Author(s): Mononen, Laura; Kujala, Tuomo

Title: Mental self-renewal as a measure of systems thinking

Year: 2024

Version: Published version

Please cite the original version:

Mononen, L., & Kujala, T. (2024). Mental self-renewal as a measure of systems thinking. Systems Research and Behavioral Science, Early View. https://doi.org/10.1002/sres.3017

Received: 27 June 2023 | Revised: 26 April 2024 | Accepted: 2 May 2024

DOI: 10.1002/sres.3017

RESEARCH PAPER

SYSTEMS and BEHAVIORAL RESEARCH SCIENCE WILEY

Mental self-renewal as a measure of systems thinking

Laura Mononen | **Tuomo Kujala**

Faculty of Information Technology, University of Jyväskylä, Mattilanniemi 2, Building Agora (Ag), Jyväskylä, FI-40014, Finland

Correspondence
Laura Mononen, Faculty of Information Technology, University of Jyväskylä, Mattilanniemi 2, Building Agora (Ag), PO Box 35, Jyväskylä FI-40014, Finland.
Email: laura.m.mononen@jyu.fi

Abstract

Systems thinking research confronts theoretical and empirical challenges, and new measures based on the cognitive sciences have been sought. In this paper, mental self-renewal is proposed as a suitable new theoretical construct for studying systems thinking. The objective was to construct and validate a psychometric scale of mental self-renewal (MSRS) and to investigate its associations with complex postformal thinking (CPFT), existing systems thinking scores (STSR) and visual remote associative thinking (vRAT). Data were collected by surveying 311 international designers. Exploratory factor analysis and correlative analyses indicate construct validity for a novel scale with 14 different factors that, when taken together, measure designer's mental self-renewal. The MSRS is a strong predictor of CPFT, whereas its correlation with STSR is weak. MSRS or CPFT did not predict performance in the vRAT test, while STSR did. In conclusion, MSRS can measure novel aspects of systems thinking; however, further research is necessary.

KEYWORDS

complex postformal thinking, dynamical systems paradigm, embodied dynamism, mental self-renewal, systems thinking, visual remote associates

1 | INTRODUCTION

The main factor that makes research on systems thinking challenging is that the concept is hard to define (Buckle Henning & Chen, 2012; Cabrera, Colosi & Lobdell, 2008; Hossain et al., 2020). One of the reasons why the field confronts challenges is its transdisciplinary nature; systems thinking is applied in a variety of fields and contexts. Several different conceptualisations have emerged in the literature, for example, hard and soft systems thinking (Checkland, 1985), applied systems thinking (Córdoba-Pachón, 2011), systems dynamics (Sterman, 2001), critical systems thinking (Flood & Jackson, 1991), creative holism or methodological pluralism (Jackson, 2003) and systems intelligence (Hämäläinen et al., 2014). Despite the plurality of concepts and methods, researchers seem to agree on one aspect: its importance for creatively solving problems we are facing now and in the future. Systems thinking is important for understanding the ever-complexifying world, especially when designing and redesigning the systems we live in and with (Meadows, 2008; Senge, 1990).

The definitions of the concept of systems thinking are plentiful, and the phenomena are difficult to approach; therefore, the measurement of systems thinking has run into several challenges, and diverse methodologies are being tested and used (Cabrera et al., 2008). Previous research has focused, for example, on problem-solving interventions (Grohs et al., 2018), effects of systems

dynamics interventions on mental models (e.g., Schaffernicht & Groesser, 2011), the use of systems language (Whitehead, Scherer & Smith, 2015) and investigating how well system phenomena such as stock and flow dynamics (Cronin et al., 2009) or nonlinear causal structures (Plate, 2010) are understood. In addition, a research line investigating teaching and learning systems concepts and methods exists (e.g., Taylor, Calvo-Amodio & Well, 2020). Despite research efforts, technical understandings and the study of complex problems, theoretical understanding has shed little light on the issue of which mental functions are involved and used when systems thinking is conducted. It has been claimed that systems thinking has been investigated mainly through the lens of interventions rather than the effectiveness of the skill (Buckle Henning & Chen, 2012) or related cognitive processes (Doyle, 1997; Randle & Stroink, 2018). Among the research, there are few conclusive findings and no established theories (Buckle Henning & Chen, 2012).

Doyle (1997) suggested that research on systems thinking should focus more on the relationship between systems thinking and basic cognitive processes such as learning, memory, problem-solving, decision-making and mental representations. Quite recently, there has been an emergent theme in the systems thinking literature suggesting that the foundations of systems thinking lie in cognitive processes and should be investigated from the cognitive perspective (Cabrera et al., 2008; Davis & Stroink, 2016; Maani & Maharaj, 2004). It has also been proposed that while systems thinking overlaps with some psychological concepts, it might be, at least to some degree, an independent cognitive construct (Randle & Stroink, 2018). Therefore, the intersection of cognitive science and systems thinking (e.g., Grisold & Peschl, 2017) could be a fruitful ground for future research.

Creativity has been proposed as one of the main features of systems thinking (Jackson, 2003). Even though systems thinking's ability to foster creativity is often promoted in practical workbooks (Buckle Henning & Chen, 2012), actual empirical studies that validate this connection are scarce. Recently, Randle and Stroink (2018) studied how systems thinking links to divergent thinking and found that it was positively associated with the creativity measure used. People who scored higher on the systems thinking scale also generated more responses (Randle & Stroink, 2018). It has also been suggested that systems thinking is essential to adulthood and maturity and that more developmentally mature people can acquire better systems thinking abilities (Randle & Stroink, 2018; Ståhle et al., 2020). Creativity and change in thinking intermingle and underlie several conceptualisations of systems thinking; these concepts seem to constitute the aspect of the mind that transfers beyond the borders and rules of our own thinking.

Despite its benefits and promise for complex problem solving, the term 'systems thinking' continues to challenge researchers. There is a need to understand more profoundly its underlying assumptions and shared principles for it to serve us by its nature as a transdisciplinary practice (Cabrera, 2006, p. 7). This study aims to contribute to this research endeavour by developing a new measure of systems thinking, the mental self-renewal scale (MSRS), which is based on recent developments in cognitive science and includes the creative and developmental aspects that are quested. Here, the objective is to investigate the scale in the context of human–technology interaction (HTI) designers' thinking, since it is a field and context in which systems thinking is currently highly relevant for solving wicked problems in multidisciplinary teams in dynamic environments.

Human–technology interaction is defined in this research according to the work Saariluoma et al. (2016) in a holistic and historical manner. The concept emerged from the first tools humans made and used (cave paintings, fire, axe). The term 'human' is understood as a whole being with various roles (not just a user) and including human life in its many forms. 'Technical artefacts' or 'artefacts' can constitute any human-made object or process, natural process, or even modified natural phenomenon that is used to, for example, improve performance, satisfy human needs or desires or increase the quality of life. Furthermore, 'technology' refers to a combination of artefacts as well as their human uses, meaning all the things people do with artefacts and how human beings are organised around them. Consequently, interaction that is the focus of design can manifest in different ways, such as wielding a hammer, looking at graffiti, using services, wearing clothes, driving a car or shopping online.

Design is understood in this work as the conception and planning of the artificial—to design is to devise artefacts to attain goals (Saariluoma et al., 2016; Simon, 1996). Design thinking is approached as practical reasoning (Schön, 1983; Simon, 1996) and argumentation, which is based on the application of versatile knowledge (e.g. scientific and intuitive or general and particular) and even conflicting perspectives (Saariluoma et al., 2016). The challenge for a designer is the integration of several different lines of reasoning to attain the desired results. Most problems that designers encounter are considered wicked (Buchanan, 1992). Wicked problems are defined here as a 'class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and

decision makers with conflicting values and where the ramifications in the whole system are thoroughly confusing' (Churchman, 1967, p. B-141). The indeterminacy of wicked problems refers to the fact that they are without definitive limits or conditions. In design practice, problems and solutions are often in co-evolution. Understanding, defining and framing the problem is the most important aspect of the design process, especially when creative outcomes are desired (Dorst & Cross, 2001).

Systems science and research have concepts, theories, philosophies and methods for advancing design thinking and its research (Mononen, 2017). Systems thinking and design, even though they are separate fields and have diverse philosophical assumptions, also have several overlapping techniques, methods and practices, especially when applied to larger-scale problems (Buchanan, 2019). The nexus of systems thinking and design has the potential to aid in the development of new ways to approach wicked problems. Systems thinking is essential, especially in HTI design, as the technology we create also shapes our environment and our minds.

1.1 | Building a new measure for systems thinking: The mental self-renewal scale (MSRS)

Ståhle et al. (2020) recently conducted a theoretical analysis on the relationship between systems thinking conceptualised as self-renewal (orig. Ståhle, 1998) and post-formal thinking (orig. Sinnott, 1998). Their analysis concluded that there is a major overlap between these constructs; therefore, it was proposed that this relationship be investigated further. The concept, which aims to explain the renewal that is born out of the capability to transform and purposefully adapt to change, is based on theories of self-organisation (orig. Prigogine, 1980), autopoiesis (orig. Maturana & Varela, 1972/1980) and self-referring systems (orig. Luhmann, 1995). This conceptualisation is suggested to offer a way of understanding renewal characteristics to systems thinking—the focus is on the relationship of the individual and the surrounding environment; thus, the internal dynamics of the systems are seen in a new way (Ståhle et al., 2020). Since the underlying concepts are originally from the fields of physics and biology, they have been criticised in terms of their applicability in the context of human mental or social systems (see, e.g., Mingers, 1992, 2002).

Self-renewal has previously been applied only to the study of social and organisational systems, such as groups. Thus, its application to research in which the unit of analysis is an individual is still lacking (Ståhle et al., 2020). The analysis of conceptual and theoretical foundations of mental self-renewal (Mononen & Kallio, 2024) suggests that when applying self-renewal to the study of the human mind, the research could benefit from building on the embodied dynamism paradigm of cognition (Thompson, 2010), since it contains the same concepts (self-organisation and autopoiesis).

The embodied dynamical paradigm is one of the three main approaches to studying cognition, which was developed after cognitivism and connectionism (Thompson, 2010), both seeing the mind foremost as an information processing system. The embodied dynamical paradigm also referred to as the 4E (embodied, embedded, extended and enactive) paradigm of cognition, aims to bridge explanatory gaps of the prevailing paradigms, especially regarding the body, subjective experience and the relationship of the mind and the real world. Crucially, this paradigm challenges the classical computational cognition (CC) view of human cognition as a rule-based symbol-manipulating machine in the head and suggests that the mind is an embodied dynamical system acting in the world. In this research, we suggest that the embodied dynamism paradigm of cognitive science (Thompson, 2010) has the potential to bridge the research gap existing in self-renewal studies.

The mind, according to the embodied dynamical view, is understood as a 'self-organising and dynamic system – where cognitive processes emerge from the non-linear and circular causality of continuous, sensi-motor interactions involving the brain, body and environment' (Thompson, 2010, pp. 10–11). Moreover, it suggests a phenomenological attitude (orig. Husserl, 1970) could assist in explaining self-renewal when studied in the context of mental events (Mononen & Kallio, 2024). The aspects of mental processes that are included in the mental self-renewal construct from phenomenology are phenomenological attitude and, more specifically, phenomenological reduction and epoché. Phenomenological reduction (Thompson 2010, p. 18) is the ability to redirect attention to the way in which something appears to oneself. Epoché (Thompson 2010, p. 19), on the other hand, refers to the suspension of immersion in experience or at least the capacity to notice that one is in such an immersive state. These considerations are also in line with the systems thinking literature since several authors (e.g., Buckle Henning & Chen, 2012; Córdoba-Pachón, 2011) claim that systems thinking is not only about thinking or observing external systems or having a particular worldview. Instead, the object of systems thinking is also the subjective content of an experience—the person observing the system. Subjectivity and the ability to orient inquiries inwardly as well as outwardly must be considered, especially when studying systems that contain human beings (Buckle Henning &

Chen, 2012). Phenomenology is grounded in an understanding that mental events are not something that happens in isolation; they are always lived and experienced by someone—the human body is a lived, inhabited body (Heinämaa, 2014).

Accordingly, mental self-renewal is defined in this paper as the 'mind's ability to cultivate inner transformation, adapt continuously to change, and consequently produce novel and applicable outcomes in interaction with its environment' (Mononen & Kallio, 2024). In this research, the construct was built and elaborated on based on the previous research and analysed as follows:

- ***Self-organisation (orig.*** Prigogine, 1980***)*** is a process in which a new order is born out of chaos. It has several states and qualities, and the process is organised by the system and not controlled outside of it.
  - *A far-from-equilibrium state* means that the system is able to tolerate imbalance. There are contradictions and forceful fluctuations inside the system that challenge it.
  - *Entropic knowledge creation* means that the system is able to increase and decrease entropy and act spontaneously in the moment without a predetermined structure.
  - *Iterative feedback system* refers to the engine of the system. Being sensitive to feedback (whether positive or negative) can create new structures and influence the entire system.
  - *Bifurcative decision-making* refers to the possible outcome of the process. New solutions and outcomes are born, entropy usually dissipates, and truly new knowledge is created when this state is reached.
  - *Maintenance of the process in time* is manifested as a reliance on the process and knowing the right timing to act. All different aspects of renewal take time to occur; therefore, this requires patience and trust.
- ***Autopoiesis (orig.*** Maturana & Varela, 1972/1980; Luhmann, 1995**)** is sometimes referred to as self-making since it is a process in which the system continuously creates itself in interaction with its environment.
  - *Self-reference* is an essential aspect of social systems because it is the process of creating and maintaining boundaries, which are the basic aspects of autonomy.
  - *Double contingent relationships* are the basis of social functioning. In renewal, mutual interdependence, trust and equal power are essential.
  - *Experiential information* means that information acts as an event rather than a fact; therefore, the information must have an impact or subjective touch in order to act as an element in the process.
  - *Collectively processed meanings* are the basic structural elements in systems that are social. Meanings are collectively created in these interactions and pace the renewal process.
  - *Double-crossing* means that individuals can act in several different cultural systems and can therefore increase renewal by transferring information from one culture to the next.
- ***Phenomenological attitude (orig.*** Husserl, 1970***)*** refers to a way of habiting experience with awareness and attunement. It refers to the study of the structures and contents of consciousness to identify the inherent meanings of ideas, objects or situations.
  - *Phenomenological reduction* refers to a redirection of attention away from a natural immersive way into the actual way the world appears to oneself. It manifests as flexibility of attention and the ability to use it in different manners.
  - *Epoché* is a method that aims to refrain from judgement, and it requires awareness of awareness. It is a way of being that lacks immersion into the natural way and involves stepping away from theoretical and objective beliefs about reality.

In Appendix A, these constructs are further defined and divided into factors that are then operationalised into survey items in an effort to develop a new measurement of HTI designers' mental self-renewal abilities.

2 | METHODS

The objective of the study was to design and validate a psychometric scale on mental self-renewal (mental self-renewal scale, MSRS) via exploratory factor analysis and correlative analyses of its relationship with postformal thinking, established systems thinking worldview and associative thinking. For the latter analyses, the MSRS's construct validity was assessed by measuring its correlations with complex postformal thinking (CPFT, Cartwright et al., 2009), the systems thinking scale revised (STSR, Randle & Stroink, 2018) and the visual remote associative test (vRAT, Olteţeanu & Zunjani, 2020).

2.1 | Scales and measures

The MSRS was designed based on previous research on the criteria of self-renewal (Ståhle, 1998; Ståhle et al., 2020) and mental self-renewal (Mononen & Kallio, 2024). The criteria for mental self-renewal and the related originally targeted factor structure with the candidate

survey items can be found in Appendix A. The aim of the survey item design was to capture the interaction of a designer with the design environment (stakeholders, co-designers and users), the inner dynamics (system-state experiences) evident during the design process and designers' relationship with their own thinking.

The complex postformal thought questionnaire (CPFT) is a validated measure of adult cognitive development (Cartwright et al., 2009). It is based on Sinnott's thorough study of the development of thinking in adulthood (1998). This questionnaire was chosen for this study to test the hypothesis that systems thinking and postformal thinking are associated (Ståhle et al., 2020). It is explicitly based on systems theories (Sinnott, 1998; Ståhle et al., 2020).

The systems thinking scale revised (STSR) was chosen in order to investigate the expected relationship between self-renewal and the cognitive paradigm of systems thinking as a worldview. Previous research has suggested that the STSR is a valid measure of systems thinking (Randle & Stroink, 2018). This view advocates that systems thinking is best described as a worldview—an orientation towards the world that compasses personal and societal philosophies and epistemologies as well as core beliefs, values and assumptions (Davis & Stroink, 2016). There should be a positive association between STSR and MSRS if the latter measures an aspect of systems thinking.

The visual Remote Associates Test (vRAT, Olteţeanu & Zunjani, 2020) are based on Mednick's (1962) work on the associative basis of creativity for measuring the factor of associative or convergent creativity in the visual domain. The central ability of systems thinking has been referred to as seeing interrelationships and making associations between seemingly separate things. Therefore, vRAT was chosen to study the relationship of associative creativity, mental self-renewal, CPFT and STSR. Since the participants were international designers, the test was visual and not linguistic, as in the original version. Previous research has validated the measurement in cross-cultural settings (Toivainen et al., 2019). The discussion of whether the associative capability is part of divergence or convergence modes of creative thinking (or both) is a complex problem and an ongoing debate (see, e.g., Lee et al., 2014; Sowden et al., 2015). Both aspects of the creative process are present and essential to self-renewal criteria. Therefore, the visual associates test was useful in this study. In total, there were 46 tasks in the vRAT. Each task was scored either 0 or 1 based on the correctness of the written answer, and a total vRAT score was calculated by adding up the scores.

CPFT and STSR were based on self-report, whereas the vRAT score was calculated based on the respondents' performance on the visual Remote Associates Test, which was completed online together with the other surveys. Together, these measurements served as construct validity measures for the analysis of the novel MSR scale.

2.2 | Procedure and participants

The overall research procedure is illustrated in Figure 1. In a pilot study, the internal consistency of 23 originally targeted mental self-renewal factors (Appendix A) was tested with Cronbach's alphas. In total, the online pilot survey contained 141 statements in English on self-renewal as Likert items (1–5) described in Appendix A. The survey was implemented using the Webropol survey tool. It was answered by 21 students and university faculty staff studying or working in a field related to technology design. In general, the alphas were at an acceptable level for 20/23 of the factors and the survey validation was therefore continued. The alphas of three factors were at an unacceptable level and these were excluded from the survey at this point (see Appendix A for these factors). In addition, the number of items per factor was reduced based on the alpha analyses. This resulted in a second version of the survey with 20 factors and 62 items.

The actual data were collected in two parts as Webropol online surveys. Both surveys were conducted in English. The first part—a longer survey—consisted of demographic variables, the 62 MSRS items, CPFT, STSR and vRAT tasks. An alternative uses a test (AUT, Guilford, 1967) and a creativity definition task in this longer version of the survey that was responded to by 90 participants. For the second survey with 221 participants, only demographics, MSRS, CPFT and STSR were included because the longer survey proved to be too time-consuming (median response time: 47 minutes). Both surveys also contained six open-ended questions. This qualitative data is not reported here.

The first part of the survey was distributed on social media and personal networks ($n = 30$), and further responses were gained via the Prolific online participant recruitment service ($n = 60$). Overall, 90 design professionals responded to the first survey in fall 2020 and spring 2021. In winter 2023, a further sample of 221 participants responded to the second shorter survey via the Prolific service. The respondents were required to be competent in English and to have a design background. At the time of the survey, 11 771 matching participants were active in the Prolific database. All the Prolific participants were rewarded for their time at a rate of £9.54/hour. Response times were manually reviewed and

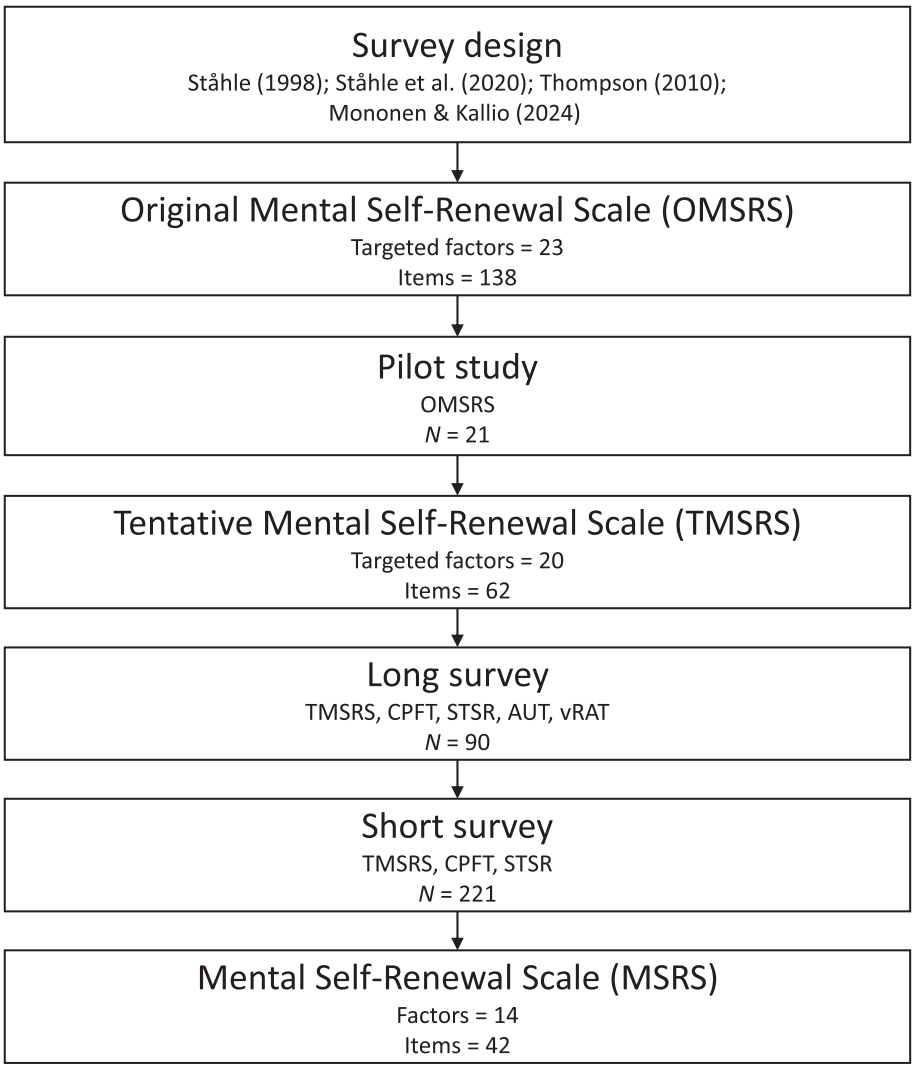

FIGURE 1 Research procedure.

replies that were too short were rejected. Nine respondents were rejected based on the set minimum response time of 20 minutes for the longer survey. Some of the items were formulated as negative statements to make the participants pay more attention to their replies. These negative items were also used to check the consistency of the participants' replies. The vRAT scores ($N = 90$) were also reviewed to ascertain whether the participants had put effort into their answers. None of the respondents were rejected for non-attentive responses.

In total, there were 311 participants in the two surveys from 22 different countries from Europe, Asia, Australia, Africa and North America. The participants were either design professionals or otherwise had experience with design. Their mean work experience as designers was 4.7 years (SD: 5.4). There were 134 male and 85 female participants, and two participants did not want to disclose their gender. Their ages varied from 19 to 67 years (M: 31.8, SD: 9.4). About one-fifth (21.9%) reported English as their native language. The sample size ($N = 311$) was considered sufficient for an exploratory factor analysis based on the rules-of-thumb of five $\times$ items minimum ($5 \times 62 = 310$, Gorsuch, 1983; Kyriazos, 2018) and a minimum total sample size above 300 (Tabachnick et al., 2013).

3 | RESULTS

3.1 | Exploratory factor analysis

Exploratory factor analysis (EFA) was performed using a generalised least squares extraction method with Promax rotation (SPSS v28). These methods were selected because it was assumed that the underlying factors behind mental self-renewal ability can and should correlate (Pituch & Stevens, 2016). The minimum threshold for sufficient factor loading in the pattern matrix was set to 0.40 (Pituch & Stevens, 2016). Bartlett's test of sphericity indicated that the correlation matrix of the survey

TABLE 1 Cronbach's alpha and descriptives (min and max) for the mental self-renewal scale (MSRS) and each included factor ($N = 311$).

Scale (abbreviation)	α	Min	Max
Mental self-renewal scale (MSRS)	0.832	−1.80	1.34
MSR1. Tolerance of chaos	0.776	−2.63	1.95
MSR2. Embracement of the tension of opposites	0.712	−3.31	1.89
MSR3. Recognition of opportunities	0.730	−3.37	1.89
MSR4. Ability to dissipate entropy	0.753	−3.31	1.76
MSR5. Embracement of disintegration	0.739	−4.04	1.03
MSR6. Embracement of feedback	0.748	−3.39	1.16
MSR7. Reflection of existence	0.822	−2.77	1.61
MSR8. Recognition of boundaries	0.661	−2.35	1.59
MSR9. Continuous self-reflection	0.668	−3.55	1.10
MSR10. Recognition of ethical impact	0.797	−3.18	1.67
MSR11. Use of personal experiences	0.727	−3.40	1.51
MSR12. Use of inner reactions	0.817	−3.15	1.61
MSR13. Sensitivity to meanings	0.768	−3.07	1.45
MSR14. Flexibility of attention	0.772	−2.56	1.90

items has significant correlations among its components, $\chi^2(1891) = 7667.700$, $p < 0.001$. Also, the Kaiser-Meyer-Olkin test of sampling adequacy indicated that the data was suitable for EFA (KMO: 0.839). Mean communality was 0.669. Factors with eigenvalues above 1 were selected for the factor solution. Additionally, a parallel analysis was conducted to ensure that the number of factors was appropriate for the data (O'Connor, 2000; Pituch & Stevens, 2016).

Twenty items did not have a factor loading over 0.40 to any of the factors and these were removed from the final factor solution after nine iterations. The item 'I value other people's opinions when designing a solution' loaded into the Embracement of feedback factor, which was judged to make theoretical sense by the authors; therefore, it was included in this factor. Also, the item 'I know that I have reached the right solution when I have a moment of insight during my creative process' loaded into factor Use of inner reactions, which makes sense, and was therefore included in it.

For the final solution, 14 factors were extracted in nine iterations by removing items with factor loadings of less than 0.40 in each iteration. Rotation converged in seven iterations. A goodness-of-fit test for the final solution suggested that the number of factors is suitable for the data, $\chi^2(364) = 352.424$, $p = 0.659$. Furthermore, according to the parallel analysis, 14 factors had eigenvalues higher than the eigenvalues of generated 95th percentile eigenvalues, suggesting that 14 is the proper number of factors to account for the covariances in the data (Pituch & Stevens, 2016). There were no cross-loadings over 0.40 in the pattern matrix.

The final solution and the included items' factor loadings per factor based on the pattern matrix are presented in Appendix B. Factor scores were calculated and saved for the 14 factors using regression. There were significant correlations between the 14 MSR factors, but these were not too high for independent factors of mental self-renewal (Appendix C). A cut-off acceptance criterion of 0.70 for Cronbach's alphas was utilised in the analysis of internal consistency, but factors with questionable alpha levels (0.60–0.70) were accepted if these were judged to make theoretical sense by the authors. For two of the MSR factors, alphas were just below 0.70 (0.661 and 0.668), but all the factors were judged to make theoretical sense by the authors based on the theoretical framework described in this article. In addition, the factor scores were based on a reliable factor solution (Table 1).

3.2 | Scale of scales: The mental self-renewal scale

The correlations between the 14 MSR factors (Appendix C) and the theoretical concepts behind the operationalisations of the factors (Appendix A) suggest that these could be combined into one scale representing mental self-renewal ability. The Cronbach's alpha for this MSR scale (MSRS) was at a good level ($\alpha = 0.832$, Table 1). The MSRS score was calculated as an average over the standardised MSR factor scores, and the distribution of the participants' scores was found to be approximately normally distributed (Figure 2).

3.3 | Descriptive statistics – Construct validity measures

Cronbach's alphas and descriptives for the construct validity measures (CPFT, STSR scales and vRAT task performance) are reported in Table 2. Alphas for CPFT and STSR were at an acceptable level (>0.70). The histograms for each construct validity measure are illustrated in Figures 3 (CPFT), 4 (STSR) and 5 (vRAT). All the variables were reasonably close to the normal distribution for parametric tests. Note that all but one of the participants scored above 3.5 in the STSR ($M = 5.05$, Figure 3), but the sufficient variability in the scores enabled meaningful analyses. Most of the participants also scored better than the middle of the CPFT scale ($M = 5.46$), with two exceptions (Figure 4). However, there was again sufficient variability in the scores for meaningful analyses.

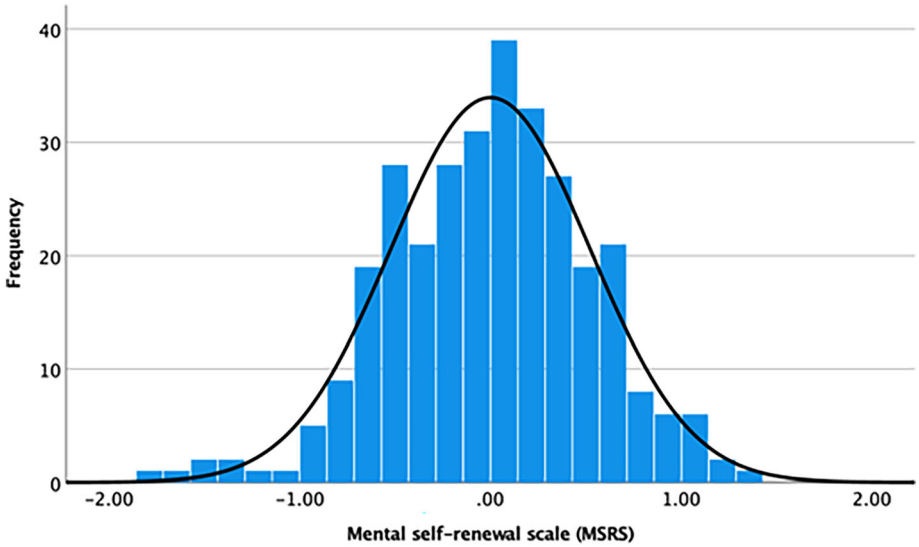

FIGURE 2 Distribution of MSRS scores ($N = 311$). [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Cronbach's alphas and descriptives for CPFT, STSR and vRAT.

Construct validity measure (abbreviation)	*N*	Scale range	Items or tasks	*α*	Mean (SD)	Min	Max
Complex postformal thought questionnaire (CPFT)	311	1–7	10	0.792	5.46 (0.73)	3.10	7.00
Systems thinking scale revised (STSR)	311	1–7	15	0.726	5.05 (0.69)	3.33	6.60
Visual Remote Associates Test score (vRAT)	90	-	46	-	15.31 (6.35)	4.00	32.00

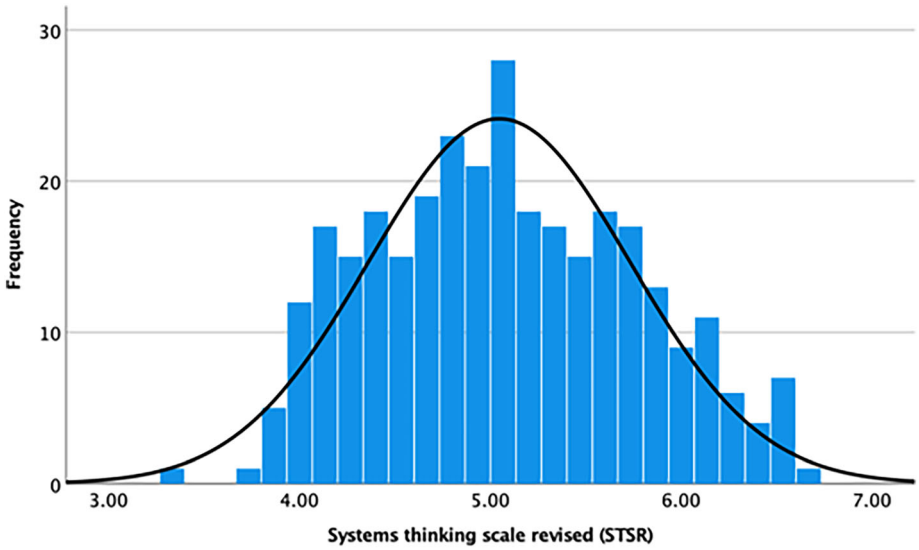

FIGURE 3 Distribution of participants on the systems thinking scale revised (STSR, $N = 311$). [Colour figure can be viewed at wileyonlinelibrary.com]

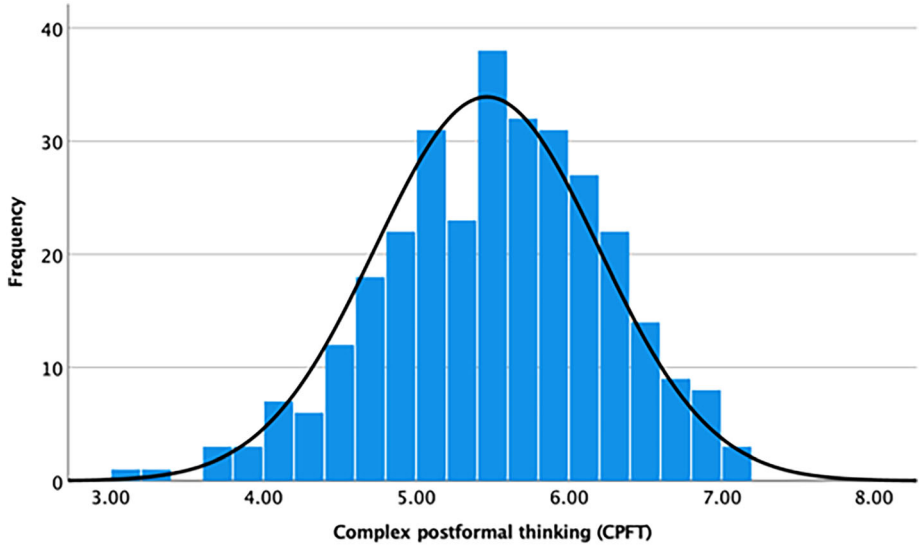

FIGURE 4 Distribution of participants on the complex postformal thought questionnaire (CPFT, $N = 311$). [Colour figure can be viewed at wileyonlinelibrary.com]

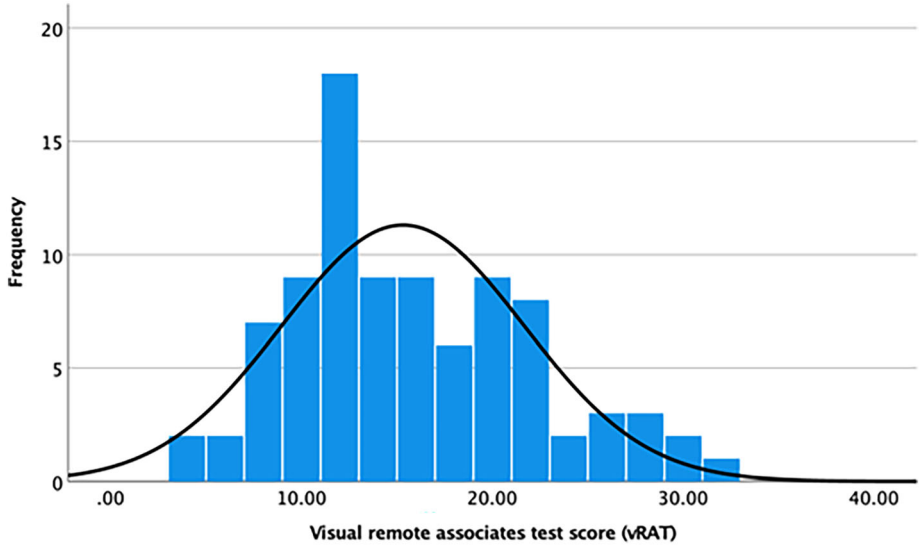

FIGURE 5 Distribution of visual Remote Associates Test scores ($N = 90$). [Colour figure can be viewed at wileyonlinelibrary.com]

3.4 | Correlations between scales: MSRS vs. CPFT and STSR

Statistical associations between MSRS and the construct validity measures CPFT and STSR were first analysed with Pearson's product-moment correlation coefficient. There was a strong positive correlation between MSRS and CPFT (Figure 6), $r = 0.688$, $p < 0.001$, suggesting that mental self-renewal scores could predict 47.4% of the variability in the complex postformal thinking score (or the other way around, $R^2 = 0.474$).

There was a weak correlation between MSRS and STSR, $r = 0.290$, $p < 0.001$ (Figure 7). There was also an intermediate correlation between STSR and CPFT, $r = 0.336$, $p < 0.001$ (Figure 8).

Considering these correlations, a regression analysis was conducted to predict the variability in MSRS with CPFT and STSR ($N = 311$). According to the model (F (2310) = 140.694, $p < 0.001$, $R^2 = 0.477$), only CPFT was a significant predictor of MSRS (Beta: 0.475, standardised Beta: 0.666, $p < 0.001$, STSR: 0.051, 0.066, $p = 0.130$).

3.5 | Correlations: Visual RAT vs. MSRS, CPFT and STSR

The distribution of visual RAT (vRAT: Olteţeanu & Zunjani, 2020) scores (sum of individual task scores, $N = 90$) was slightly skewed towards lower scores but showed good variability for enabling meaningful analyses. It could be argued that the variable could be normally distributed in the population (Figure 5). Therefore, Pearson's correlation coefficient was utilised for analysing the associations between vRAT and MSRS and between

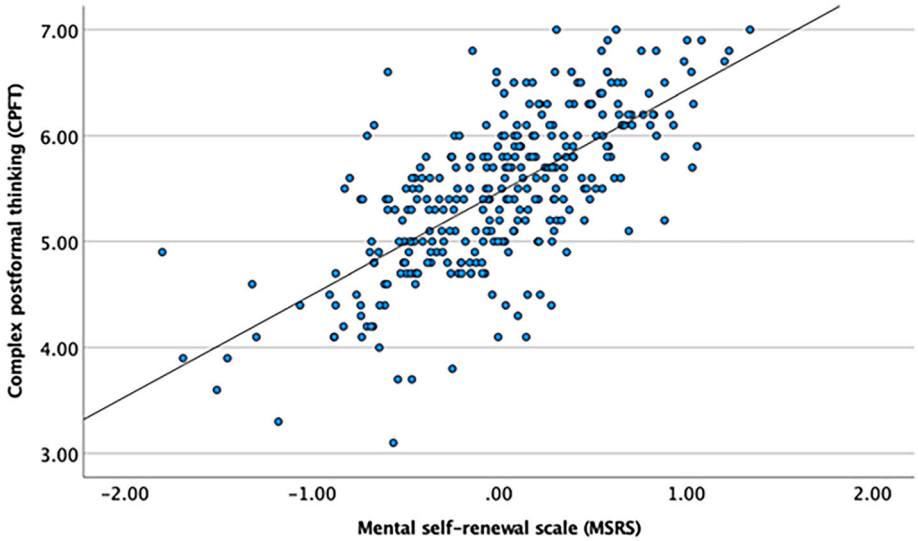

FIGURE 6 CPFT scores vs. mental self-renewal scale scores ($N = 311$). [Colour figure can be viewed at wileyonlinelibrary.com]

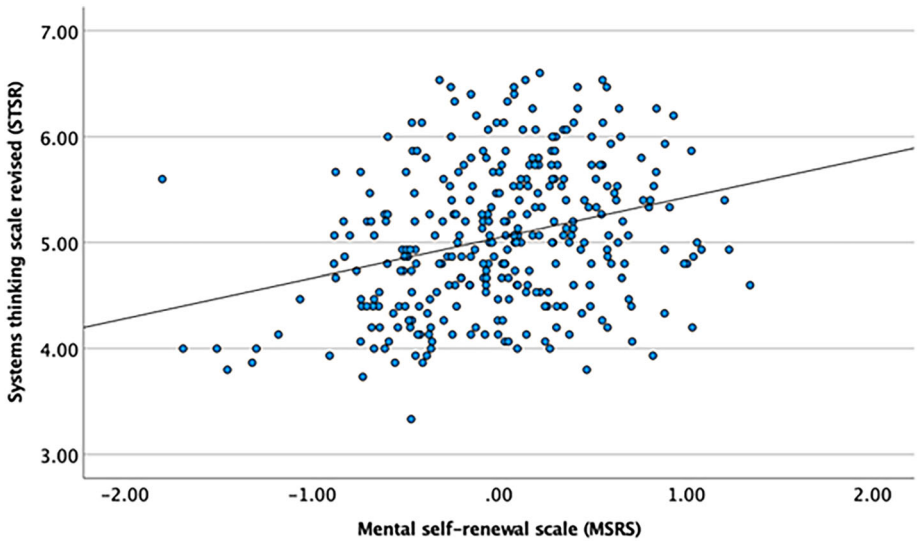

FIGURE 7 STSR scores vs. mental self-renewal scale scores ($N = 311$). [Colour figure can be viewed at wileyonlinelibrary.com]

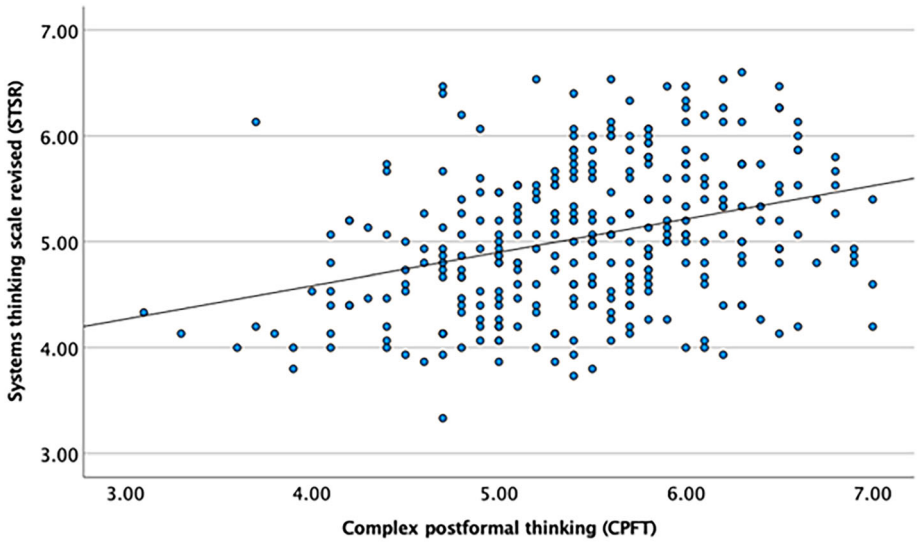

FIGURE 8 STSR scores vs. CPFT scores ($N = 311$). [Colour figure can be viewed at wileyonlinelibrary.com]

vRAT and the other two construct validity measures, CPFT and STSR.

No correlations were found between vRAT and MSRS ($r = -0.058$, $p = 0.587$) or between vRAT and CPFT ($r = 0.039$, $p = 0.716$). However, there was an intermediate positive correlation between vRAT and STSR ($r = 0.305$, $p = 0.004$). STSR score predicted 9.3% of the variability in the vRAT score ($R^2 = 0.093$) (Figure 9).

4 | DISCUSSION

A novel mental self-renewal scale was created based on previous research on self-renewal in groups (Ståhle, 1998) and theoretical understanding of the underlying concepts (self-organisation, autopoiesis and phenomenological attitude) according to the embodied dynamical paradigm of mind. A revised factor structure and scale (MSRS) for measuring mental self-renewal was found via exploratory factor analysis. The expected correlations of MSRS with existing validated measurements of the complex postformal thinking thought questionnaire (CPFT, Cartwright et al., 2009; Sinnott, 1998) and the systems thinking scale revised (STSR, Randle & Stroink, 2018) suggest that the new scale is able to measure mental self-renewal ability. It is important to note that the scale does not measure the actual self-renewal ability directly (ad hoc); instead, it reflects its past subjective experiences through self-reflection of creative work processes and thinking in design.

The results show that there is a much stronger relationship between MSRS and CPFT than between MSRS and STSR. One possible explanation for this could be that the mental self-renewal scale measures the process of renewal as a respondent experiences it, while the STSR measures a cognitive paradigm called a 'worldview'. The STSR is based on a definition of systems thinking in line with the dynamical systems paradigm, where the person sees themselves as well as the world as dynamic and ever-changing, in constant interaction and interdependence with the environment (Randle & Stroink, 2018). The measurement tests-core beliefs, values and assumptions concerning reality, which act as guidelines in personal life. The measurement targets a holistic mindset, which is generalistic in nature and is not necessarily tied to any special training or domain-specific systems thinking ability. Therefore, STSR focuses on the differences between reductionistic and holistic thinking. Instead, mental self-renewal and complex postformal thinking focus on the ability of thinking and its operations, for instance, for creating meaning, embracing contradictions and integrating different viewpoints. Even though these measurements are theoretically based on the same paradigm, they do not approach systems thinking or adult thinking as a particular worldview of a particular paradigm; instead, they emphasise the process rather than the outcome. Systems thinking, in this view, is an on-going creative developmental thinking process, not a fixed destination. When understood this way, systems thinking includes and encompasses both reductionist and dynamical system worldviews and considers them as different logical systems (in terms of Sinnott, 1998).

In previous studies, STSR scores have been positively associated with creativity test scores measuring divergent thinking (Furnham & Nederstrom, 2010; Randle & Stroink, 2018). There are also several studies on the relationship between creativity and postformal thought. In this study, we found evidence that there is a moderate positive association between STSR and associative thinking (vRAT, Olteţeanu & Zunjani, 2020), but not between vRAT and MSRS or CPFT. Perhaps this is because mental self-renewal includes both divergent and convergent

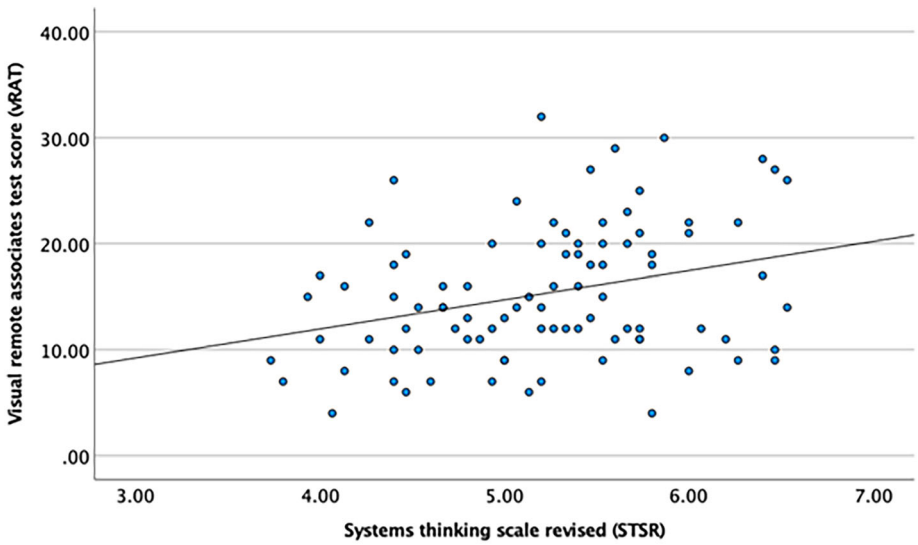

FIGURE 9 vRAT scores vs. STSR scores ($N = 90$). [Colour figure can be viewed at wileyonlinelibrary.com]

aspects of creative thought (the ability to increase and decrease entropy as part of knowledge creation). On the other hand, the creativity of mature cognition and complex problem solving—characteristic of systems thinking—could be qualitatively different and/or need a different conceptualisation and measurement of such aspects of creativity that the existing creativity tests cannot measure.

In sum, what should we focus our research efforts on when studying systems thinking? The findings of the present study suggest that the relationships among mental self-renewal, creativity and adult cognitive models could be the focus of future studies that aim to understand the quality of the complex thinking required to act in dynamic environments and to solve wicked HTI design problems. Therefore, the embodied dynamical view of the mind and its development to maturation adopted in this paper could help us understand how systems thinkers interact with themselves, others and the environment. After all, in the actual use and application of systems thinking, systems' current nature has to be understood and (en)acted in a variety of contexts rather than rationally controlled or intellectually explained away. Instead of having the right answers and strict plans or behaving according to deterministic laws, this view leaves open a small window of free will and a living autonomous agent able to renew itself. As one of the grounding fathers of this view has insightfully observed: 'Wanderer the road is our footsteps, nothing else; you lay down a path in walking' (Varela, 1987, p. 63, in Thompson, 2010).

5 | CONCLUSION

Systems thinking is an interdisciplinary field, and as a recent review and bibliometric analysis has pointed out, research on this topic has primarily been conducted in fields other than 'mind sciences' (Hossain et al., 2020). This research contributes to the nascent research endeavour that aims to investigate systems thinking within the fields of psychology and cognitive science (e.g., Grisold & Peschl, 2017; Randle & Stroink, 2018). This paper's aim was to contribute to the field by studying how mental self-renewal based on the embodied dynamism paradigm of cognition could assist in understanding aspects of thinking that previous conceptualisations and measurements had not been able to reach.

The specific goal of this study was to develop a measurement for mental self-renewal and to validate it by investigating its connections to constructs that were chosen based on previous theoretical research. The developed mental self-renewal scale was found to be internally consistent, and it seemed able to measure the phenomena it was designed to measure. There was a strong association between the novel mental self-renewal scale and the complex postformal thought questionnaire (CPFT, Cartwright et al., 2009; Sinnott, 1998), but only a weak association between the mental self-renewal scale and the systems thinking scale revised (STSR, Randle & Stroink, 2018). On the other hand, only STSR was moderately associated with the vRAT score (Olteţeanu & Zunjani, 2020). Future research could focus more on the theoretical relationship between mental self-renewal and adult cognitive development from the perspective of the embodied dynamical paradigm of cognition. It could also empirically examine the relationship between mental self-renewal and creativity.

The current study serves as the first step in the development of a novel scale and its focus was on finding appropriate operationalisation of the factors behind mental self-renewal and their relationship with existing, validated scales of STSR and CPFT and vRAT scores, which are intended to measure associative creativity. Even if the current scale is targeted at designers, it could be easily modified to measure mental self-renewal capacities in general, for example, by reformulating the item statements to fit the general population's practices of problem-solving and creative processes (instead of the context of design practice). For practical purposes, the number of items on the new mental self-renewal scale can probably be significantly reduced by further studies to enable shorter response times. The majority of participants on Prolific are proficient in English, but the respondents' English fluency was not screened for. In future studies, the understandability of the items to non-native English speakers should be ensured and the survey translated into other languages.

As this research has demonstrated, mental self-renewal is an ability that develops during adulthood. However, for some time, research on systems thinking has emphasised the importance of supporting related skills during childhood and education (e.g., Senge et al., 2012). Therefore, future research should also focus on investigating the developmental foundations of the ability of mental self-renewal in children. One way to achieve this could be with educational practices, which are grounded in a holistic conception of human beings and on the embodied dynamical paradigm of understanding the mind (Kallio, Mononen & Ek, 2024). In addition, the current MSR scale could be developed so that its items are more readily understood by young children.

ACKNOWLEDGEMENTS

The authors want to thank several contributors for their input on this research, Olteţeanu and Zunjani (2020), for

offering the visual RAT survey items and anonymous feedback received from the participants of the pilot study.

ORCID

Laura Mononen https://orcid.org/0000-0001-7236-897X
Tuomo Kujala https://orcid.org/0000-0001-8222-8540

REFERENCES

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues*, *8*(2), 5–21.

Buchanan, R. (2019). Systems thinking and design thinking: The search for principles in the world we are making. *She Ji: The Journal of Design, Economics, and Innovation*, *5*(2), 85–104.

Buckle Henning, P., & Chen, W. C. (2012). Systems thinking: Common ground or untapped territory? *Systems Research and Behavioral Science*, *29*(5), 470–483. https://doi.org/10.1002/sres.2155

Cabrera, D. A. (2006). Boundary critique: A minimal concept theory of systems thinking. In *Proceedings of the 50th Annual Meeting of the ISSS-2006*.

Cabrera, D., Colosi, L., & Lobdell, C. (2008). Systems thinking. *Evaluation and Program Planning*, *31*(3), 299–310.

Cartwright, K. B., Galupo, M. P., Tyree, S. D., & Jennings, J. G. (2009). Reliability and validity of the complex postformal thought questionnaire: Assessing adults' cognitive development. *Journal of Adult Development*, *16*(3), 183–189.

Checkland, P. (1985). From optimizing to learning: A development of systems thinking for the 1990s. *Journal of the Operational Research Society*, *36*(9), 757–767. https://doi.org/10.1057/jors.1985.141

Churchman, C. W. (1967). Guest editorial: Wicked problems. *Management Science*, *14*(4), B141–B142. http://www.jstor.org/stable/2628678

Córdoba-Pachón, J. R. (2011). Embracing human experience in applied systems-thinking. *Systems Research and Behavioral Science*, *28*(6), 680–688.

Cronin, M. A., Gonzalez, C., & Sterman, J. D. (2009). Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. *Organizational Behavior and Human Decision Processes*, *108*(1), 116–130.

Davis, A. C., & Stroink, M. L. (2016). The relationship between systems thinking and the new ecological paradigm. *Systems Research and Behavioral Science*, *33*(4), 575–586.

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem–solution. *Design Studies*, *22*(5), 425–437.

Doyle, J. K. (1997). The cognitive psychology of systems thinking. *System Dynamics Review: The Journal of the System Dynamics Society*, *13*(3), 253–265. https://doi.org/10.1002/(SICI)1099-1727(199723)13:3<253::AID-SDR129>3.0.CO;2-H

Flood, R. L., & Jackson, M. C. (1991). *Critical systems thinking*. Wiley.

Furnham, A., & Nederstrom, M. (2010). Ability, demographic and personality predictors of creativity. *Personality and Individual Differences*, *48*(8), 957–961. https://doi.org/10.1016/j.paid.2010.02.030

Gorsuch, R. L. (1983). *Factor analysis* (2nd ed.). Erlbaum.

Grisold, T., & Peschl, M. F. (2017). Why a systems thinking perspective on cognition matters for innovation and knowledge creation. A framework towards leaving behind our projections from the past for creating new futures. *Systems Research and Behavioral Science*, *34*(3), 335–353. https://doi.org/10.1002/sres.2456

Grohs, J. R., Kirk, G. R., Soledad, M. M., & Knight, D. B. (2018). Assessing systems thinking: A tool to measure complex reasoning through ill-structured problems. *Thinking Skills and Creativity*, *28*, 110–130. https://doi.org/10.1016/j.tsc.2018.03.003

Guilford, J. P. (1967). Creativity: Yesterday, today and tomorrow. *The Journal of Creative Behavior*, *1*(1), 3–14. https://doi.org/10.1002/j.2162-6057.1967.tb00002.x

Hämäläinen, R., Jones, R., & Saarinen, E. (2014). *Being better better-living with systems intelligence*. Aalto ARTS Books.

Heinämaa, S. (2014). Husserl's ethics of renewal: A personalistic approach. In M. Tuominen, S. Heinämaa, & V. Mäkinen (Eds.), *New perspectives on aristotelianism and its critics* (pp. 196–212). Koninklijke Brill NV.

Hossain, N. U. I., Dayarathna, V. L., Nagahi, M., & Jaradat, R. (2020). Systems thinking: A review and bibliometric analysis. *Systems*, *8*(3), 23.

Husserl, E. (1970). *The crisis of European sciences and transcendental phenomenology: An introduction to phenomenological philosophy*. Northwestern University Press.

Jackson, M. C. (2003). *Systems thinking: Creative holism for managers*. John Wiley & Sons, Inc.

Kallio, E. K., Mononen, L., & Ek, T. (2024). Holistic wisdom education: Towards transformational creativity. In Transformational Creativity: Learning for a Better Future (pp. 169–182). Cham: Springer International Publishing.

Kyriazos, T. A. (2018). Applied psychometrics: Sample size and sample power considerations in factor analysis (EFA, CFA) and SEM in general. *Psychology*, *9*(8), 2207–2230. https://doi.org/10.4236/psych.2018.98126

Lee, C. S., Huggins, A. C., & Therriault, D. J. (2014). A measure of creativity or intelligence? Examining internal and external structure validity evidence of the Remote Associates Test. *Psychology of Aesthetics, Creativity, and the Arts*, *8*(4), 446–460. https://doi.org/10.1037/a0036773

Luhmann, N. (1995). *Social systems*. Stanford University Press.

Maani, K. E., & Maharaj, V. (2004). Links between systems thinking and complex decision making. *System Dynamics Review: The Journal of the System Dynamics Society*, *20*(1), 21–48. https://doi.org/10.1002/sdr.281

Maturana, H. R., & Varela, F. J. (1972/1980). *Autopoiesis and cognition: The realization of the living*. Reidel.

Meadows, D. H. (2008). *Thinking in systems: A primer*. Chelsea Green Publishing.

Mednick, S. (1962). The associative basis of the creative process. *Psychological Review*, *69*(3), 220–232. https://doi.org/10.1037/h0048850

Mingers, J. (1992). The problems of social autopoiesis. *International Journal Of General System*, *21*(2), 229–236. https://doi.org/10.1080/03081079208945073

Mingers, J. (2002). Can social systems be autopoietic? Assessing Luhmann's social theory. *The Sociological Review*, *50*(2), 278–299. https://doi.org/10.1111/1467-954X.00367

Mononen, L. (2017). Systems thinking and its contribution to understanding future designer thinking. *The Design Journal*, *20*(sup1), S4529–S4538.

Mononen, L., & Kallio, E. K. (2024). A step towards understanding systems thinking as mental self-renewal. [Unpublished manuscript].

O'Connor, B. P. (2000). SPSS and SAS programs for determining the number of components using parallel analysis and Velicer's MAP test. *Behavior Research Methods, Instruments, & Computers*, *32*(3), 396–402. https://doi.org/10.3758/BF03200807

Olteţeanu, A. M., & Zunjani, F. H. (2020). A visual Remote Associates Test and its validation. *Frontiers in Psychology*, *11*, 26. https://doi.org/10.3389/fpsyg.2020.00026

Pituch, K. A., & Stevens, J. P. (2016). *Applied multivariate statistics for the social sciences* (6th ed.). Sage.

Plate, R. (2010). Assessing individuals' understanding of nonlinear causal structures in complex systems. *System Dynamics Review*, *26*(1), 19–33. https://doi.org/10.1002/sdr.432

Prigogine, I. (1980). *From being to becoming time and complexity in the physical sciences*. W. H. Freeman and Company.

Randle, J. M., & Stroink, M. L. (2018). The development and initial validation of the paradigm of systems thinking. *Systems Research and Behavioral Science*, *35*(6), 645–657. https://doi.org/10.1002/sres.2508

Saariluoma, P., Cañas, J. J., & Leikas, J. (2016). *Designing for life: A human perspective on technology development*. Springer. https://doi.org/10.1057/978-1-137-53047-9

Schaffernicht, M., & Groesser, S. N. (2011). A comprehensive method for comparing mental models of dynamic systems. *European Journal of Operational Research*, *210*(1), 57–67. https://doi.org/10.1016/j.ejor.2010.09.003

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. Basic Books.

Senge, P. M. (1990). *The fifth discipline. The art & practice of learning organization*. Doubleday Currence.

Senge, P. M., Cambron-McCabe, N., Lucas, T., Smith, B., & Dutton, J. (2012). *Schools that learn (updated and revised): A fifth discipline fieldbook for educators, parents, and everyone who cares about education*. Currency.

Simon, H. A. (1996). *The sciences of the artificial* (3rd ed.). The MIT Press.

Sinnott, J. (1998). *The development of logic in adulthood: Postformal thought and its applications*. Plenum Press.

Sowden, P. T., Pringle, A., & Gabora, L. (2015). The shifting sands of creative thinking: Connections to dual-process theory. *Thinking & Reasoning*, *21*(1), 40–60. https://doi.org/10.1080/13546783.2014.885464

Ståhle, P. (1998). *Supporting a system's capacity for self-renewal*. University of Helsinki.

Ståhle, P., Mononen, L., Tynjälä, P., & Kallio, E. K. (2020). Systems thinking and adult cognitive development. In E. Kallio (Ed.), *Development of adult thinking: Interdisciplinary perspectives on cognitive development and adult learning* (pp. 191–207). Routledge.

Sterman, J. (2001). System dynamics: Systems thinking and modeling for a complex world. *California Management Review*, *43*(4), 8–25.

Tabachnick, B. G., Fidell, L. S., & Ullman, J. B. (2013). *Using multivariate statistics* (Vol. 6) (pp. 497–516). Pearson.

Taylor, S., Calvo-Amodio, J., & Well, J. (2020). A method for measuring systems thinking learning. *System*, *8*(2), 11.

Thompson, E. (2010). *Mind in life: Biology, phenomenology, and the sciences of mind*. Harvard University Press.

Toivainen, T., Olteteanu, A. M., Repeykova, V., Likhanov, M., & Kovas, Y. (2019). Visual and linguistic stimuli in the Remote Associates Test: A cross-cultural investigation. *Frontiers in Psychology*, *10*, 926. https://doi.org/10.3389/fpsyg.2019.00926

Varela, F. J. (1987). Laying down a path in walking. In W. I. Thompson (Ed.), *Gaia: A way of knowing, political implications of the new biology* (pp. 48–64). Lindisfarne Press.

Whitehead, N. P., Scherer, W. T., & Smith, M. C. (2015). Use of natural language processing to discover evidence of systems thinking. *IEEE Systems Journal*, *11*(4), 2140–2149. https://doi.org/10.1109/JSYST.2015.2426651

How to cite this article: Mononen, L., & Kujala, T. (2024). Mental self-renewal as a measure of systems thinking. *Systems Research and Behavioral Science*, 1–27. https://doi.org/10.1002/sres.3017

APPENDIX A: CANDIDATE FACTORS AND ITEMS OF MENTAL SELF-RENEWAL AND THEIR THEORETICAL AND CONCEPTUAL BASIS

Concept/state/mental self-renewal factor	Characteristics of concept/state/mental self-renewal factor	Operationalisation: Item statement candidates (Applied to the context of Human-Technology Interaction design)
1. Self-organisation (Prigogine, 1980)	Systems that can self-organise have dissipative structures; they are in constant motion, and they produce order out of chaos. The process has different states, and it is controlled inside, instead of outside of the system.	
1.1 State of far-from-equilibrium (Prigogine in Ståhle, 1998, pp. 71–74, 116)	The source of new order is in or near a chaotic condition. In this state disintegration, confusion, discrepancies and disharmony are present. *i. Contradictionary* conditions exist inside the system (e.g., competing interests, opposing viewpoints, tension between polarisations) and it keeps the system energised. *ii. Forceful fluctuations* happen inside the system (e.g., boundaries are tested and challenged, exchange of and responding to information).	
1.1.1 Tolerance of chaos	The system does not disintegrate in the turmoil of chaos, instead it creates new order and oscillates between chaos and order as well as reorganises itself into higher level of complexity. It has ability to tolerate instability, disorder, complexity, uncertainty and chaos.	• I am able to tolerate confusion. • I am up to tolerate the uncomfortable feelings the design process can bring. • I am prepared to endure periods of high confusion and uncertainty in my design process. Removed after pilot: • I am capable of tolerating uncertainty. • Disharmony is a natural part of life. • I am able to work in an unorganised way. • For me, being in confusion is impossible. (Neg.)
1.1.2 Embracement of the tension of opposites	Embracing tension of opposites and conflicts is the source of energy in the system. Contradictory conditions and polarisations exist inside the system (e.g., competing interests or opposing viewpoints).	• Contradiction can be fruitful for the progress of work. • Opposing viewpoints have a tendency to bring forward a fruitful solution to problems. • The best solutions are found when there is tension between viewpoints. Removed after pilot: • People in disagreement provide fertile grounds for debate. • I don't mind when people disagree with each other. • Conflicting viewpoints are not helping the problem-solving in a design process. (Neg.)
1.1.3 Recognition of opportunities	Responding sensitively to information as well as thoughts and deeds of the participants keeps the system energised, re-organised and involved. Recognition of challenges in the environment (e.g., new information, competitors and nature).	• I can detect opportunities when they reveal themselves (e.g. business opportunities, customer needs, trends). • I tend to recognise challenges in the environment (e.g., reasons for product/service failure, changes in the markets).

(Continues)

Concept/state/mental self-renewal factor	Characteristics of concept/state/mental self-renewal factor	Operationalisation: Item statement candidates (Applied to the context of Human-Technology Interaction design)
		• I am usually detecting 'weak signals' (signs of new themes or trends) when they reveal themselves. Removed after pilot: • I am able to see the changes in culture or trends (e.g., new fashions, new ways of life). • I constantly follow trends and pick up relevant changes in my field. • I do not often notice relevant changes in the environment or culture. (Neg.)
1.1.4 Awareness of oscillation **(Removed after pilot study)**	The system oscillates between the stages of disorganisation and new organisation. It happens in a rhythmic cycle of recurring stable and chaotic periods in the creative process.	• My design process is constituted by stable and chaotic periods. • Usually when I design, the process oscillates between chaos and order. • My design process has rhythmic changes between messy periods and more clear periods. • There are organised and disorganised phases in my design process. Removed after pilot: • My design process does not have different phases. (Neg.)
1.2 Entropic knowledge creation (Prigogine in Ståhle, 1998, pp. 74–78, 91, 116)	Abundant communication and production of ideas are the source of entropy. Considering different angles of information without any certainty as to whether they will prove to be useful.	
1.2.1 Ability to increase entropy **(Removed at factor analysis)**	Ability to increase disorder and uncertainty by increasing information can happen by seeking new patterns and looking ahead in anticipation. Accumulation of information is crucial, even though some of it will be wasted. Production of more information than is needed and wasted resources are normal part of knowledge-creation in this manner.	• If I am trying to solve a problem, first I produce as many ideas as possible. • Generating ideas, which are not all useful is important for finding the right solutions. • I am able produce lots of ideas for solutions when needed. Removed after pilot: • When solving problems I look at them from different angles. • It is important to gather lots of information when solving a problem during creative work. • Having too many ideas is not useful for solving a complex problem. (Neg.)
1.2.2 Ability to dissipate entropy	Ability to reduce disorder, uncertainty and organise information into coherent patterns is part of coping with entropy. Choosing the essential as well as discarding the unproductive (e.g., establishing priorities, focus and concentration).	• When situations seem to be messy, I am able to bring order into them by prioritising, focusing and concentrating on important things. • I am capable to find relevant information, when there are lots of different ideas. • I am capable of finding the essential factors from information. Removed after pilot: • I am good at making decisions, focusing and concentrating when facing chaos. • I am capable of bringing order to disorder during my design process.

Concept/state/mental self-renewal factor	Characteristics of concept/state/mental self-renewal factor	Operationalisation: Item statement candidates (Applied to the context of Human-Technology Interaction design)
		• When the design process is in a chaotic state with too many ideas, I am not able to manage it. (Neg.)
1.2.3 Embracement of disintegration	The value and usefulness of the information cannot be known in advance; therefore, it is essential to be able to act intuitively and spontaneously without a predetermined structure. Willingness to abandon old ways of thinking and acting is the way in which energy dissipates.	• Failure is normal part of design practice. • Making errors is part of a normal design process, not something that can be totally avoided. Removed after pilot: • 'Stabbing in the dark' is part of a successful design practice. • Making mistakes is a part of a successful design process. • I am able to tolerate failure and I am not afraid of making mistakes. • The design process should proceed flawlessly and in an organised manner. (Neg.)
1.3 Iterative feedback system (Prigogine in Ståhle, 1998, pp. 26–27, 71–74, 78–81, 116)	Active and frequent response to other's ideas, opinions and reactions is part of the extremely sensitive internal interaction dynamic. This is the real power of self-organisation, enforcing new structures and carrying effects into the system at large.	
1.3.1 Readiness to iteration **(Removed at factor analysis)**	Iteration is continuous and nonlinear. Here it means an extremely sensitive feedback system, which could be described as resonance. Sensitivity on what happens inside and outside of the system.	• My problem-solving is an iterative process, which is in constant dialogue with the user/customer and the organisation I work for. • I am ready to change a design process based on feedback as many times as necessary. • Based on feedback, I'm able to start again from scratch. Removed after pilot: • I will usually have many drafts and prototypes before I find the final solution. • I am able to let go of ideas ('kill my darlings') based on feedback. • I usually move straight from problem formulation to the final solution.
1.3.2 Embracement of feedback	Feedback can be positive or negative, it is crucial part of self-organisation. Sensitive dependence on initial conditions provides spontaneity and can move the system to bifurcation point.	• Feedback (positive and negative) is necessary. • Feedback (positive and negative) provides the thrust for me to create and improve. • During the design process, I am actively searching for feedback (positive and negative) and developing the solution based on it. Removed after pilot: • Feedback feeds my creative process. • I actively and frequently ponder on the developing idea/solution based on feedback. • I really don't appreciate feedback during my design processes. (Neg.) *feedback quality in parenthesis, positive and negative was added after pilot study

(Continues)

Concept/state/mental self-renewal factor	Characteristics of concept/state/mental self-renewal factor	Operationalisation: Item statement candidates (Applied to the context of Human-Technology Interaction design)
1.4. Bifurcative decision making (Prigogine in Ståhle, 1998, pp. 71–74, 81–83, 116)	Bifurcation is an appearance of a new solution. Momentums in the system's life when genuine choices can be made. Bifurcation is a source of innovation and diversification, since it endows a system with a new solution.	
1.4.1 Reliance on bifurcation **(Removed in factor analysis)**	The system abandons a large amount of information and new order is created, entropy decreases, and a choice is made. It is truly nondeterministic since it cannot be predicted. True knowledge creating situation and process.	• I know that I have reached the right solution, when I have a moment of insight during my creative process. *merged with factor 'use of inner reactions' • It takes time and work, but the process often leads to a sudden insight, which offer the answer to my design problem. • Moments of truly good and workable solution is often the time when all the uncertainty disappears in the design process. Removed after pilot: • During my design process, I usually have moments of crystallisation, when suddenly the right solution appears to me. • When I arrive at the solution in my design process it is a point of no return for the older ideas or choices. • My creative process progresses steadily, there are no sudden bursts of insight. (Neg.)
1.5 Maintenance of process in time (Prigogine in Ståhle, 1998, pp. 49–52, 59, 71–74, 84–89, 116)	Process always need time. Reliance on the process manifest as inner peace, being actively passive and letting things happen without control. Dealing with time is essential element of any developmental process. All the different aspects of the process need time to happen.	
1.5.1 Reliance on the process **(Removed in factor analysis)**	Every process will show its own patterns in the rhythm of chaos and new order. Challenge is to trust in the system's capacity to organise itself in time and due to continuous interaction. Self-organisation cannot be forced or controlled; it is mutually created in the process of spontaneous interaction.	• I have trust in my own creative process. • I am sure that I will arrive at the right design solution during my creative process. • I know that the design process actively continues through time even when I'm not working. Removed after pilot: • I can be sure that the design process will arrive at right conclusion eventually. • I don't have to control my design process, I know the right solutions will eventually find their way to me. • I have learned through time, trial and error, how to best work with my design process. • Despite practice, I still don't trust my ability to arrive at a solution during a design process. (Neg.)
1.5.2 Sensitivity to timing **(Removed after pilot study)**	Time is not static; it is active and attached to entropy. Time furnishes the particular history of a system, which it makes with specific choices. The process advances from bifurcation point to another and reveals the meaning of right time and timing.	• The right solutions have a tendency to come at the right time and with perfect timing, if one is sensitive enough to see them. • The solution to problems can be always found, it just takes time.

Concept/state/mental self-renewal factor	Characteristics of concept/state/mental self-renewal factor	Operationalisation: Item statement candidates (Applied to the context of Human-Technology Interaction design)
		• Time is essential for solving complicated design problems. • The good solutions cannot be found without enough time. Removed after pilot: • Time is not essential for design progress. (Neg.)
2. Autopoiesis Maturana and Varela (1972/1980) and Self-referential systems Luhmann (1995) in Ståhle (1998)	Autopoiesis is the presupposition behind the need for renewal of self. It means continuous self-reproduction, self-maintenance, sameness and harmony. The system generates and realises the networks of its own production as well as boundaries. (Autos = self, poiein = to make, produce, to preserve existence, remake, conceptualise)	
2.1 Self-referential closure Luhmann in Ståhle, 1998, pp. 89–106	System must interact with other systems and use them as a point of reference for itself (e.g., reflection of existence, identity and boundaries). System is independent and autonomous, using the information from the environment. Ability to regulate boundaries is the basis of autonomy.	
2.1.1 Reflection of existence	Boundaries are an evolutionary achievement and a characteristic to the development of all the higher-level systems. In the quest for meaning the system is actualising its own potential. Defining one's own existence can mean basic ideas for being and doing, values, principles and goals.	• I have reflected on existential issues several times during my life. • I have had a major crisis during my life. • I have profoundly questioned myself, my values and the purpose of my life. Removed after pilot: • I know what is important and meaningful for me in life because I have pondered on them. • I have never questioned myself or my existence. • I have clarified my values and goals during my life.
2.1.2 Recognition of boundaries	The ability to regulate boundaries is relevant to autonomy, which is an essential feature of self-referring systems. Boundary is prerequisite to newer developments, separating internal interdependencies from the environment.	• It is easy for me to separate my opinions (my thoughts and feelings) from those of others. • When in conflict, it is easy for me to hear others opinions and at the same time keep in touch with my own. • Its easy for me to assert my own viewpoints. Removed after pilot: • I know who I am and what I stand for. • I am open to new viewpoints, when aiming to solve a conflicting situation. • I am very sure of who I am and know what is others' and what is mine. • I easily give in to others or I am too rigid with my opinions in conflict situations. (Neg.)
2.1.3 Continuous self-reflection	Continuously making distinction between itself and its environment. 'Negative looking-glass self', seeing oneself in terms of how it is not like the other.	• Self-reflection is part of my everyday life; I meditate or keep a journal frequently or use other ways of self-reflection. • Getting to know myself better is important for me.

(Continues)

Concept/state/mental self-renewal factor	Characteristics of concept/state/mental self-renewal factor	Operationalisation: Item statement candidates (Applied to the context of Human-Technology Interaction design)
		Removed after pilot: • Soul-searching is a part of my ways to get to know myself better. • I frequently ponder on encounters with people and events afterwards and my own role in them. • Self-reflection is not a part of my life. (Neg.)
2.1.4 Recognition of ethical impact	The connectivity of the system is important, since without its double contingent relationships it cannot function, and without them it is impossible to produce its meanings mutually or to test them. The function of the system is based on the meanings (knowing what is important and significant).	• I constantly reflect on how my designs will impact the people I design to. • I find the work of a designer very responsible since it is changing people's lives. • I am considering how my design affect the quality of users' lives. Removed after pilot: • Ethics are important for me as a designer. • It is important for me to design products and services that are sustainable. • It is not important for me how my designs affect the people or the environment. (Neg.)
2.2 Double contingent relationships (Luhmann, in Ståhle, 1998, pp. 106–108, 116)	Mutual interdependence, power balance and trust within the system. Everyone is of equal value and positively dependent on each other. The relationship of two persons is the basic explanation of a social functioning.	
2.2.1 Embracement of interdependence **(Removed at factor analysis)**	The change in the system is not about individuals but the relationships between them, which offers connectivity and provides function. There is symmetry, voluntariness and bond of trust or mistrust, which are tested before starting to process meaning (and it must happen in that order). All relationships include risks, trust is given freely and contingently.	• I think it is important to be trustworthy design cooperation. • I value other peoples' opinions when designing a solution. *merged with factor 'embracement of feedback' • Communicating and solving miscommunication with other people during a design process is important. Removed after pilot: • I am good at relating to other people's viewpoints, no matter what they are. • In my view, all people have equal and valuable viewpoints in the design process. • Open communication is most important in a successful design process. • I don't think it's important to consider other's opinions during a design process. (Neg.)
2.3 Experiential information (Luhmann in Ståhle, 1998, pp. 108–109, 116)	Exchange of information is the system's renewing power. Information must have influence on others and thus it always changes the state of the system. Information means an 'event' rather than fact in systemic language.	
2.3.1 Use of personal experiences	Information is experienced not enacted; information content is not relevant, instead external data that do not touch people personally cannot act as information.	• I use my personal experiences and personal feelings as a tool for design. • I frequently use my personal experiences and knowledge to relate with the customer. • Empathising with the customer via my own experiences is part of my design process. Removed after pilot:

Concept/state/mental self-renewal factor	Characteristics of concept/state/mental self-renewal factor	Operationalisation: Item statement candidates (Applied to the context of Human-Technology Interaction design)
		• In my design process, it is important to personally experience the context where my design will be used. • It is important for me to personally meet the user/customer and visit the place where my design • will be used. • I do not use feelings or subjective experiences as guidance in the design process. (Neg.)
2.3.2 Use of inner reactions	Only if information causes reactions (e.g., changes the state of the system) and therefore becomes an element in the creative process. Consequently, information which is repeated no longer function as information, because it is not causing reactions in the system.	• I know I have succeeded in my design, when I feel that it touches me. • The design is good, if it causes strong feelings in me. • When I have a strong feeling about something, I know I am in a right track. Removed after pilot: • When I feel strong spontaneous reactions, they are a good sign of success in design. • I use my feelings and intuitions as my guide in the design process. • My way of working is to gain information about the user in an objective manner (e.g., data). (Neg.)
2.4 Collectively processed meanings (Luhmann in Ståhle, 1998, pp. 108–109, 116)	What occurs in the process of interaction is meaning. Meanings are created collectively within the system through jointly created events. It is the basic structural element of a social system. Psychic and social systems have evolved together and therefore have same elements.	
2.4.1 Sensitivity to meanings	Renewal pace is in relationship with the process of meaning (how fast the system can create and develop information). Therefore, connectivity of the system is essential (e.g., it gives the competitive edge in organisations).	• It is important to understand the meaning(s) the user has for the design context and the design. • In order to communicate through the design at hand, it is important to understand the users' meaning-making processes. • To understand what solution works, it is important to understand what meaning the user gives to the design. Removed after pilot: • To be able to design artefacts, it is important to understand how the user has understood their situation and the solution. • For me, it is important to understand the meaning and significance (symbolic value) of the creations I produce from the perspective of as many people (communities) as possible. • Meanings the user has related to the design are not important for a design to be effective. (Neg.)

(Continues)

Concept/state/mental self-renewal factor	Characteristics of concept/state/mental self-renewal factor	Operationalisation: Item statement candidates (Applied to the context of Human-Technology Interaction design)
2.5 Double-crossing Ståhle, 1998, pp. 165–166	Boarders and boarder zones are important issues. Boarders are defined by system itself; they are flexible and conditional. The links between the two systems become relevant.	
2.5.1 Awareness of mediating information between cultures **(Removed at pilot study)**	Individuals who are part of different subsystems become bearers of those cultures. Crossing boundaries of information culture means being able to conduct more exchange of information as well as carrying knowhow from one culture to the next.	• I often find myself crossing the borders between professional fields and disciplines. • I feel like the mediator between several groups of professionals. • There does not seem to be a professional title that exactly describes or fits the description of what I do within my profession. • I am often asked 'whose or what hat' I am wearing when I engage in professional conversation. • I often feel like an outsider and that I don't belong to a group or profession. Removed after pilot: • I am specialised in one specific field of work. (Neg.)
3. Phenomenological attitude (Husserl, 1970)	Studying the structures and contents of consciousness as experienced from the first-person view. Identifying inherent meaning of an idea, object or situation. The aim is not to break the flow of experience, but to reinhabit it in a fresh way, namely, with heightened awareness and attunement.	
3.1 Phenomenological reduction (Husserl in Thompson, 2010, pp. 16–36)	Phenomenological reduction means 'leading back' (reducere) or redirection of thought away from its unreflective and unexamined immersion in the world (the natural attitude) and directing attention to the way in which the world appears to us.	
3.1.1 Flexibility of attention	Deriving meaning out of direct experience and investigating the situation 'as it is given'. Ability to step into the experience as it appears to oneself and focusing interest in how things are experienced.	• When starting a design process, I aim at exploring the design context without any preconceived ideas. • I am aiming to studying the design context with pure and unbiased view. -> I aim at studying the design context with pure and unbiased view. • I consciously aim at ignoring any stereotypes or previous knowledge when I start designing new things. Removed after pilot: • When targeting at gaining new ideas I aim at encountering situations with a view of a newborn/novice/first-timer. • To see how the design context really works, I aim at suspending judgement and seeing how it works in reality. • For me, it is not important about how my previous experiences influence my way of encountering the design context. (Neg.)

Concept/state/mental self-renewal factor	Characteristics of concept/state/mental self-renewal factor	Operationalisation: Item statement candidates (Applied to the context of Human-Technology Interaction design)
3.2 Epoché (originally in Greek skepticism, abstaining from belief) (Husserl in Thompson, 2010, pp. 16–36)	Epochè (method) means to suspend or refrain from judgement 'suspension', 'neutralization' or 'bracketing' of both our natural 'positing' attitude and our theoretical beliefs and assertions (whether scientific or philosophical) about 'objective' reality.	
3.2.1 Awareness of awareness (meta-awareness) **(Removed at factor analysis)**	Is a flexible and trainable mental skill of being able to both suspend one's inattentive immersion in experience and to turn one's attention to the manner in which something appears or is given to experience.	• I am very much aware of how my thoughts and feelings affect the way I perceive things. • I am very curious of how I create meaning of things I perceive. • To me studying how my perception works is an on-going practice. • I understand how I have come to see the world the way I do. Removed after pilot: • I do not know how my thoughts and experiences affect the way I perceive things. (Neg.)

APPENDIX B: MENTAL SELF-RENEWAL SCALE (FINAL) WITH CRONBACH'S ALPHAS AND FACTOR LOADINGS FOR EACH ITEM PER FACTOR (SORTED BY LOADING)

Factor (alpha)	Items	Loading
MSR1. Tolerance of chaos ($\alpha = 0.776$)	1) I am able to tolerate confusion.	0.818
	2) I am prepared to endure periods of high confusion and uncertainty in my design process.	0.808
	3) I am up to tolerate the uncomfortable feelings the design process can bring.	0.608
MSR2. Embracement of the tension of opposites ($\alpha = 0.712$)	4) Contradiction can be fruitful for the progress of work.	0.815
	5) Opposing viewpoints have a tendency to bring forward a fruitful solution to problems.	0.674
	6) The best solutions are found when there is tension between viewpoints.	0.614
MSR3. Recognition of opportunities ($\alpha = 0.730$)	7) I usually detect 'weak signals' (signs of new themes or trends) when they reveal themselves.	0.746
	8) I can detect opportunities when they reveal themselves (e.g., business opportunities, customer needs, trends).	0.667
	9) I tend to recognise challenges in the environment (e.g., reasons for product/service failure, and changes in the markets).	0.634
MSR4. Ability to dissipate entropy ($\alpha = 0.753$)	10) I am capable of finding the relevant information, when there are lots of different ideas.	0.901
	11) I am capable of finding the essential factors from information.	0.607
	12) When situations seem to be messy, I am able to bring order to them by prioritising, focusing and concentrating on important things.	0.602
MSR5. Embracement of disintegration ($\alpha = 0.739$)	13) Making errors is a part of a normal design process, and not something that can be totally avoided.	0.993
	14) Failure is a normal part of design practice.	0.567
MSR6. Embracement of feedback ($\alpha = 0.748$)	15) Feedback (positive and negative) is necessary.	0.797
	16) During the design process, I am actively searching for feedback (positive and negative) and developing a solution based on it.	0.733
	17) Feedback (positive and negative) provides the thrust for me to create and improve.	0.683
	18) I value other people's opinions when designing a solution.	0.416
MSR7. Reflection of existence ($\alpha = 0.822$)	19) I have profoundly questioned myself, my values and the purpose of my life.	0.875
	20) I have reflected on existential issues several times during my life.	0.761
	21) I have had a major crisis during my life.	0.738
MSR8. Recognition of boundaries ($\alpha = 0.661$)	22) When in conflict, it is easy for me to hear other's opinions and at the same time keep in touch with my own.	0.740
	23) It is easy for me to separate my opinions (my thoughts and feelings) from those of others.	0.697
	24) It's easy for me to assert my own viewpoints.	0.491
MSR9. Continuous self-reflection ($\alpha = 0.668$)	25) Getting to know myself better is important for me.	1.046
	26) Self-reflection is part of my everyday life; I meditate or keep a journal frequently or use other ways of self-reflection.	0.470
MSR10. Recognition of ethical impact ($\alpha = 0.797$)	27) I constantly reflect on how my designs will impact the people for whom I design.	0.822
	28) I am considering how my design affect the quality of users' lives.	0.801
	29) I find the work of a designer very responsible since it is changing people's lives.	0.776

Factor (alpha)	Items	Loading
MSR11. Use of personal experiences ($\alpha = 0.727$)	30) I frequently use my personal experiences and knowledge to relate with the customer.	0.861
	31) I use my personal experiences and personal feelings as tools for design.	0.720
	32) Empathising with the customer via my own experiences is a part of my design process.	0.483
MSR12. Use of inner reactions ($\alpha = 0.817$)	33) I know I have succeeded in my design, when I feel that it touches me.	0.839
	34) The design is good, if it causes strong feelings in me.	0.776
	35) When I have a strong feeling about something, I know I am on the right track.	0.774
	36) I know that I have reached the right solution, when I have a moment of insight during my creative process.	0.477
MSR13. Sensitivity to meanings ($\alpha = 0.768$)	37) It is important to understand the meaning(s) the user has for the design context and the design.	0.792
	38) In order to communicate through the design at hand, it is important to understand the users' meaning-making processes.	0.751
	39) To understand what solution works, it is important to understand what meaning the user gives to the design.	0.678
MSR14. Flexibility of attention ($\alpha = 0.772$)	40) When starting a design process, I aim at exploring the design context without any preconceived ideas.	0.816
	41) I consciously aim at ignoring any stereotypes or previous knowledge when I start designing new things.	0.780
	42) I aim at studying the design context with a pure and unbiased view.	0.616

APPENDIX C: CORRELATION MATRIX BETWEEN THE MENTAL SELF-RENEWAL SCALE (MSRS) AND THE MSR FACTORS ($N = 311$)

Scale (abbreviation)	MSRS	MSR1	MSR2	MSR3	MSR4	MSR5	MSR6	MSR7	MSR8	MSR9	MSR10	MSR11	MSR12	MSR13	MSR14
MSR1. Tolerance of chaos	0.538***														
MSR2. Embracement of the tension of opposites	0.507***	0.462***													
MSR3. Recognition of opportunities	0.645***	0.379***	0.166**												
MSR4. Ability to dissipate entropy	0.668***	0.449***	0.334***	0.502***											
MSR5. Embracement of disintegration	0.449***	0.169**	0.329***	0.069	0.207***										
MSR6. Embracement of feedback	0.585***	0.290***	0.248***	0.257***	0.335***	0.271***									
MSR7. Reflection of existence	0.285***	0.042	0.108	−0.005	0.099	0.134*	0.037								
MSR8. Recognition of boundaries	0.605***	0.224***	0.132*	0.378***	0.464***	0.174**	0.433***	0.102							
MSR9. Continuous self-reflection	0.635***	0.182***	0.270***	0.287***	0.410***	0.182***	0.258***	0.288***	0.349***						
MSR10. Recognition of ethical impact	0.721***	0.280***	0.357****	0.497***	0.460***	0.206***	0.463***	0.145**	0.419***	0.428***					
MSR11. Use of personal experiences	0.668***	0.177**	0.170**	0.411***	0.340***	0.318***	0.362***	0.098	0.416***	0.387***	0.554***				
MSR12. Use of inner reactions	0.470***	0.115*	0.056	0.365***	0.121*	0.112*	0.123*	0.067	0.142*	0.339***	0.253***	0.385***			

Scale (abbreviation)	MSRS	MSR1	MSR2	MSR3	MSR4	MSR5	MSR6	MSR7	MSR8	MSR9	MSR10	MSR11	MSR12	MSR13	MSR14
MSR13. Sensitivity to meanings	0.682***	0.327 ***	0.202***	0.456***	0.403***	0.246***	0.409***	0.077	0.408***	0.374***	0.448***	0.520***	0.271***		
MSR14. Flexibility of attention	0.403***	0.163**	0.162**	0.351***	0.144*	0.050	0.130*	0.012	0.147**	0.185***	0.165**	0.110	0.332***	0.233***	

* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.