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Exploring complexity and learning: insights from the DIBH-app project using NASSS-CAT

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Abstract
Digital health tools, such as radiotherapy preparation apps, can support person-centred care, though their development is shaped by evolving complexity. This study examined how perceived complexity changed during the development of the Deep Inspiration Breath Hold Preparation App and assessed the utility of the NASSS-CAT. A longitudinal observational study was conducted, with complexity assessed at three development stages using the NASSS-CAT. Stakeholders from clinical, academic, and industry settings completed individual assessments followed by group discussions. Quantitative data were analyzed descriptively; qualitative data provided contextual understanding. Perceived complexity varied by domain and over time. Initially, technical complexity was rated highest. Over time, total complexity declined, especially in strategic and operational domains, reflecting greater integration and shared understanding. The NASSS-CAT supported stakeholder reflection and adaptive decision-making. Integrating complexity-informed evaluation into development processes may improve the scalability, sustainability, and person-centredness of digital health interventions.

Keywords Complex systems · Co-creation · Digital health · Innovation diffusion · Patient-centered care

1 Background

Digital health tools, such as radiotherapy preparation apps, can support person-centred care, particularly when designed to reduce treatment-related stress and enhance procedural adherence. The Deep Inspiration Breath Hold (DIBH) Preparation App was developed through co-design with patients, clinical teams, researchers, and technical experts. It aims to help persons undergoing radiotherapy practice the breath-hold technique prior to treatment, using a stretch sensor and Bluetooth-connected app that simulates the clinical setting. This at-home preparation supports standardisation of instructions, improves patient readiness, and reduces cardiac radiation exposure during treatment.

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However, the development and implementation of such tools are shaped by evolving complexities that arise from technical, clinical, organizational, and contextual factors (Moullin et al. 2019). Assessing these complexities is critical for ensuring their scalability, sustainability, and real-world impact.

As digital tools become more prominent in healthcare, ensuring the safe and effective integration of digital health interventions requires a rigorous evidence-based approach. These tools must be evaluated for their technological feasibility, impact on clinical workflows and patient outcomes, and overall safety and usability (Ross et al. 2018a, b). However, assessing their real-world impact remains challenging, particularly in terms of effectiveness, scalability, and sustainability (Murray et al. 2016). A key limitation in digital health research is the lack of standardized evaluation frameworks, making it difficult to generate robust evidence for their adoption and integration into healthcare systems (Sheikh et al. 2021; Duffy et al. 2022).

Traditional evaluation methods in healthcare have focused on predefined outcomes such as clinical effectiveness, patient adherence, or cost-effectiveness (Benedetto et al. 2023). Yet digital health interventions often face additional layers of complexity due to their dependence on infrastructure, user engagement, integration with existing infrastructures, and responsiveness to evolving healthcare environments (Ross et al. 2018a, b; Papoutsi et al. 2021).

This study adopts a complexity-aware approach to evaluation, shifting away from traditional models that primarily measure intervention outcomes toward an approach that assesses the entire development process. Digital health interventions require ongoing adaptation based on user feedback, regulatory considerations, and system-level changes. Recognizing this, the Nonadoption, Abandonment, Scale-up, Spread, and Sustainability-Complexity Assessment Tool (NASSS-CAT) provides a structured yet flexible method for capturing these evolving complexities. This complexity-aware perspective aligns with the notion of "agile science" (Patrick et al. 2016; Marwaha et al. 2022), which advocates for real-time assessment and iterative refinement of digital health interventions. Rather than viewing complexity as a challenge to be reduced, this approach embraces it as a critical aspect of implementation, allowing for better alignment with stakeholder needs and healthcare system constraints (Perski and Short 2021; Ventura et al. 2022).

Despite growing recognition of the importance of complexity in healthcare innovation, many digital health interventions continue to be evaluated through linear models that do not fully account for the dynamic nature of implementation challenges (Ventura et al. 2022). Complexity science offers a more nuanced perspective, recognizing that digital health tools operate within constantly evolving systems shaped by technological advances, policy shifts, and stakeholder behaviours (Abimbola et al. 2019).

This study seeks to contribute to the growing body of research that calls for a complexity-informed approach to digital health evaluation. By applying the NASSS-CAT framework, it moves beyond conventional assessments that focus on isolated intervention components, instead embracing a holistic view that considers technical, operational, and contextual dimensions (Hellstrand Tang et al. 2024).

1.1 Contextualizing the DIBH app

The DIBH-App was developed to support patients undergoing deep inspiration breath-hold (DIBH) radiotherapy, providing digital guidance to enhance treatment preparation and adherence. By taking a deep breath hold, the distance between the chest wall and the heart increases, thus protecting it from unwanted radiation. Patients are instructed at the clinic during preparatory CT-scan and are supposed to breath in the same way when treatment starts. This can be stressful for patients, and cause disruption in treatment as well as more scans to adjust target areas. Previous research shows that patients undergoing practice and coaching five days prior to start of DIBH, have acquired potentially cardiac sparing doses and performed better during treatment (Kim et al. 2018). DIBH-App takes the practice one step further, by providing patients with stretch sensors and the app, which is designed to be as similar as possible to the real-life experience at the clinic. Using Bluetooth, the stretch sensor connects to the App and the patient can follow her breathing; practicing the breath hold technique required at the clinic. Additionally, it applies a newly developed breathing instruction that can both increase the distance between the chest wall and the heart and is also easy to standardize for staff instructing patients. Patients are provided DIBH-App minimum four days prior to CT-scan and are instructed to practice at home. The intention is thus twofold; to prepare at home before first visit at the radiation clinic and to evaluate the new instruction for feasibility and effect.

Prior studies have shown that patients appreciate the ability to prepare for medical procedures using digital tools at home, as evidenced by the DigiDo project (Grynne et al. 2021, 2023). DigiDo demonstrated that patients valued digital solutions for self-preparation before radiotherapy, highlighting a growing demand for such interventions. However, previous evaluations of digital health tools primarily focused on patient satisfaction and usability, without incorporating a structured complexity assessment (Ventura et al. 2022).

2 Aim

This study aims to explore stakeholder perceptions of complexity during the development of the DIBH Preparation App within a healthcare innovation project by applying the NASSS-CAT project tool.

3 Methods

This study applied NASSS-CAT tool to evaluate the development of the DIBH Preparation App within a healthcare innovation project. The NASSS-CAT project tool was used to assess complexity at multiple time points, capturing stakeholder perceptions across technical, operational, strategic, people-related, and political domains, while integrating both quantitative complexity scores and qualitative reflections (Greenhalgh et al. 2017).

3.1 Sample

A purposive sampling strategy was used to ensure representation from key stakeholder groups involved in the development and implementation of the DIBH Preparation App. The target sample size was approximately 10–12 stakeholders, selected based on their expertise and level of involvement in the project, allowing for diverse perspectives on complexity. All participants were approached individually by the research team and provided verbal informed consent after receiving information about the study's objectives, procedures, and voluntary nature of participation. For this assessment, patients were not involved since they could not be expected to have knowledge of possible complexity within the system. However, they were deeply involved in the design process of the application, ensuring it had the right content and usability.

In total, 11 stakeholders participated in the study, including healthcare researchers and project leaders with expertise in digital health innovation and clinical workflows, who contributed with insights into strategic decision-making and alignment with clinical practice. Healthcare professionals, including oncology specialists, respiratory therapists, and hospital physicists, were involved in integrating the DIBH app into clinical settings, offering perspectives on operational and patient-related complexities. Industry partners from two technology companies provided input on system integration and software development, highlighting technical and business-related challenges. Additionally, their technical expertise into sensor technology, contributed to discussions on interoperability, functionality, and technological feasibility (Table 1).

This multidisciplinary composition ensured that the study captured a comprehensive view of complexity as perceived by those directly engaged in the app's design, future implementation, and clinical use.

3.2 Data collection

Data collection was conducted at three time points, specifically selected to align with key milestones in the app's development. First, at the onset of the project, second after having tested a beta-version DIBH Preparation App, and third before the final version to be

Table 1 Overview of stakeholder roles and involvement in the complexity assessments

Role	Sector	Assessment involvement		
		T0	T1	T2
Project leader	Academic/clinical	Yes	Yes	Yes
Project coordinator	Academic/clinical	Yes	Yes	Yes
Medical physicist	Clinical	Yes	Yes	Yes
Physiotherapist	Clinical	No	Yes	Yes
Oncology specialist	Clinical	Yes	No	No
Technical expert	Industry	Yes	Yes	Yes
Product designer	Industry	Yes	No	No
Product designer	Industry	No	Yes	No
Product designer	Industry	No	Yes	No
Product designer	Industry	No	No	Yes
Software developer	Industry	No	No	Yes

launched in a clinical study. At each stage, stakeholder perceptions of complexity were assessed using the NASSS-CAT project tool (Greenhalgh et al. 2017).

Participants were first asked to complete the NASSS-CAT assessment individually, ensuring that a diverse range of perspectives was captured. This tool captures multiple dimensions of complexity by structuring the assessment around five key domains: technical, operational, strategic, people-related, and political complexity. Stakeholders rated complexity levels within each domain using a structured scale, indicating whether they perceived low, moderate, or high complexity. The assessment included guiding questions designed to ensure consistency in responses and to help stakeholders reflect on specific aspects of the development process. In addition to the structured responses, the tool incorporated open-ended fields where respondents could describe concerns or contextual factors that influenced their complexity perceptions.

The group discussions that followed enabled a synthesis of individual reflections, providing a broader and more integrated understanding of complexity across different stakeholder domains. These discussions were essential in clarifying the reasoning behind complexity perceptions and ensuring that the evaluation accounted for both individual insights and shared experiences. Results from these discussions provided insights on what complexities the project was facing, and from that, what actions were needed to proceed with the development process.

3.3 Data analysis

To track changes over time, the complexity ratings and qualitative insights gathered at each time point were compared. This longitudinal perspective allowed for an analysis of trends, shifts in stakeholder perceptions, and areas where complexity was perceived to have increased or decreased as the project progressed.

Quantitative complexity scores from the NASSS-CAT project tool were analysed to identify patterns across different domains, highlighting variations in perceived complexity over the three assessment points. Descriptive statistics were used to summarize overall complexity scores, and comparisons were made across stakeholder groups to assess differences in perception based on professional background and role in the project. Qualitative data from stakeholder reflections were thematically analysed to contextualize the complexity scores, providing insights into the factors driving changes in perceived complexity. Key themes were identified, focusing on challenges related to technology integration, organizational alignment and user engagement.

Ethical approval was obtained from the relevant review authority (Dnr 2021-04031). All stakeholders provided informed consent to participate.

4 Results

To assess the complexity of developing the DIBH Preparation Application, the NASSS-CAT tool was applied was applied at three key stages: at the onset of the project, after stakeholders tested a beta-version of the DIBH Preparation App, the final version was launched in a clinical study. Spider diagrams captured complexity scores across five domains: strategic,

technical, operational, people-related, and political. Below is an analysis of stakeholder perspectives and their evolving complexity perceptions.

At baseline (Fig. 1), the technical domain was rated as the most complex (24/70). Stakeholders with product end-use backgrounds, such as healthcare researchers and project leaders, perceived the highest complexity in this domain. The operational domain followed (17/70), with moderate complexity reported by stakeholders directly involved in clinical work, such as the oncology specialist. Strategic complexity (12/70) varied, with some stakeholders, including industry partners, perceiving challenges in aligning the app with broader project goals.

The people-related and political domains scored lowest, both around 8–9 points. Stakeholders like the technical expert and industry partners perceived minimal complexity in these areas, potentially reflecting early optimism about social integration and regulatory challenges. Healthcare researchers and project leaders reported the highest overall complexity (18 and 15 points, respectively), reflecting concerns about the app's real-world functionality, while the technical expert reported the lowest overall score (5 points), indicating confidence in the early technical development.

In the second assessment (Fig. 2), the total complexity score increased to 93/150, with the technical domain remaining the most complex (31/93). Healthcare researchers and other professionals, such as the physiotherapist and hospital physicist, identified ongoing technical challenges, possibly related to integration with hospital systems and reflecting the concerns with the lack of components to product development.

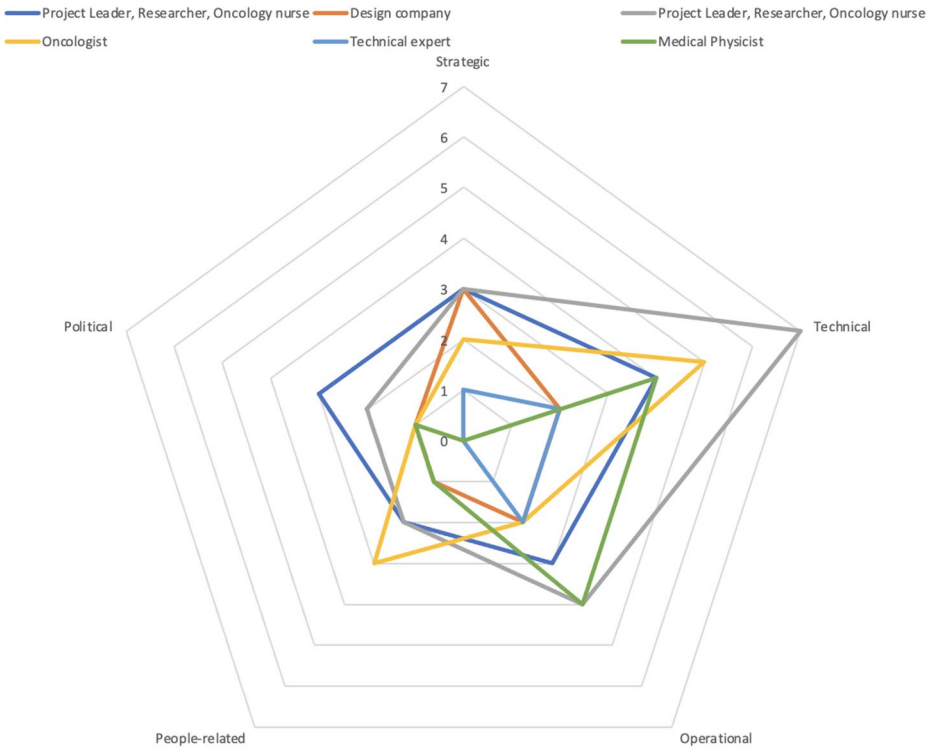

Fig. 1 Complexity assessment at project onset

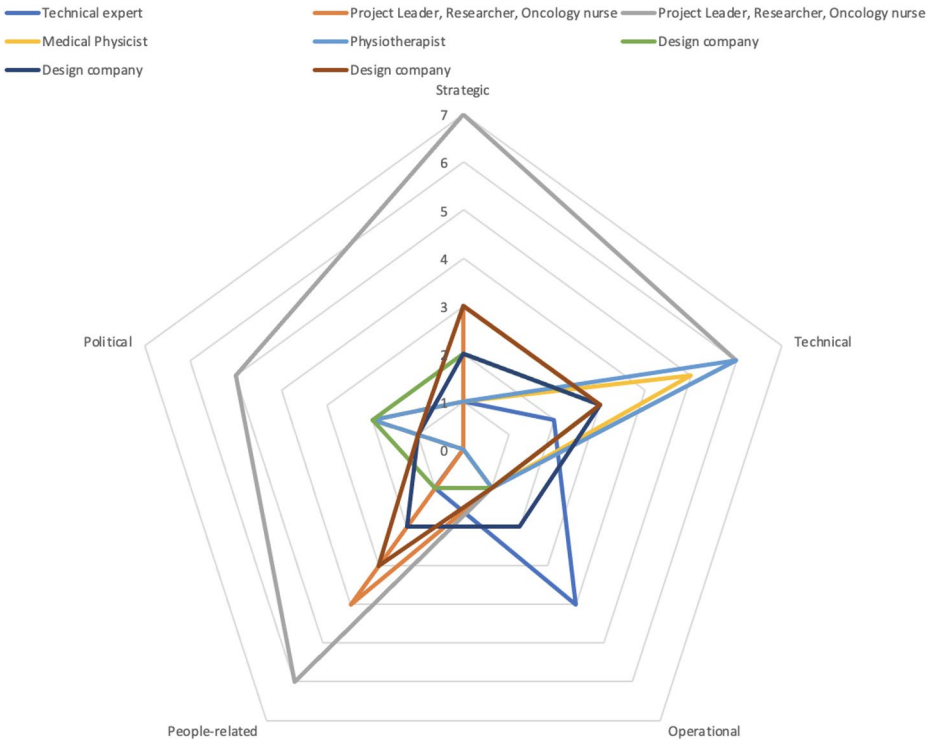

Fig. 2 Complexity assessment after having tested a beta-version of the DIBH preparation app

The strategic domain followed (20/93), likely driven by sustainability concerns. People-related complexity also increased (17/93), with more stakeholders involved in patient care, such as nursing professionals, reporting challenges, possibly related to educating both healthcare staff and patients on using the app, as well as the challenge of balancing product user-friendliness with the research needs.

From a stakeholder perspective, healthcare researchers perceived the highest complexity (25 points), particularly in the technical and strategic domains. Other stakeholders, including healthcare professionals and industry partners, reported moderate complexity (11 points each), noting challenges related to patient engagement and operational issues. The technical expert and hospital physicist reported lower complexity (8 and 9 points, respectively), reflecting fewer concerns in these areas.

In the last assessment (Fig. 3), total complexity decreased to 49/150. The technical domain remained the most complex (19/49), but scores had improved, potentially reflecting better app integration but low functionality related to the sensor band usability issues. Healthcare researchers and technical experts reported fewer challenges, while stakeholders such as industry partners and healthcare professionals noted operational improvements.

The operational domain was the second-most complex (11/49), with stakeholders like the hospital physicist and industry partners identifying ongoing workflow integration challenges. Strategic complexity remained a focus (10/49), though stakeholders noted better alignment with project goals.

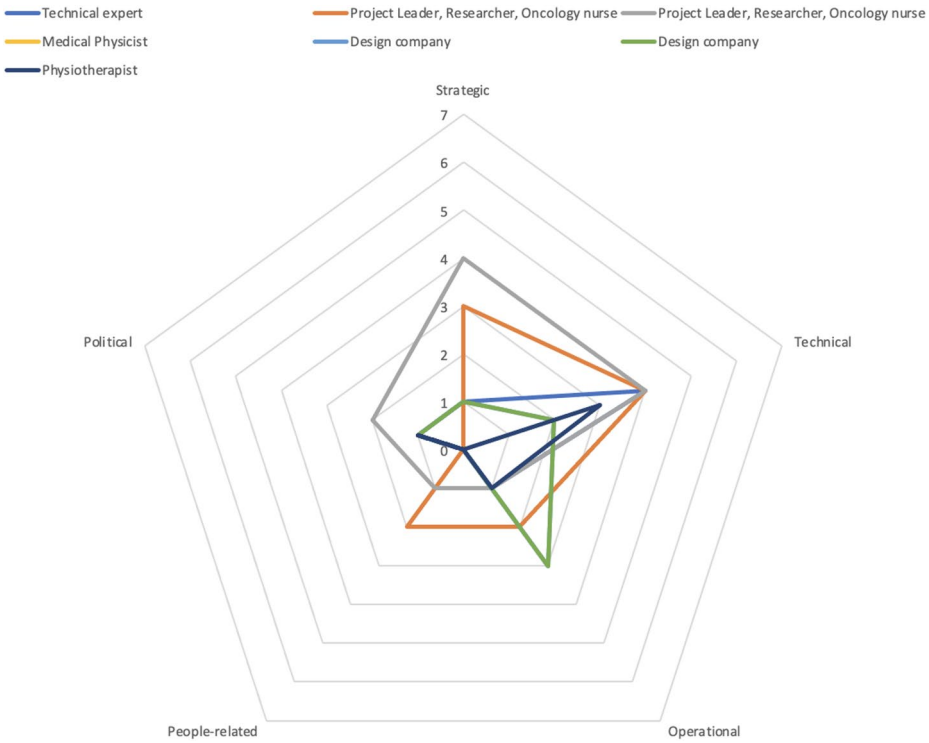

Fig. 3 Complexity assessment before the final version to be launched in a clinical study

Healthcare researchers/project leaders again reported the highest complexity (i.e., 12 and 11 points), though their perceptions decreased significantly compared to earlier assessments, reflecting a more optimistic view of the app's future, yet with concerns about operational challenges and strategic alignment. Technical experts and industry partners reported lower complexity, indicating that they perceived fewer barriers to success at this stage.

In summary, complexity perceptions evolved as stakeholders became more familiar with the project and the app's integration into clinical workflows (Fig. 4). Healthcare researchers, initially perceiving the highest complexity, reported reductions over time, particularly in strategic areas. The oncology nurses noted improvements in operational aspects, while the hospital physicist and technical expert continued to highlight unresolved technical challenges. Overall, complexity scores decreased as familiarity with the project increased and results from the scores were used to address challenges in the next phase of the development.

5 Discussion

The complexity surrounding the development and implementation of digital health interventions, such as the DIBH Preparation App, has been widely acknowledged in the field of implementation science. This study further provides support for the growing call to adopt evaluation approaches that incorporate real-time stakeholder feedback and promote contin-

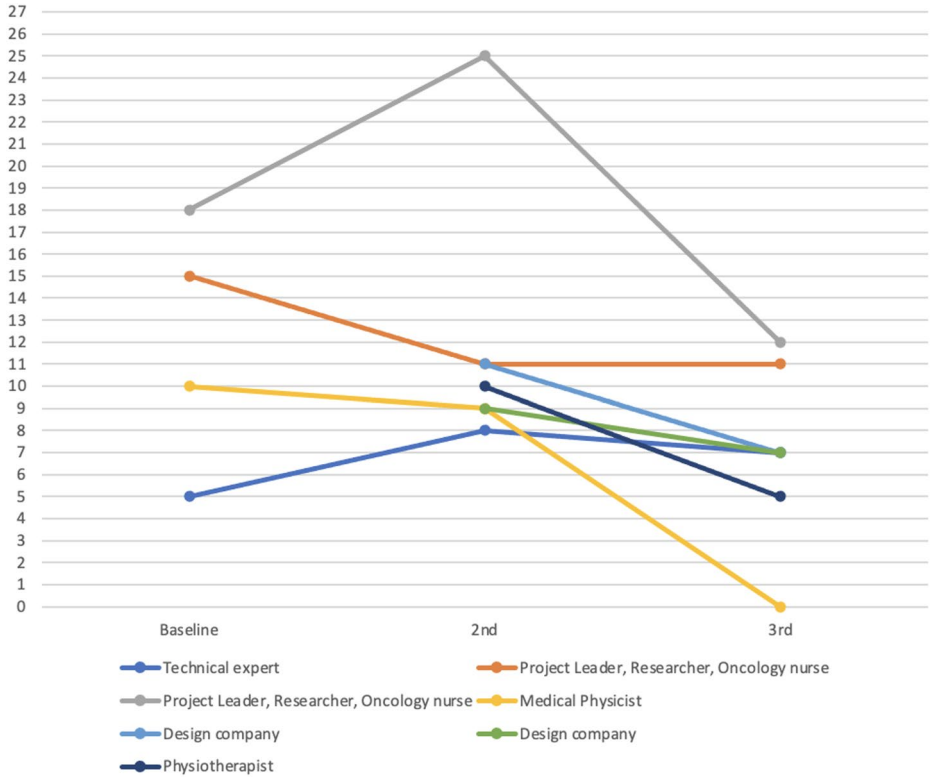

Fig. 4 Stakeholders' complexity perceptions over time

uous adaptation (Gilbert et al. 2023). By using the NASSS framework and the NASSS-CAT project tool, the study findings brought insights into the evolving nature of complexity, particularly regarding the timing of assessments, stakeholder engagement, and domain-specific challenges.

The timing of complexity assessments emerged as a central consideration. Specifically, perceptions varied across different time points, indicating that both regular and milestone-based evaluations offer distinct and complementary advantages. Time-based assessments, conducted at regular intervals, allowed for continuous feedback and early identification of emerging concerns, which has previously shown to enhance outcomes throughout implementation (Moullin et al. 2020). As noted by Abimbola et al. ongoing assessments also help to identify interdependencies and uncertainties not apparent at a project's outset (Abimbola et al. 2019). In this study, continuous assessment supported project development by enabling early identification of stakeholder concerns and facilitating informed responses. Moreover, the use of a common language within the NASSS-CAT framework helped to clarify complex issues and foster transparent communication across the team.

Milestone-based assessments, conducted at key stages such as beta testing and preparation for clinical implementation, were also found to be valuable. These assessments provided focused insights into the challenges encountered during transitions and were instrumental in preventing issues from escalating. As highlighted in prior work (Moullin et al. 2019; Ross et

al. 2018a, b), assessments conducted at such critical moments can inform timely decisions and reduce risk. In this project, combining time-based and milestone-driven approaches enabled complexity to be addressed dynamically as conditions evolved.

Stakeholder expertise played a significant role in shaping complexity perceptions. Participants with technical and clinical experience more frequently identified challenges related to system integration and workflow alignment, which is an observation consistent with the literature on digital health implementation (Sheikh et al. 2021; Ross et al. 2018a, b). However, the involvement of less-experienced stakeholders also proved beneficial. As noted by Bird et al. and Dyb et al. individuals with limited technical knowledge can offer important perspectives on usability and end-user experiences (Bird et al. 2021; Dyb et al. 2021). Their input helped to ensure that complexity was understood from a systems perspective as well as from the standpoint of everyday use. The balance of these perspectives allowed to achieve a more comprehensive understanding of implementation challenges. The importance of real-time performance monitoring and inclusion of diverse stakeholder insights has also been emphasized in the literature (Moullin et al. 2019; Gilbert et al. 2023).

The integration of individual and group assessments further enriched the evaluation process. Individual assessments allowed participants to reflect independently on complexity, while group discussions enabled the co-creation of strategies and consensus-building. This dual approach supported both personal insight and collective learning. Bird et al. have advocated for co-design strategies that engage stakeholders from early stages (Bird et al. 2021), while Papoutsi et al. (2021) and Talwar et al. (2023) have shown that inclusive discussions across organizational levels can support alignment and reduce resistance to innovation.

The composition of the project team was also found to influence how complexity was steered. When expertise in legal and financial domains was included from the start, potential regulatory and economic barriers were more effectively anticipated and addressed, which was similarly recommended in previous studies (Benbya et al. 2020). The presence of diverse competencies strengthened the project's ability to manage challenges that spanned multiple domains.

Moreover, the findings reinforce that complexity in digital health is not a fixed state, but rather an evolving characteristic that requires ongoing attention. In this study, complexity assessment was not treated as an endpoint but as a facilitator for reflection and strategic alignment. This supports the perspective that successful implementation depends on continuous adaptation across all project phases (Moullin et al. 2020) and calls for agility in response to emerging data and shifting contexts (Marwaha et al. 2022). Dynamic factors such as user engagement and acceptability, which are central to intervention success, must also be revisited over time (Perski and Short 2021).

An important consideration when interpreting the decreasing complexity scores over time is the potential influence of response shift, i.e., a change in participants' understanding and appraisal of complexity as they became more familiar with the project (Vanier et al. 2021; Ortega-Gómez et al. 2022). While reductions in complexity likely reflect real improvements in strategic alignment, operational workflows, and technical integration, they may also indicate evolving internal standards or expectations among stakeholders. As familiarity with the tool and the project increased, stakeholders may have reassessed their interpretation of complexity, leading to more tempered ratings over time. This dynamic reinforces the value of repeated, reflective assessments and underscores that complexity is not only a feature of the intervention but also shaped by how it is perceived.

Approaching complexity from a domain-specific perspective, was found to be particularly helpful. Specifically, more precise and effective responses could be formulated through the identification of challenges within each domain. This perspective is supported by prior research, which has shown that breaking down complexity assessment into domains can prevent follow-on effects and promote strategic alignment of goals and expectations (Benbya et al. 2020; Bashi et al. 2020). Addressing complexity at the domain level also prevents cascading effects, such as when technical challenges create operational inefficiencies, ultimately affecting strategic decision-making. As noted by Hellstrand Tang et al. evolving organizational, financial, and regulatory environments further contribute to the need for nuanced and context-sensitive complexity assessment (Hellstrand Tang et al. 2024).

Finally, the need to adapt complexity assessment tools to cultural and linguistic contexts was highlighted. Although the NASSS-CAT tool was useful across stakeholder groups, variation in comprehension and interpretation was observed. This highlights the need, as discussed by Ventura et al. (2022) and Gilbert et al. (2023), for tools to reflect local realities to ensure relevance and reliability (Ventura et al. 2022; Gilbert et al. 2023). In this study, language clarity and contextual familiarity were found to influence how complexity was assessed and understood.

Some considerations should be made when generalising the findings. Not all stakeholders participated in every assessment point, which may have influenced the completeness of trend interpretations. Missing data were not imputed; instead, we focused on within-participant changes where available and on group-level patterns at each time point. The results reflect stakeholder perceptions within a specific development context, and while diverse professional roles were included, patients did not participate in the complexity assessments. Interpretation should also consider the qualitative nature of the data and the exploratory design. Still, consistency across stakeholder groups and time points supports the credibility of observed trends. Although generalisability may be limited to similar clinical and organisational settings, the approach is likely transferable to other digital health interventions in early development.

6 Conclusion

Understanding complexity in digital health implementation is essential for developing resilient and adaptable interventions. This study applied the NASSS-CAT framework to assess the evolving complexity of the DIBH Preparation App, highlighting how stakeholder perceptions shifted over time and across key implementation domains. The findings reinforce that complexity is not static but fluctuates throughout the project lifecycle, necessitating ongoing assessment and adaptation.

The study underscores the value of combining time-based and milestone-driven assessments to capture emerging challenges. Stakeholder expertise shaped complexity perceptions, emphasizing the need for a balanced approach that integrates both expert insights and end-user perspectives. Additionally, complexity assessment proved to be more than an evaluative exercise, facilitating stakeholder engagement and collective learning, thereby supporting proactive problem-solving.

Future research should focus on adapting and validating complexity assessment tools like the NASSS-CAT to ensure relevance across diverse healthcare settings. Integrating

complexity-informed evaluation into routine digital health development will enhance the sustainability and real-world impact of digital interventions. Embracing complexity as a guiding principle can support more effective, scalable, and person-centred digital health solutions.

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Author contributions MB and FS conceptualised and led the study, coordinated data collection, and contributed to data interpretation, and manuscript revision. FV contributed to study design, data analysis and interpretation, and drafting the manuscript revision. All authors approved the final version for submission.

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Data availability The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to the nature of the data, they are not publicly available to ensure participant confidentiality.

Declarations

Competing interests The authors declare no competing interests.

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