks are available to develop NCD-prevention games and apps. Native frameworks for mobile applications or cross-platform game engines like Unity have been successfully used by analyzed games and apps and are recommended.

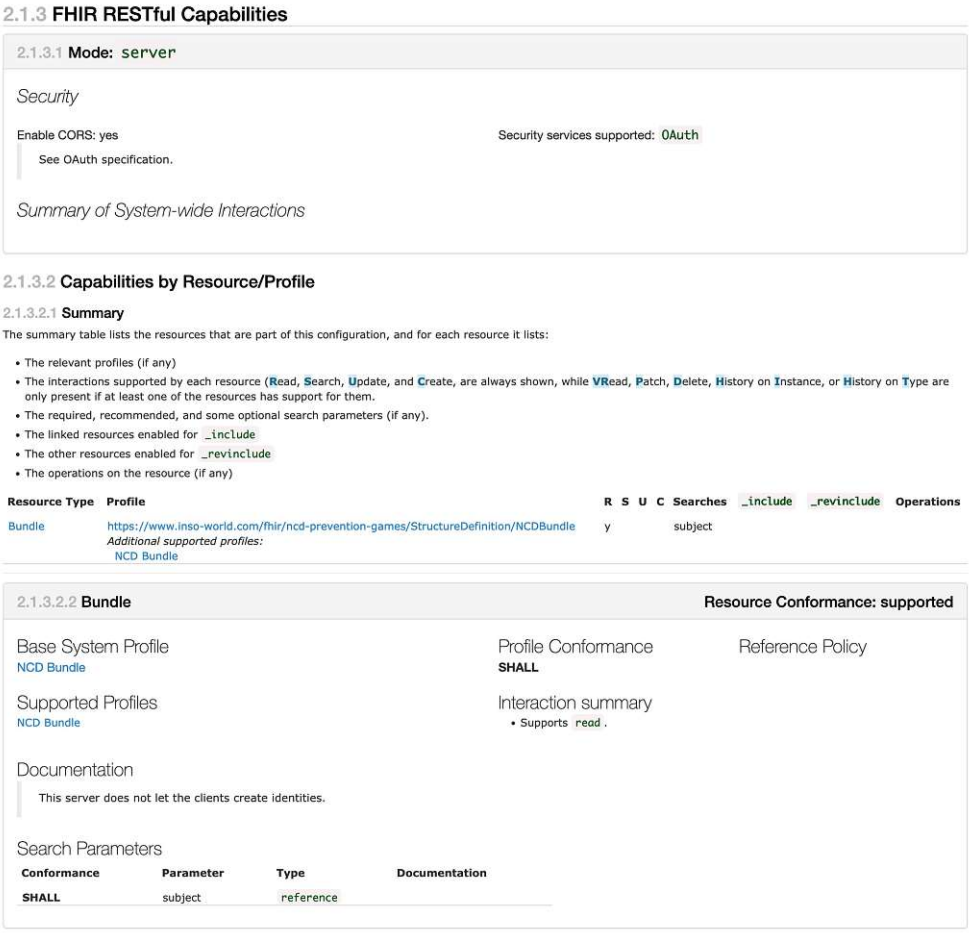


Figure 5.28: Framework: Web rendering of the FHIR capability statement

Game analytics and telemetry Telemetry data can help developers improve games by allowing them to analyze user interactions. Therefore, this framework encourages the collection of telemetry data, provided data security and privacy aspects are considered.

Backend services Games and apps can use their proprietary backend systems if required for specific use cases. Since all analyzed applications did not use backend services, this framework neither encourages nor discourages the use of such systems. However, developers should adhere to the data security and privacy standards discussed within the framework.

Security and privacy aspects Since sensitive data can be stored in proprietary backend systems, games and apps must adhere to common data privacy laws. This framework highly recommends integrating the General Data Protection Regulation

(GDPR) for apps and games distributed in the European Union [253]. The respective data protection laws must be followed if games and apps are provided in other countries.

Data should always be transmitted in an encrypted way and, if possible, stored in an end-to-end encrypted form on any backend systems. Encryption ensures that only users have direct access to the data stored on a server on their behalf. Data transmitted to national or personal health records must be encrypted with transport layer encryption. Data storage depends on the specific health record system's technical specification and is not within this framework's scope.

5.4 Evaluation

Note: A version of this whole section was published as a journal paper by Aigner et al. in [35].

This section compares the framework's six key areas, C1-C6, with the actual state of the games and apps that were developed beforehand and served as the foundation for defining the best practices. Table 5.14 gives an overview of the degree of fulfillment in each key area, "full," meaning the game or app fully fulfills each part in that area; "part." meaning partial fulfillment; and "none," meaning no fulfillment.

Table 5.14: Framework: Comparison of the apps in terms of framework key areas [35]

ID	Work	C1	C2	C3	C4	C5	C6
G1	BreathIn	none	part.	none	none	part.	part.
G2	Food Pyramid Escape	none	part.	none	none	part.	part.
G3	Nutrition Garden	none	part.	none	none	part.	part.
G4	NutritionRush	none	part.	none	none	part.	part.
G5	NutriMine	none	part.	none	part.	part.	part.
G6	recoverApp	none	part.	none	none	part.	part.
G7	MoodBooster	none	part.	none	none	part.	part.
G8	DiaBeaThis	none	part.	none	none	part.	part.

None of the analyzed games and apps currently fulfill requirements regarding organizational and semantic interoperability (key areas C1 and C3) since they were only being evaluated in smaller clinical settings and are not yet widely available. Furthermore, the defined HL7 FHIR implementation guide was unavailable when these apps were designed and implemented.

All analyzed apps fulfill at least some of the defined best practices (key area C2) since they successfully implement BCTs and include engaging gamification aspects and game mechanics.

Except for NutriMine, which was already successfully integrated into a prototypically implemented serious game appliance, the other apps still need to fulfill parts of key area C4 regarding serious games ecosystem.

All analyzed apps at least partially fulfill the key areas of usability and technical aspects (areas C5 and C6). They were also playtested and evaluated with users from the target groups. However, since all analyzed apps are still at a prototypical stage, best practices regarding game engines, APIs, backend services, and security measures have yet to be fulfilled.

CHAPTER 6

Discussion

The principal results of this dissertation were the design, development, and evaluation of three serious games and three gamified applications for reducing multiple NCD risk factors like smoking, unhealthy diet, and mental health and thus helping in the prevention of various NCDs. Together with two more from the state-of-the-art, these games and apps were used for a comparative analysis that served as the foundation for constructing an interoperable framework for NCD-prevention serious games incorporating six key areas.

Within the introduction of this dissertation, three research questions were stated and answered during the course of this thesis in different phases, as can be seen in Figure 1.1. The following sections will discuss all of them and go into more detail regarding each.

6.1 Research Question 1

Which classes of requirements can be identified for behavior change-driven serious games, respectively, mobile applications that incorporate gamification elements to prevent NCDs, and what would actual classes of implementations look like?

The first research question deals with the identification of classes of requirements for behavior change-driven serious games and gamified mobile apps for NCD prevention and actual classes of implementations. As part of this dissertation, six scientific concepts were completed together with students and colleagues from the author's research group, leading to seven conference publications. Three prototypes were full serious games: Food Pyramid Escape (Section 5.1.2), BreathIn (Section 5.1.3), and NutriMine (Section 5.1.5), although NutriMine is considered a serious modification since it enhanced the already existing and very popular open-world game Minecraft with serious game elements. The other three prototypes were mobile applications with added gamification elements:

recoverApp (Section 5.1.1), Nutrition Garden (Section 5.1.4), and MoodBooster (Section 5.1.6), which also contained a web application for therapists. Table 6.1 gives an overview of all developed applications as part of this work.

Table 6.1: Developed applications

Application	**Requirements**	**Requirement source**	**Prototype**	**Evaluation**
recoverApp	15 requirements	State-of-the-art	Mobile app and web app	Evaluation with 2 therapists
Food Pyramid Escape	18 requirements	State-of-the-art	Mobile app	Evaluation with 2 participants
BreathIn	12 requirements	Two surveys with 466 participants in total, 9 interviews	Mobile app	Psychiatrist and two evaluations with 13 participants in total
Nutrition Garden	21 requirements	State-of-the-art, Interviews with 3 individuals and 2 experts	Mobile app	Playtest and interview with 5 participants
NutriMine	8 requirements	State-of-the-art, nutritional expert	Minecraft modification	Playtest with 11 participants
MoodBooster	Principal app concept and 4 game ideas	State-of-the-art	Mobile app	Evaluation with 10 participants

recoverApp is a mobile health solution for stationary rehabilitation that includes a mobile app for patients and a web platform for therapists. State-of-the-art analysis and the feedback of two therapists deducted 15 functional requirements. These requirements were then prototypically implemented, leading to an Android app for patients and a web application for therapists that can be used in any modern web browser on PCs or laptops. Two therapists evaluated the application.

Food Pyramid Escape is a serious escape adventure game depicting all seven Austrian Food Pyramid levels. A state-of-the-art analysis gathered 18 requirements, which were then prototypically implemented and subsequently evaluated by two people from the target group. However, only two of the seven designed levels were realized in the prototype.

BreathIn is a serious game that is realized as a platformer (also called a jump 'n' run game) for people to stop smoking. Based on an online survey with 304 participants and

further semistructured interviews with 9 participants, 12 requirements were assembled. These requirements first led to the development of mockups, which consequently led to the implementation of a fully functioning prototype of the game that was playtested afterward.

Nutrition Garden is a gamified nutrition tracker that allows users to grow and foster a virtual garden. During the app's principal design, 21 requirements were gathered by involving a nutritional scientist and potential users from the target group and conducting a state-of-the-art analysis. These were then implemented within a prototype, although two requirements regarding progress statistics were not included. Five users from the target group tested the prototype and were interviewed afterward.

NutriMine is a modification for the popular game Minecraft. Eight requirements were identified through a literature review and an interview with a nutritional expert. These were then prototypically implemented as a modification that can be played directly with every installation of the Java edition of the game.

MoodBooster is a gamified application that helps with student mental health and contains four mini-games. The requirements for the main app and the ideas for the four mini-games were based on a state-of-the-art analysis of student mental health. The main app and two games were then prototypically implemented and evaluated by individuals from the target group.

These six applications lead to a total of 74 requirements and one general concept with four distinct game ideas. These requirements describe game elements, game mechanics, or gamification elements and also elaborate on basic app features like user management, login, chat messages, statistics, and visual and sound design. Even though not all requirements were considered to be realized during the practical phases, all six games and apps were prototypically implemented after the design phases using different technologies, and, in one case, even a specialized modding tool for the game Minecraft was used.

All developed apps were also thoroughly evaluated. recoverApp was presented to a group of two therapists who were oncology specialists. They stated that the application could be beneficial but were also skeptical about certain features. Two people from the target group evaluated Food Pyramid Escape. They found the game to be good overall and had positive impressions. They did state, however, that the scope and amount of theoretical information was sometimes perceived as overwhelming. Both saw the game as part of an intervention, not as a stand-alone one. The evaluation of BreathIn was conducted within two distinct parts. The low-fidelity prototype was shown to a group of six people from the target group and also a practicing psychiatrist. The game idea was received very positively. The psychiatrist agreed that a playful approach is good for smoking cessation intervention. The high-fidelity prototype was evaluated with a playtest consisting of seven target group participants. The playtest lasted between 5 and 24min. Twelve improvements were gathered from it. The game felt fun to play, and the players felt positive about the game's help in quitting smoking.

Nutrition Garden was also evaluated as a playtest with five users from the target group in

20-30-minute sessions. Users enjoyed the nutritional facts the app teaches and found the gamification aspects very positive and useful. The NutriMine playtest lasted from 30 to 120 minutes and had a total of 11 participants. The Minecraft modification helped users to think about their diet, and they learned new aspects about nutrition and believed that the mod could change their dietary behavior. MoodBoster evaluation was conducted in two parts by a total of ten participants. Part one covered general questions about the application and usability, and part two focused on the included mini-serious games. The feedback was mostly positive, and the users stated that the games were entertaining and the design was functional and mostly intuitive.

In total, 45 users from their respective target groups participated in evaluations and playtests of the games and apps. Additionally, six medical experts were involved and gave valuable feedback on the applications as well. Overall, all games and gamified apps were well received, and users stated that gameful elements and educational content could help them change their behavior and, therefore, reduce NCD risk factors. However, most playing sessions lasted only briefly, so long exposure to the games and apps could not be tested.

In summary, the author believes that RQ1 was sufficiently answered by demonstrating that various risky behaviors related to contracting glsNCDs can effectively be incorporated into serious games or gamified apps. This conclusion is supported by a total of 74 requirements gathered from literature and state-of-the-art reviews, interviews with medical professionals, including therapists and doctors, feedback from members of the respective target groups, as well as questionnaires and subsequent prototypical implementations. Finally, evaluations were conducted involving 41 users from the target group and three medical experts.

6.2 Research Question 2

Which classes of personal, game, behavioral, or medical data do behavior change-driven serious games, respectively, gamified mobile apps to prevent NCDs, have in common, and how can patients and clinicians benefit from them if personal or electronic health records incorporate such data?

The second research question deals with the classes of personal, game, behavioral, and medical data produced by serious games and gamified apps for NCD prevention. This question was answered within this work by interpreting the results of the comparative analysis conducted as a prerequisite for the definition of the interoperable framework. This analysis was performed with the six games and apps described within this work as part of the results and two additional that were developed within the author's research group. The two additional applications were NutritionRush, a serious game for better nutrition, and DiaBeaThis, a gamified web application for diabetes patients. These concepts were selected because they address a range of the most prevalent risk factors for NCDs, such as nutrition, smoking cessation, and mental health.

The most common classes of data were patient data (e.g., name, patient, age, or gender), game progress data (game state, progression, inventory), and diary data, whether it concerned food diaries, smoking diaries, mood-tracking, or classical diary entries. Certain apps support recording basic health measurement data like body weight, body height, and BMI, as was the case with NutritionRush, and blood glucose level and insulin dosage with the app DiaBeaThis. Also very common with the support of four out of six applications were achievement and badge data (BreathIn, Nutrition Garden, recoverApp, and MoodBooster).

Additionally, BreathIn also records the current price of a cigarette package and the number of cigarettes per package to calculate the costs that have been avoided due to smoking cessation. MoodBooster stores questionnaires about current stress levels, and recoverApp stores existing tasks and completed challenges.

The comparative analysis showed a diverse range of classes of data that serious games and gamified applications for NCD prevention produce. These include:

- Personal data in the form of patient master data, including name, age, and gender.
- Medical data in the form of measurement data like body weight, body height, and BMI, as well as specific clinical data like blood glucose level or insulin dosage. Mood tracking data and the results of questionnaires about mental health status can also be considered medically relevant data.
- Game data in the form of game progression, game state data, inventory, challenges, and achievements/badges.
- Behavioral data in the form of food diaries, smoking diaries, task tracking, or basic diary recordings.

All of the previously mentioned classes of data are significant for the patients themselves in terms of self-tracking behaviors and actively promoting behavior change. They can also play a crucial role in the patient-doctor relationship as part of ongoing and future treatments. For instance, clinicians might be interested in medical data to monitor mood trends and body measurements over time. Doctors may focus on smoking habits or dietary intake to provide patients with practical health-related advice and referrals to other specialists who can offer more tailored care according to the patient's needs. In this context, the seamless exchange of these classes of data is even more critical so that the referred expert can access the patient's pertinent data over time. Recording this information can also be essential for future care episodes. For example, a food diary from the past can offer insights into current metabolic conditions and lead to specific dietary recommendations for patients.

Furthermore, if all these types of data are stored in national or supranational electronic health records, they can also be advantageous for scientific purposes. Of course, utilizing this data requires thorough anonymization to ensure it is not traceable back to actual

patients. The more data is available in a semantically interoperable manner, the more it can be utilized for clinical decision support systems or other big data scenarios, including the application of large language models (LLMs). A study by Chang and Sung indicates that integrating biomedical knowledge sources, such as the multidimensional terminology SNOMED CT, which is recommended as part of the implementation guide defined in this work, into LLMs may improve their performance on biomedical tasks. However, while their findings suggest potential benefits of SNOMED CT integration, the absence of standardized evaluation methods and comprehensive performance reporting prevents definitive conclusions regarding its effectiveness. Work by Rigas et al. [254], which utilizes HL7 FHIR data for AI-based applications in smart hospitals, and Plaza et al. [255], which employs FHIR for LLMs within a clinical decision support model in an ICU ecosystem, demonstrate the potential of using semantically interoperable data standards from the medical informatics field.

The author considers RQ2 sufficiently answered based on the comparative analysis results and the analysis of the various classes of data the compared apps produce.

6.3 Research Question 3

How can a semantic interoperable and technical framework for behavior change-driven serious games, respectively, gamified mobile apps, be defined? What are the best practices for the design and implementation of such applications? Which health informatics standards can be used to represent personal, game, behavioral, or medical data interoperably, and how can these datasets be integrated into healthcare records?

The third and final research question emphasizes the construction of a semantic interoperable and technical framework for behavior change-driven serious games and gamified mobile apps.

An interoperable framework with six key areas was defined to answer this question based on a comparative analysis of eight serious games and gamified apps for NCD prevention. The six key areas are organizational interoperability, design and development best practices, semantic interoperability, serious game ecosystem, usability, quality aspects, and technical aspects.

A central part of the framework was the definition of an implementation guide for the interoperable extraction and exchange of personal, game, behavioral, and medical data for further use within electronic health records aiding in patient care and as part of secondary use for clinical research purposes based on the state-of-the-art medical informatics standards HL7 FHIR and FHIR-shorthand for the profile definition. The guide is available through technical artifacts (HTML representation, JSON, Excel, CSV). Also, it includes a capability statement with API definitions that implementers can use when designing novel, serious games.

Furthermore, the framework suggests best practices for designing and developing NCD-prevention games and apps by providing key requirements and guidelines for behavior change techniques, gamification elements, game mechanics, configuration aspects, serious games metadata, app registers, serious games appliances and general usability and technical aspects like design guidelines, software testing, APIs, protocols, game engine, backend services, authentication, authorization, telemetry and data security and privacy aspects. It also addresses organizational aspects like care processes, governmental platforms, health data spaces, and regulatory compliance.

Best practices that were defined in the form of a requirement catalog include the integration of BCTs as core elements, the integration of engaging game mechanics within full serious games and gamification elements for gamified apps, the execution of intuitive controls, the availability of games and apps for patients, the inclusion of therapists and clinicians, and the ability to extract and exchange data in a semantically interoperable way. The requirements mentioned above were marked as a "must" for their level of fulfillment. Further requirements were defined as "should" or "may" regarding their respective fulfillment level.

The presented framework can serve as a fundamental guideline for creating new games and applications aimed at reducing risk factors for non-communicable diseases (NCDs). The limitation of the framework largely arises from the number of applications analyzed, with a total of eight apps examined. Future work should involve a greater number of apps to refine the developed interoperable framework further. Additionally, the implementation guide created can be regarded as a prototype and should be utilized in practice as part of future efforts. For instance, some elements are currently represented as string values and need to be parsed correctly by the systems that consume them. For example, the DIN metadata should be defined as an FHIR composition rather than a string value.

The definition of the framework that includes best practices for designing and developing novel serious games and gamified apps for NCD prevention and using the medical informatics standards HL7 FHIR, SNOMED CT, and LOINC can be seen as a comprehensive answer to the question RQ3 in the opinion of the author.

CHAPTER 7

Conclusion and Future Work

This dissertation focused on behavior-change-driven serious games and gamified applications aimed at reducing non-communicable disease (NCD) risk factors, thereby helping prevent NCDs. It began with a comprehensive introduction to the theoretical foundations of NCDs, nutrition, smoking cessation, mental health, mobile health, serious gaming, gamification, relevant psychology theories, semantic interoperability, and a state-of-the-art analysis of mental health applications in rehabilitation. The analysis also covered games and apps for nutritional education and food tracking, student mental health apps, and frameworks for interoperability and serious games. Building on this theoretical foundation, the design, development, and evaluation of six NCD-prevention applications were described in detail. Three of the designed applications were full-fledged serious games, although NutriMine can be viewed as a serious modification of the entertainment game Minecraft. The other three were mobile applications that incorporated gamification elements. Additionally, recoverApp offered a web application for therapists.

A comparative analysis was carried out, starting with these six applications and two additional prototypes developed within the author's research group. This analysis resulted in the establishment of an interoperable technical framework for NCD-prevention games and applications. The framework outlined a novel approach to best practices for developing serious NCD-prevention games and gamified apps that should be considered when creating new concepts in this field.

7.1 Limitations

Although this work's findings and the games and apps that were built can be considered valuable for the crucial area of non-communicable disease prevention, some limitations need to be considered.

The number of applications developed for NCD prevention was limited within the scope of this work, as only six concepts were realized. Additionally, not all major NCD risk factors were addressed by the developed games and apps. Further risk factors identified by the WHO, such as physical inactivity, the harmful use of alcohol, and air pollution, were not included in any of the developed applications and should be considered in future work.

Additionally, the number of respective experts and participants from target groups involved in requirement analysis, evaluation, and playtests was limited, representing only a small portion of the targeted populations. The evaluations that were conducted were limited in time and resources, and no official clinical trials were performed, limiting assertions about long-term behavior change proposed within the developed concepts.

The technical framework constructed for NCD-prevention games and apps was based on the six applications mentioned above, along with two additional concepts from the author's research group. Consequently, the established best practices regarding the design and development of NCD-prevention games and apps within the framework can be considered partially limited due to the narrow sample size. Although each of the developed concepts represents a unique approach to integrating behavior change techniques and innovative game elements, the range of user experiences, functionalities, and design paradigms that could be gained from a broader dataset becomes difficult to capture, given that only eight applications were involved in the process. A more comprehensive approach that incorporates a larger array of NCD-prevention games and apps could create a more effective interoperable framework for NCD prevention that does not inadvertently reflect the specific characteristics of the selected games and apps, thus potentially overlooking other successful strategies or innovations available in different applications.

The technical implementation guide, which is part of the framework and uses HL7 FHIR and FHIR shorthand to define extensions and profiles for NCD-prevention game and clinical data elements, was only implemented on a prototypical basis and needs further evaluation in real-world scenarios, such as exchanging actual data to health records or other medical applications.

7.2 Future Work

For future work on this thesis, more games and apps from the state-of-the-art must be included to refine the framework further. This improvement can be achieved by conducting a larger-scale comparative analysis of existing work in the field of NCD-prevention games and apps. The work to be included can be identified through a detailed literature review and collaborations with other research groups. The results should then be utilized to improve the technical implementation guide and develop case studies where actual data is extracted for use in electronic health records. Furthermore, since the implementation guide is currently a prototype, technical refinements, such as the aforementioned implementation of more structured data in the case of the DIN norms on serious games, should be incorporated.

Moreover, the application of large language models (LLMs) for HL7 FHIR data in NCD prevention is under evaluation, as this area is regarded as an emerging field in semantic interoperability research in the opinion of the author [256]. The integration of LLMs into NCD-prevention games offers the opportunity to utilize even more gaming, behavioral, and medical data for exchange and further use.

Additionally, the games and apps developed will be improved, and a more extensive evaluation of each will be carried out in future work. A specific example is the Minecraft modification NutriMine, which is currently being playtested on a larger scale and is considered for a future journal publication. The playtest will include advanced metrics like the User Engagement Scale (UES) [257], the System Usability Scale (SUS) [258], and the Game Experience Questionnaire (GEQ) [259] to gain more insight into the impact of the modification on NCD prevention and deduce further requirements.

Figure 7.1: Screenshot of the VR app "Nutri-G" [260]

Another example is the gamified app Nutrition Garden, which is currently being transformed into a virtual reality (VR) game as part of an additional scientific concept. The goal is to integrate the existing mobile nutrition tracking app with a fully interactive virtual reality garden application to enhance user engagement and encourage behavior change. By developing a backend component, tracking food items within the mobile app will allow users to earn points in their accounts that can be spent on their VR garden. Social features should be included as well, such as visiting friends' virtual gardens. Figure 7.1 shows the current state of the game world and assets of the virtual garden that is being developed as part of a high school research prototype supervised by the author.

The MoodBooster app will also be enhanced by implementing the other two mini-games designed and conducting a larger evaluation with more university students. The prototypical implementation of Food Pyramid Escape only included the first two levels of the Austrian food pyramid. Future work should include implementing the remaining five levels to provide a complete gaming experience. Finally, BreathIn has the potential to be utilized in larger-scale smoking cessation interventions. The current prototype needs

to be enhanced by developing more levels and providing more possibilities for the game character to be influenced by the users' smoking behavior to achieve this.

In general, the evaluation of the framework described in Chapter 5 showed that all analyzed applications from the comparative analysis revealed significant gaps in the framework's six defined key areas. Therefore, it is crucial for future work to address these gaps and ensure that all games and apps comply with the criteria and best practices defined within the interoperable framework.

Overall, the developed games and apps, best practices, and implementation guide serve as a very good foundation for future work within the field of behavior change-driven applications for NCD prevention. As NCD risk factors become increasingly prevalent and the global incidence of NCDs is on the rise, this work can be understood as a valuable contribution to this field.

Overview of Generative AI Tools Used

For the construction of this doctoral thesis, AI-supported tools such as Grammarly from Grammarly, Inc. for writing support (including suggestions and rewrites), DeepL from DeepL SE for translations, and scite.ai from scite LLC, as well as Perlego from Perlego Ltd, for research on the theoretical foundation and state-of-the-art (including suggestions for text content), were used.

The author thoughtfully revised every piece of generated text, ensuring that no section was used in its original, unreflected form.

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Glossary

ACM Association for Computing Machinery. 12

AI Artificial Intelligence. 30, 103, 160

API Application Programming Interface. 46, 50, 138, 151, 154, 160, 161

ARF Acute Rheumatic Fever. 18

ASCII American Standard Code for Information Interchange. 42

BCT Behavior Change Technique. 3, 4, 39, 57, 137, 139, 142, 143, 154, 161

BMI Body mass index. 25, 61, 122, 135, 159, 169

BPMN Business Processing Modeling Notation. 53

CAM Content Aggregation Model. 36, 37

CBT Cognitive Behavioral Therapy. 86, 133

CDA Clinical Document Architecture. 42, 44–46, 51

CHF Congestive Heart Failure. 18

COPD Chronic obstructive pulmonary disease. 16, 19, 20

CRC Colorectal Cancer. 19

CRD Chronic respiratory disease. 19, 20, 28

CSV Comma-separated values. 160

CVD Cardiovascular disease. 17, 18

DiGA Digitale Gesundheitsanwendung. 32, 57, 65, 71, 74, 138, 142, 150

DIN Deutsches Institut für Normung. 35, 71, 146, 149, 161

DNA Deoxyribonucleic Acid. 19

DSS Decision Support System. 69, 70, 74

eFA Elektronische Fallakte. 51

EHDS European Health Data Space. 4, 139

ELGA Elektronische Gesundheitsakte. 51, 144

ePA Elektronische Patientenakte. 51, 71, 144

EU European Union. 4, 32, 138

FHIR Fast Healthcare Interoperability Resources. 5, 6, 8, 42, 46, 47, 70, 71, 74, 83, 143–146, 149–153, 160, 161, 164, 165, 169, 170

FSH FHIR shorthand. 144, 145

GPS Global Positioning System. 30, 31, 34

GUI Graphical User Interface. 121, 122, 170

HL7 Health Level Seven. 5, 6, 8, 12, 41–46, 50, 51, 70, 71, 74, 83, 143–145, 148, 151, 153, 160, 161, 164, 165, 169

HTML Hypertext Markup Language. 46, 151, 160

ICU Intensive Care Unit. 160

IEEE Institute of Electrical and Electronics Engineers. 12

IFRC International Federation of Red Cross and Red Crescent Societies. 15, 16

IG Implementation Guide. 144, 145, 148

IHE Integrating the Healthcare Enterprise. 42, 50, 51, 144

JSON JavaScript Object Notation. 160

LLM Large Language Model. 160

LOINC Logical Observation Identifiers Names and Codes. 6, 47, 48, 69, 70, 144, 161

MDR Medical Device Regulation. 32

NCD Non-communicable disease. 2–8, 13, 15–17, 20, 22–24, 28, 29, 55, 64, 65, 70, 74, 85, 103, 112, 113, 116–118, 125, 131–133, 136–145, 148–151, 155, 158–161, 163–166

NSCLC Non-Small Cell Lung Cancer. 19

RE Requirement Engineering. 51

REST Representational State Transfer. 46, 70, 72, 151

RHD Rheumatic Heart Disease. 18

RIM Reference Information Model. 42–44, 46, 169

RTE Run Time Environment. 36, 37

SCORM Sharable Content Object Reference Model. 36, 37, 70, 71, 74

SCTID SNOMED CT Identifier. 48, 49

SNOMED CT Systematized Nomenclature of Medicine Clinical Terms. 5, 47–50, 70, 144, 160, 161, 169

TNBC Triple-Negative Breast Cancer. 19

UML Unified Modeling Language. 52, 53

WHO World Health Organization. 3, 15, 16, 18, 21, 22, 25–27, 30, 48, 164

XDS Cross-Enterprise Document Sharing. 51, 144

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Appendix

Overview of all participants

Name	Age	Gender	Profession	Phase	Concept
P1	35	m	Therapist	Evaluation	recoverApp
P2	x	m	Therapist	Evaluation	recoverApp
P3	23	m	Student	Evaluation	Food Pyramid Escape
P4	27	f	Employed Person	Evaluation	Food Pyramid Escape
P5	25	m	x	Design	BreathIn
P6	55	f	x	Design	BreathIn
P7	27	m	x	Design	BreathIn
P8	57	m	x	Design	BreathIn
P9	70	f	x	Design	BreathIn
P10	23	f	x	Design	BreathIn
P11	24	m	x	Design	BreathIn
P12	24	m	x	Design	BreathIn
P13	61	m	x	Design	BreathIn
P14	x	m	Psychiatrist	Implementation	BreathIn
P15	19	f	Student	Evaluation	BreathIn
P16	24	m	Software developer	Evaluation	BreathIn
P17	28	m	Employed Person	Evaluation	BreathIn
P18	35	f	Employed Person	Evaluation	BreathIn
P19	37	m	Employed Person	Evaluation	BreathIn
P20	53	f	Employed Person	Evaluation	BreathIn
P21	57	m	Retiree	Evaluation	BreathIn
P22	27	m	Computer Specialist	Design, Implementation	Nutrition Garden
P23	23	m	Student	Design	Nutrition Garden

Name	Age	Gender	Profession	Phase	Concept
P24	55	f	Accounting	Design, Implementation	Nutrition Garden
P25	29	m	Nursing Assistant	Implementation	Nutrition Garden
P26	76	f	Pensioner	Implementation	Nutrition Garden
P27	58	m	Programmer	Implementation	Nutrition Garden
P28	37	f	Nutritionist + Fitness Trainer	Consulting	Nutrition Garden
P29	22	f	Student	Consulting	Nutrition Garden
P30	53	f	Nutritional expert	Design	NutriMine
P31	16-30	m	x	Evaluation	NutriMine
P32	16-30	m	x	Evaluation	NutriMine
P33	16-30	m	x	Evaluation	NutriMine
P34	16-30	m	x	Evaluation	NutriMine
P35	16-30	m	x	Evaluation	NutriMine
P36	16-30	f	x	Evaluation	NutriMine
P37	16-30	m	x	Evaluation	NutriMine
P38	16-30	m	x	Evaluation	NutriMine
P39	16-30	m	x	Evaluation	NutriMine
P40	45+	m	x	Evaluation	NutriMine
P41	16-30	f	x	Evaluation	NutriMine
P42	21-24	f	Student	Evaluation	MoodBooster
P43	21-24	f	Student	Evaluation	MoodBooster
P44	21-24	f	Student	Evaluation	MoodBooster
P45	25-28	f	x	Evaluation	MoodBooster
P46	29+	f	x	Evaluation	MoodBooster
P47	29+	f	Student	Evaluation	MoodBooster
P48	29+	m	x	Evaluation	MoodBooster
P49	29+	m	x	Evaluation	MoodBooster
P50	x	x	x	Evaluation	MoodBooster
P51	x	x	x	Evaluation	MoodBooster

Overview of all requirements

Req. ID	Description	Affected actor	Concept
R01	Create therapy task	Therapist	recoverApp
R02	Create private task	Patient	recoverApp
R03	Perform therapy task	Patient	recoverApp
R04	Perform private task	Patient	recoverApp
R05	Record mood data	Patient	recoverApp
R06	Access mood data	Therapist	recoverApp
R07	Derive mood trends	Therapist	recoverApp
R08	Create challenges	Therapist	recoverApp
R09	Perform challenges	Patient	recoverApp
R10	Create skills	Patient/Therapist	recoverApp
R11	Write diary entry	Patient	recoverApp
R12	Read public diary entries	Therapist	recoverApp
R13	Award skill points	Therapist	recoverApp
R14	Receive skill points	Patient	recoverApp
R15	Send messages via chat	Patient/Therapist	recoverApp
R16	Represent the seven levels of the Austrian Food Pyramid		Food Pyramid Escape
R17	Communicate subject matter using riddles in the game		Food Pyramid Escape
R18	Solving the riddles contributes to reaching the game goal		Food Pyramid Escape
R19	Each finished level unlocks the next one		Food Pyramid Escape
R20	Finished levels can be revisited		Food Pyramid Escape
R21	The game status can be resumed after leaving and restarting		Food Pyramid Escape
R22	The instructional goal is well defined by a curriculum		Food Pyramid Escape
R23	The subject matter is summarized in an encyclopedia		Food Pyramid Escape
R24	The player can interact with the game environment		Food Pyramid Escape
R25	A riddle's progress is communicated using feedback		Food Pyramid Escape

Req. ID	Description	Affected actor	Concept
R26	The riddles' difficulty increases linearly with the player's knowledge		Food Pyramid Escape
R27	The taught knowledge is correct and taken from respectable sources		Food Pyramid Escape
R28	Recommendations are suitable for Austrians, age-specific, and for omnivores		Food Pyramid Escape
R29	Emphasis lies on teaching information to help shift dietary shortcomings		Food Pyramid Escape
R30	Deepening knowledge is available but not game-relevant		Food Pyramid Escape
R31	No foreknowledge on nutrition, chemistry or biology is necessary		Food Pyramid Escape
R32	The nutritional knowledge is taught one section at a time to avoid an information overload		Food Pyramid Escape
R33	Food-based intake recommendations are used		Food Pyramid Escape
R34	The user defines the personal reasons and goals to quit smoking. These are permanently present in the application so that the user is frequently confronted and, therefore, remembers the personal goal.		BreathIn
R35	To create new routines and provide an alternative behavior to smoking, the serious game needs to be played every day. With challenges or levels, the game animates the user to interact with the application regularly. Therefore, a new behavior is trained.		BreathIn

Req. ID	Description	Affected actor	Concept
R36	Health and strength of the avatar mirror the health of the user. The health of the avatar is improving as the user keeps being abstinent. Therefore, the avatar's health symbolizes the positive effects of not smoking. By tracking the last smoked cigarette and reporting any relapse, the user is monitoring one's behavior and is more motivated to stick to the goal. With the avatar getting stronger, new challenges and levels are unlocked.		BreathIn
R37	Negative consequences in-game: The game continuously reminds the user of the negative consequences of smoking through specific challenges where the avatar is persuaded to smoke a cigarette. The user needs to decline the offer; otherwise, the avatar is weakened. Another idea is a game where the user must avoid cigarettes that are thrown toward the avatar.		BreathIn
R38	Negative consequences triggered by real-world events: If the user smokes a cigarette, the days since the last cigarette are reset to zero, and the avatars' strength is also set back to the initial strength. This action is supposed to show the user the negative consequences of smoking.		BreathIn

Req. ID	Description	Affected actor	Concept
R39	The design and graphics are selected to represent the progress. In the beginning, the avatar is visualized with dark colors, and the stronger the avatar gets - with continuous abstinence from the user - the brighter and more colorful the avatar will become. This is also true for the environment around the avatar to visualize that smoking is also affecting the surroundings.		BreathIn
R40	To keep the user interested, the game should have a story. The avatars' goal is to reach the user-defined goals. On the path, the avatar is followed by enemies who are trying to persuade him or her to smoke a cigarette. The user must throw cigarettes at these enemies. The enemies will smoke those cigarettes and get too weak to catch up with the avatar. On the path, the avatar can rest on checkpoints where he or she is saved from enemies. Mini bosses need to be defeated to reach a checkpoint.		BreathIn
R41	To offer some form of distraction to the user, riddles should be included in the serious game. They are either part of a level or can be solved spontaneously to distract the user from the urge to smoke. These riddles are built like quizzes where the user answers facts on smoking and smoking cessation. This also increases the user's knowledge and the motivation to protect one's health.		BreathIn

Req. ID	Description	Affected actor	Concept
R42	Achievements and positive feedback. The serious game tracks the last smoked cigarette. Every day the user opens the application, he or she is reminded of the days that have passed since the last smoked cigarette and gets positive feedback (motivational quotes). The application also reminds the user of the progress towards self-defined goals. For every completed week of smoking abstinence, the user gets a special achievement with newly unlocked items that can be used within the game. These items can be clothes to outfit the avatar or give the avatar a health boost.		BreathIn
R43	Social support: To enable social interaction, events from the game can be shared on social media. The user can share achievements and milestones that have been reached. This enables positive feedback from family and friends.		BreathIn
R44	Music and sound effects are used for different interactions. When the avatar moves through the scene, background music is played, and the music changes when an enemy appears. For successfully unlocked achievements, the sound effects should be happy and motivational. This helps the user perceive information and match interactions to resulting actions accurately.		BreathIn

Req. ID	Description	Affected actor	Concept
R45	The game should be played for a period of six months. There must be enough levels so that users can achieve their goals within those six months. A level itself should last for about five minutes.		BreathIn
R46	The user should be able to register for the application		Nutrition Garden
R47	The user should be able to log in to the application		Nutrition Garden
R48	The user should be able to log out of the application		Nutrition Garden
R49	The user should be able to show a simple list of foods		Nutrition Garden
R50	The user should be able to select the food consumed from the simple list of foods		Nutrition Garden
R51	The user should be able to add the selected food to the food diary		Nutrition Garden
R52	The food diary with all the day's consumed foods should be shown to the user		Nutrition Garden
R53	Each food in the food diary should contain a photo, name, points, and the amount of the food		Nutrition Garden
R54	The user should be able to show detailed information about the food		Nutrition Garden
R55	The user should be rewarded with points for each nutritional food he or she consumed from the food list of the application		Nutrition Garden
R56	The user should have an overview of the daily and total points, as well as other achievements, like the gathered fruits		Nutrition Garden
R57	The user should be able to show the weekly progress diagram		Nutrition Garden

Req. ID	Description	Affected actor	Concept
R58	The user should be able to show the monthly progress diagram		Nutrition Garden
R59	The user should be able to show the yearly progress diagram		Nutrition Garden
R60	Scientific nutritional facts should be shown on the home screen		Nutrition Garden
R61	The user should be able to buy tree seeds on the market if he or she has enough points		Nutrition Garden
R62	The user should be able to show the tree and water it		Nutrition Garden
R63	The user should be able to harvest the tree if it carries fruits		Nutrition Garden
R64	The harvested fruits will be recognized as additional achievements		Nutrition Garden
R65	The user should be able to show account details		Nutrition Garden
R66	The user should be able to update account details		Nutrition Garden
R67	Is an adaptation of an existing game		NutriMine
R68	Does not interfere with base game mechanics excessively		NutriMine
R69	Provides fun and challenging game mechanics		NutriMine
R70	Provides clear goals		NutriMine
R71	Rewards desired behavior		NutriMine
R72	Is not overly complex		NutriMine
R73	Gives players cues on their behavior		NutriMine
R74	Simulates consequences of healthy/unhealthy diet		NutriMine