Juha Törmänen **Systems Intelligence – Measurement and Modelling** **Aalto University** **2021**

Department of Industrial Engineering and Management

Systems Intelligence – Measurement and Modelling

Juha Törmänen

Aalto University

DOCTORAL DISSERTATIONS

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Systems Intelligence – Measurement and Modelling

Juha Törmänen

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Abstract

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Abstract

Systems Intelligence (SI) refers to intelligent behavior in the context of complex systems involving interaction and feedback. Systems intelligent individuals and organizations are able to successfully and productively engage with the holistic feedback mechanisms of their environment. This study operationalizes the concept of SI by providing novel measurement and modelling tools and approaches that help take Systems Intelligence from the laboratory to the real world.

The SI Inventories introduced in this study provide both measurement tools and a multi-dimensional conceptual framework for evaluating and discussing how individuals and organizations can succeed in wholes. The study introduces eight factors of SI – Systemic Perception, Attunement, Positive Attitude, Spirited Discovery, Reflection, Wise Action, Positive Engagement and Effective Responsiveness – and argues for their usefulness for individual and organizational development. The dissertation presents and validates inventories for self, peer, an organizational evaluation of SI, and opens new perspectives for discussing organizational learning.

As applications of the framework, the study also presents visualization and simulation solutions for helping people explore and improve their capability to succeed in systemic contexts. Visual displays of individual and team SI scores help people communicate and understand their systems-related strengths and weaknesses, and the Positive Systems Intelligence Teams (PoSITeams) simulator helps to explore socio-emotional systems.

The measurement and modelling tools presented in this work can help to stage interventions for improving individual and organizational capabilities to be more productive within and with respect to systems. The tools also serve as useful instruments for building learning organizations and human resource capabilities.

Keywords Systems Intelligence, Systems thinking, The learning organization

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Tiivistelmä

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Väitöskirjan nimi
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Tiivistelmä
Systeemiälyllä (Systems Intelligence, SI) viitataan älykkääseen toimintaan monimutkaisissa kokonaisuuksissa, joille vuorovaikutus ja takaisinkytkennät ovat tunnusomaisia. Systeemiälykäs yksilö tai organisaatio toimii onnistuneesti ja tuottavasti ympäristönsä monisuuntaisten vaikutusmekanismien kanssa. Tämä tutkimus operationalisoi systeemiälyn käsitettä esittelemällä mittaus- ja mallinnustyökalut, joiden avulla systeemiälyä on mahdollista viedä laboratoriosta elävään elämään.

Tutkimuksessa kehitetyt systeemiälyinventaariot voivat palvella sekä mittaustyökaluina että käsitteellisinä kehikkoina, kun arvioidaan ja keskustellaan siitä, miten yksilöt ja organisaatiot toimivat monimutkaisissa kokonaisuuksissa. Tutkimus esittelee kahdeksan SI:n faktoria – Systeeminen havaintokyky, Sanaton yhteys, Asenne, Kekseliäs mieli, Pohtivuus, Viisas toiminta, Heittäytyvä osallistuminen ja Aikaansaavuus – ja esittää niiden olevan hyödyllisiä käsitteitä yksilöiden ja organisaatioiden onnistumisen ja kehittämisen kannalta. Tutkimukseen sisältyvät artikkelit esittävät ja validoivat inventaariot yksilöiden itsearvioimiseen, vertaisarvioimiseen, sekä organisaation kyvykkyyksien arvioimiseen.

Lisäksi tutkimus esittelee lukuisia visualisaatio- ja simulaatioratkaisuja, joiden avulla yksilöt voivat kartoittaa ja kehittää kykyään menestyä monimutkaisissa kokonaisuuksissa. SI-inventaarioiden tulosten visuaaliset esitykset auttavat kommunikoimaan ja ymmärtämään kokonaisuuksiin liittyviä vahvuuksia ja haasteita, ja Positive Systems Intelligence Teams (PoSITeams) -simulaattori auttaa ymmärtämään ihmisten välisestä vuorovaikutuksesta muodostuvia systeemejä.

Tutkimuksessa kehitetyt mittaus- ja mallinnustyökalut palvelevat interventioita, joiden tavoite on auttaa yksilöitä ja organisaatioita löytämään tapoja onnistua toimimaan paremmin monimutkaisissa kokonaisuuksissa. Esitettyjä työkaluja voi käyttää oppivien organisaatioiden rakentamiseen ja henkilöstön kehittämiseen.

Avainsanat Systeemiäly, Systeemiajattelu, Oppiva organisaatio

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Preface

The work included in this dissertation is based on a period of research beginning in 2010 and stretching all the way to the present day in 2021. During these years, numerous people have contributed in ways big and small for making this dissertation happen; I apologize that I am unable to mention all of you by name here.

I would like to thank my previous and current supervisors, Professor Emeritus Raimo P. Hämäläinen and Professor Esa Saarinen for all the impact they have had on this dissertation and on my life. This dissertation relies heavily on the ground-breaking research done by Raimo and Esa, and both of you have been instrumental in helping the work presented here develop and come to fruition. Furthermore, the growth-mindset, constructively positive life-philosophical approach of Professor Saarinen and the scientifically rigorous, efficient and effective research and communication style taught to me by Professor Hämäläinen have had a huge effect on my personal and professional development. I am deeply grateful for both of you and consider you as some of the most significant persons in the story of my life.

During my studies, I have had the privilege of being a member of two warm and brilliant communities of the Aalto University School of Science; first as a student and employee of the Systems Analysis Laboratory of the Department of Mathematics and Systems Analysis, and later as a graduate student in the Department of Industrial Engineering and Management. I am thankful for the faculty and students of both departments for the inspiring, welcoming, and most of all motivating atmosphere they provided. I am especially thankful for the friendship and interesting discussion opportunities provided by Jaakko Korhonen, Peter Kenttä, Frank Martela, Tuomas Lahtinen, Joonas Ollila, Yrjänä Hynninen, Arttu Klemettilä, Suvi-Tuuli Helin, and Teemu Tiinanen. For Teemu, I am also grateful for his work done for PoSITeams that forms a major part of one of the publications in this thesis.

I am also thankful for all the members of the Systems Intelligence Research Group and people who have participated in Systems Intelligence research seminars over the years, providing viewpoints, thoughts, and approaches for the emerging field. While I cannot mention everyone by name, I would like to especially thank Rachel Jones, Heikki Peltola, Kata Kumpulainen, Riitta Juvonen, Björn Wahlström, Topi Jokinen, Pia Lappalainen, Tuomas Harviainen, Jussi Galla, Lauri Järvilehto, Barbara Malmström, Ari Tervashonka and Henriika

Maikku for insightful thoughts and ideas that have helped this dissertation reach its current form.

I am greatly thankful to the pre-examiners of this thesis, Associate Professor Hong Bui and Associate Professor Yasuo Sasaki, for agreeing and taking the time to act as pre-examiners for this dissertation. Thank you both for your prompt work and the insightful comments you provided in your pre-examination statements!

A large part of the work done for this dissertation has been done part-time while I have been working as Analyst at Crisis Management Initiative and as an entrepreneur and CTO of Inclus. I thank Crisis Management Initiative, especially my manager at the time, Ville Brummer, for allowing me to take a month of time off for finishing my first publication in 2015. I am grateful for my co-founding partner at Inclus, CEO Mikaeli Langinvainio for understanding and allowing me to spend time working on my research in addition to my entrepreneurial duties, and for my colleagues, especially Joonas Rajamäki and Valtteri Frantsi, for helping take some of the work pressure off my shoulders. I hope that my work on this dissertation has not caused you excessive stress over the years!

In large parts, the reason I have been able to do the work of both an entrepreneur and a doctoral student is thanks to the supportive environment provided by my friends and family. Thank you Kaj Sotala and Tuure Laurinolli for your long-time friendship and countless opportunities to ponder our lives together, and to my godmother Liisa Kantojärvi for motivational support and for showing me an example of a very successful doctoral dissertation and defense. Thank you, my mother Eija, father Mikko, and brother Antti for being such reliable and positive fixtures on my life. Most of all, I'm thankful to my partner, Elina, for being a loving and like-minded life companion on this long journey.

Espoo, 31 July 2021,

Juha Tapani Törmänen

Contents

List of Abbreviations and Symbols

CFA	Confirmatory Factor Analysis
DLOQ	Dimensions of the Learning Organization Questionnaire
EFA	Exploratory Factor Analysis
HRD	Human Resource Development
LO	Learning Organization
OSI	Organizational Systems Intelligence
SI	Systems Intelligence

List of Publications

This doctoral dissertation consists of a summary and of the following publications which are referred to in the text by their numerals

1. Törmänen, Juha; Hämäläinen, Raimo P.; Saarinen, Esa. 2016. Systems Intelligence Inventory. *The Learning Organization*, volume 23, issue 4, pages 218–231. https://doi.org/10.1108/TLO-01-2016-0006

2. Törmänen Juha; Hämäläinen Raimo P.; Saarinen, Esa. *On the Systems Intelligence of a Learning Organization: Introducing a New Measure*. 38 pages. Manuscript revision submitted on 11/2020.

3. Törmänen Juha; Hämäläinen Raimo P.; Saarinen, Esa. *Perceived Systems Intelligence and Performance in Organizations.* 22 pages. Manuscript submitted on 04/2021.

4. Tiinanen, T., Törmänen, J., Hämäläinen, R. P., & Saarinen, E. (2016). PoSITeams – Positive Systems Intelligent Teams, an Agent-Based Simulator for Studying Group Behaviour. *Proceedings of the 59th Annual Meeting of the ISSS-2015.*
http://journals.isss.org/index.php/proceedings59th/article/view/2718

5. Hämäläinen, R. P., Saarinen, E., & Törmänen, J. (2018). Systems Intelligence: A Core Competence for Next-Generation Engineers? *2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*, 641–644. https://doi.org/10.1109/TALE.2018.8615247

Author's Contribution

Publication 1: Systems Intelligence Inventory

Törmänen is the primary author. Hämäläinen and Saarinen proposed the topic and research questions. Hämäläinen, Saarinen and Törmänen worked together to develop the initial list of inventory items. Törmänen carried out the statistical analysis and wrote the methods and results section of the publication. Hämäläinen, Saarinen and Törmänen jointly wrote the other sections of the publication.

Publication 2: On the Systems Intelligence of a Learning Organization: Introducing a New Measure

Törmänen is the primary author. Törmänen, Hämäläinen and Saarinen developed the topic together, and Törmänen prepared the research design, gathered data, and analyzed and reported the results. Törmänen wrote the methods and results section of the publication. Hämäläinen, Saarinen and Törmänen jointly wrote the other sections of the publication.

Publication 3: Perceived Systems Intelligence and Performance in Organizations

Törmänen is the primary author. Törmänen, Hämäläinen and Saarinen developed the topic together, and Törmänen prepared the research design, gathered data, and analyzed and reported the results. Törmänen wrote the initial version of the publication, which was then further improved on by all three writers together.

Publication 4: PoSITeams – Positive Systems Intelligent Teams, an Agent-Based Simulator for Studying Group Behaviour

Tiinanen is the primary author. Törmänen was responsible for the development of the initial version of the simulation model and the web application, including its visual design. Tiinanen improved on the work to develop the final version of the simulation model, and Hämäläinen and Tiinanen were mainly responsible for writing the publication.

Publication 5: Systems Intelligence: A Core Competence for Next-Generation Engineers?

Hämäläinen is the primary author. Törmänen and Saarinen worked on latter revisions of the article, providing comments, and helping hone its direction.

1. Introduction

1.1 My Personal Path to Systems Intelligence Research

As I joined the Systems Analysis Laboratory of the Helsinki University of Technology (now Aalto University) in 2010, I originally expected to end up working on fairly limited technical simulation models and eventually finding employment writing mathematical software somewhere. Rather, thanks to Professors Hämäläinen and Saarinen, after they picked up my summer work application among a big pile of competing applicants, I found myself at the Systems Intelligence Research Group – a vibrant, multidisciplinary group of researchers working not on a limited technical field, but rather on a truly big idea – that people could and should be able to succeed better in complex situations and environments, that they should be able to be not only individually intelligent and skillful, but also *systems intelligent*.

In 2010, Systems Intelligence (SI) research was maturing from descriptive and qualitative concept-building research to more concrete ideas about providing tools, approaches, and quantifiable metrics to organizational contexts. I jumped in at this point, and soon found myself reading not only systems thinkers such as Peter Senge, but also about positive psychology, management sciences, multiple intelligences theory, psychometrics, and applied philosophy.

The work on SI led me first to work on my bachelor's thesis and master's thesis on the subject, and to also start work on a doctoral dissertation immediately afterwards. However, I soon started to develop a sense that SI isn't something that you become an expert in by simply sitting behind a desk in a university; it's much more valuable to go out to the real world to get some practical understanding, and then write with that viewpoint also in mind.

I was extremely fortunate to get an opportunity to join President and Nobel laureate Martti Ahtisaari's Crisis Management Initiative and to continue working on my doctoral studies during the same time. Travelling to countries such as Egypt, Lebanon, Iraq, and South Sudan and helping to find systems intelligent approaches for different local and regional conflicts and problems also helped me to greatly further my own thinking. Subsequently, I spun off my own technology company, Inclus Oy, with my co-worker Mikaeli Langinvainio, and we have continued the work by helping public and private organizations in Finland and abroad build common understanding and conduct joint analysis. While these detours have caused my doctoral studies to stretch out to span nearly a decade, I sincerely think that this dissertation is much stronger thanks to them.

By way of hindsight, a key reason for my own fascination for working in the SI Research Group was its blend of rigor and relevance, theory and practice. Originally a professor of applied mathematics, Raimo Hämäläinen had created the Systems Analysis Laboratory as a platform for using mathematics for the purposes of modelling complex structures relevant for engineering. "We serve as systems engineers the science of better", was one of Raimo's slogans. There was a strong vision of providing tools for the benefit of actual projects of improvement in the context of real-life operations.

That vision had also led Raimo to invite Esa, a household name in Finland and a philosopher famed for his ability to make philosophy connect with the everyday, to the faculty of the Systems Analysis laboratory of Helsinki University of Technology in 2001. The idea was to use rational judgment and modelling, be that mathematical as with Hämäläinen or qualitative as with Saarinen, for the benefit of making things work and for improving what didn't work.

It was in this context of applied science and open-mindedly oriented engineering that I found my intellectual home. For Raimo and Esa, conceptual categories were as secondary as were disciplinary boundaries in contrast to the phenomena themselves. The research on "systems intelligence" was to serve a purpose, and early on I learnt the importance of the "serviceability" of concepts (Burke, 1984; Kenttä, 2020) to be a chief aspect of what we were doing with SI within the university and outside of it. Raimo and Esa often emphasized the "iconic" nature of the phrase "systems intelligence", through which one enters a perspective that is useful and even fundamental when conceiving of "success within wholes".

But rational discourse calls for rigorous tools. To that effect, my own work hopes to make a contribution.

1.2 Introduction to the Publications

Publication 1 introduces a core measurement tool of SI, the Systems Intelligence Inventory, and the eight factors of SI. The publication documents the factor analysis strategy that was used to develop the SI Inventory, and validates the 32-item, 8-factor structure for use as a self-report questionnaire inventory for evaluating personal SI-related strengths and weaknesses.

Publications 2 and 3 apply the inventory developed in Publication 1 to organizational and peer evaluations, respectively. Publication 2 uses an "In my organization, people…" worded question to assess the perception of people in one's organization from the point of view of SI. The publication validates the resulting Organizational SI Inventory and discusses the results in the context of the Learning Organization (LO) and the commonly used Dimensions of the Learning Organization Questionnaire (Marsick & Watkins, 2003).

Publication 3 validates the inventory for peer evaluation in the form "My colleague…". The publication discusses its relationship with perceived assessment of a colleague's performance and shows that the SI inventory can also work as part of 360-style evaluations.

Publication 4 discusses the simulation tool, PoSITeams, for helping people understand and improve their behavior in teams and social networks. The

PoSITeams simulator is implemented as a web browser -based application to study different social contexts.

Publication 5 takes a more high-level viewpoint, discussing the importance of SI as a general people-related competence needed today even in engineering. The publication suggests SI to be included as a part of engineering education.

While the individual publications discuss and elaborate on specific aspects of SI, together the articles seek to provide firmer footing for the concept of SI as a framework for improvement. Especially relevant is the perspective of the LO, but other contexts of improvement are indicated as well. More generally speaking, the current work contextualizes within research that seeks to incorporate the behavioral with the rational and the theoretical with the pragmatic for the benefit of actual development. It is a humble step towards fulfilling the existential call toward “Being Better Better” (to quote the title of Hämäläinen et al., 2014). In that sense, the current work runs parallel with “behavioral operational research”, another outgrowth of the SI way of thinking (Hämäläinen et al., 2013).

2. History of Systems Intelligence

SI was born from discussions between Professors Raimo P. Hämäläinen and Esa Saarinen in the early years of the 2000's, after Professor Hämäläinen had invited Professor Saarinen to join the Systems Analysis Laboratory of the Helsinki University of Technology (now Aalto University). The two professors – Hämäläinen an expert of systems sciences, Saarinen an expert of philosophy – sparked a dialogue that resulted in the concept.

An especially fruitful forum for the discussion was the emergence of the annual student seminar series called Luovan ongelmanratkaisun seminaari (in English, "seminar on creative problem solving"). Within the seminar, the participants discussed the papers and ideas of both systems scientists such as Peter Senge, Ralph Stacey, Michael Jackson, and Robert Flood, as well as other relevant writings such as Howard Gardner's studies on multiple intelligences (Jones & Hämäläinen, 2013).

Peter Senge had already widely discussed the importance of systems thinking in his seminal book *The Fifth Discipline* (Senge, 1990), and Senge's work served as a particular inspiration for developing the idea of SI – that it is important to develop and promote the skills of individuals, teams, and organizations to be able to successfully manage and succeed in complex wholes around them.

The term *Systems Intelligence* was coined in the seminar on creative problem solving in 2002, building on the discussion on multiple intelligences of Gardner (1983) and the work on Emotional Intelligence by Daniel Goleman (1995). As Saarinen and Hämäläinen describe in their introductory essay of SI, *Connecting Engineering Thinking with Human Sensitivity* (Saarinen & Hämäläinen, 2004a), SI builds on top of these earlier theories and takes a pragmatic and active viewpoint towards real world situations. The article also includes the quintessential description of SI as:

> *… intelligent behavior in the context of complex systems involving interaction and feedback. A subject acting with Systems Intelligence engages successfully and productively with the holistic feedback mechanisms of her environment. She perceives herself as a part of a whole, the influence of the whole upon herself as well as her own influence upon the whole. By observing her own interdependence in the feedback intensive environment, she is able to act intelligently.*

The research seminars on creative problem solving were the central forums for developing the idea of SI further during the early years of the concept. The seminars not only resulted in the term *Systems Intelligence* and many of the core articles about SI, but also gave rise to a series of essays discussing, defining, and describing SI from various perspectives. The essays have been collected into eight volumes, which are publicly available at the Systems Intelligence Research Group web site (http://systemsintelligence.aalto.fi):

- Systeemiäly! *[Systems Intelligence!]* (Bäckström et al., 2003)
- Systems Intelligence - Discovering a Hidden Competence in Human Action and Organizational Life (Saarinen & Hämäläinen, 2004b)
- Systeemiäly – Näkökulmia vuorovaikutukseen ja kokonaisuuksien hallintaan *[Systems Intelligence – Perspectives on interaction and managing wholes]* (Hämäläinen & Saarinen, 2004)
- Systeemiäly 2005 *[Systems Intelligence 2005]* (Hämäläinen & Saarinen, 2005)
- Systeemiäly 2006 *[Systems Intelligence 2006]* (Hämäläinen & Saarinen, 2006)
- Systems Intelligence in Leadership and Everyday Life (Hämäläinen & Saarinen, 2007)
- Systems Intelligence – A New Lens on Human Engagement and Action (Hämäläinen & Saarinen, 2008)
- Essays on Systems Intelligence (Hämäläinen & Saarinen, 2010)

All in all, these collections consist of 126 articles and include contributions from 107 individuals – as such, even in its early stages, SI had an explosive start with a rich, multidisciplinary discussion of its contents and applicability. The essays in these publications discuss SI in various contexts such as teaching, internet security, method acting, mergers and acquisitions, architecture, seafaring, corporate leadership, dialogue, happiness, volunteerism research, and romantic partnerships. The essay collections together provide an excellent lens for the subsequent development of the concept of SI. In the latest volume, Essays on Systems Intelligence, published in 2010, Saarinen and Hämäläinen (2010), paying particular attention to emotional intelligence, suggest an alternative definition for SI:

> *Systems intelligence (SI) involves the ability to use the human sensibilities of systems and reasoning about systems in order to adaptively carry out productive actions within and with respect to systems.*

Since 2004, academic research on SI has been published across multiple topics, such as team dynamics (Luoma et al., 2008), group dialogue (Slotte, 2006), therapy (Martela & Saarinen, 2013), knowledge management (Jones et al., 2011; Sasaki, 2017), engineering education (Lappalainen, 2017), human resources (Nousiainen, 2018), behavioral operations research (Hämäläinen et al., 2013) and early childhood education (Hämäläinen et al., 2020). Appendix 1 includes a comprehensive list of SI-related publications.

I personally joined the Systems Intelligence Research Group in 2010, just as SI was starting to take the next steps in its development by developing tools and intervention methods for helping people explore and improve their systems intelligent behavior. We started to look at the possibilities offered by gamification – for example, simulations and games that would provide a low-barrier entry to SI concepts. One result of this work was the development of the "Positive Systems Intelligent Teams", or *PoSITeams* simulator. An early version of the simulator was published in my bachelor's thesis, and the more mature version is described in Publication 4 of this thesis and detailed later in this summary. Another track led to the development of the SI card game, which helps teams discuss and improve their systems intelligent behaviors, and which is also described in more depth in a later section.

A second major direction was that we started developing measurement tools for SI. The first steps to this direction were taken by John F. Rauthmann (2010) in a series of articles in the *Essays on Systems Intelligence* that lead to describing a version of a trait-based SI scale. Based on this work and further discussions with Rauthmann and the rest of the SI Research Group, we started an extensive project to develop items for a complete Systems Intelligence Inventory.

In Autumn 2010 and Winter 2010-2011, the SI Research Group spent long afternoons in the laboratory, writing, rewriting, and discussing possible phrasings for self-report SI measurement items, and running a long series of pilot studies to assess how those phrasings were understood when evaluated by individuals. The process led from an initial 76-item questionnaire described in my Master's thesis (Törmänen, 2012) to a final 8-factor, 32-item SI Inventory that was published in 2016 and is included in this thesis as Publication 1 (Törmänen et al., 2016). Most of the research presented in this dissertation is built on top of the SI Inventory factor structure, and its factors and items also serve as the structure of the SI card game.

The ideas of SI have started to become increasingly notable during the past decade. Several articles on SI have been published each year, and SI has served as a framework for many theses and dissertations during the time (these are listed in Appendix 1). The SI Inventory has been applied in practice in various context around the world, for example in Egypt and Australia.

Peter Senge held a keynote presentation at the 30th Anniversary Seminar of the Systems Analysis Laboratory, highlighting the importance of the concept (Senge, 2014). In the speech, Senge uses the concept of "systems intelligence" as a general concept that can be graphed intuitively, rather than as a construct of a theory commanded by experts only. The YouTube recording of this presentation has proven to be widely popular, exceeding 230,000 views at the time of writing this summary (14 February 2021).

Likewise, Professor Saarinen's annual Finnish lecture series "Filosofia ja systeemiajattelu" (Philosophy and Systems Thinking) has helped to popularize the concept, which has started to live a life of its own. The lecture recordings have received over a million views in total (Luoma-Aho, 2021).

A report by the World Economic Forum (2016) on the future of jobs also notes that narrow technical skills are no longer sufficient for success in the "fourth industrial revolution" of the present times. You also need skills such as ability to persuade and teach others, and emotional intelligence. While the report does not use the term SI, much of what it describes as the necessities of the future of work could be tidily summed up with the concept.

In the latter part of the 2010s, much of the SI research has been concentrated around an interdisciplinary research seminar held in Aalto University (and, in the Covid-19 complicated world of 2020-2021, online in Zoom meetings). These meetings have kept up the rich, multi-perspective and multifaceted approach to SI already present in the essay publications, by including presentations from different universities, corporations, entrepreneurs, and writers about how they see SI relate to their own field, or what research they are conducting on SI. These seminars have become a fruitful place for developing the idea of SI and ways to apply SI in practice further.

3. The Factor Models of Systems Intelligence

3.1 Theoretical Background

SI links to various skills in different systems approaches, most notably to the five disciplines described by Senge (1990) – systems thinking, personal mastery, mental models, shared vision, and team learning.

At the same time, SI connects to Howard Gardner's theory of multiple intelligences (Gardner, 1983) and the concept of Emotional Intelligence (Goleman, 1995; Salovey & Mayer, 1990). Gardner's theory and Emotional Intelligence both posit that, when discussing individual capabilities, one should not only focus on simple general intelligence, but rather consider various intelligences and skills required in the modern life. SI can be thought of an additional piece of this discussion – it can be well argumented that the capability to act intelligently in complex systemic contexts is essential.

It is worth noting that based on the original definition given by Saarinen and Hämäläinen for SI (Saarinen & Hämäläinen, 2004a) and included in the previous section, SI is better to be considered as a skill rather than a psychological trait. A person's systems intelligence is not something that is fixed from the moment she is born, but rather something that she can learn and develop; it is in the power of every individual to become better at acting in an intelligent fashion in the context of complex and interdependent systems.

To enable that kind of development, it is useful to develop measuring tools that can, at the very least, identify areas of growth for the individuals, teams, or organizations being measured, and preferably also serve as measuring sticks of how much improvement has been done. Thus, an important point in operationalizing SI is to be able to quantify it in some form.

The approach in this thesis is to conceptualize SI as a set of subdimensions or factors that one can develop and excel in; these factors are then used to develop tools that can help people understand SI capabilities better and to identify ways to improve them.

As a quantified model of SI, the resulting Systems Intelligence Inventories serve not only as central tools for systems intelligence interventions and developing SI, but also for related fields such as research on the Learning Organization (LO), as put into motion by Peter Senge. In the recently published Oxford Handbook of the Learning Organization (Örtenblad, 2019), Goh (2019) provides an insightful discussion and critique of the currently existing approaches for measuring the LO, such as the widely used Dimensions of the Learning Organization Questionnaire (Marsick & Watkins, 2003). More recently, interest in developing bottom-up and multi-level approaches for developing the LO has also been increasing, as demonstrated by Chou and Ramser (2019).

The Organizational Systems Intelligence (OSI) Inventory, described in Publication 2 of this dissertation, provides one additional alternative perspective to developing the LO. When compared to the existing measurement instruments reviewed in depth by Goh (2019), the OSI Inventory takes a strictly bottom-up approach for developing the LO; it focuses on how people behave in the organization rather than assesses how the organization is structured and led. In this, the OSI parallels some of the other more recent developments in the field, such as the psychological safety -based approach of the Learning Organization Survey (Edmondson et al., 2019). The bottom-up approach may help the OSI Inventory serve as a component of more complex models of LO, such as the one suggested by Bui and Baruch (2010).

With the bottom-up approach, the OSI is able to emphasize some of the five disciplines of Senge more explicitly than is the case with the previous LO measurement tools. As is argued in article (2), the approach reported here brings the concept of personal mastery much more strongly to the limelight than previous proposals. As we state in Publication 2, we believe that the OSI is a major step in the operationalization of Sengean insights of the LO.

3.2 Developing the Models

SI is a large concept, and relevant in nearly all areas of our everyday life. It may be sensible to talk not only about SI in general, but also SI in different contexts and organizational environments. Is an individual that is *systems intelligent* in his work life necessarily so in his personal life at her home? Is the team she belongs to at work, or at her hobby, systems intelligent? Could we even describe an entire organization as more or less systems intelligent?

To be able to connect all these different contexts and environments, it is important to introduce shared concepts and vocabulary that can be used to describe and quantify systems intelligent behaviors. Developing the SI inventories described in this thesis, we started with the simplest – an individual self-evaluating their own capabilities – and moved then onwards to also describing teams and organizations, and to validating whether the same vocabulary can also be used for assessing “perceived SI” – that is, an individual’s evaluation another individual, opening the door for also using SI as a component of 360-style evaluations.

The two common approaches for developing a measurement tool are exploratory factor analysis (EFA) and confirmatory factor analysis (CFA), with many applications landing somewhere between fully exploratory and fully confirmatory (Hurley et al., 1997). With a more exploratory development, the researcher begins with less assumptions about the underlying final structure of the data, and first uses one data set to construct a factor model; with a more confirmatory approach, the structure is hypothesized beforehand, and the analysis is simply used to "confirm" that the model fit the data suitably well.

As Publication 1 (Törmänen et al., 2016) set out to build the first complete inventory of SI, it was natural to use an exploratory approach (Vehkalahti & Everitt, 2019). During the course of building the initial Systems Intelligence Inventory, a pilot set of over 70 items describing systems intelligent behavior was step by step reduced down to an inventory of 8 factors with 4 items each – that is, a total of 32 items. We used a separate confirmatory data set to ensure that the resulting model was valid and reliable in the sense that confirmatory factor analyses, done most often in structural equation modelling (Bollen, 1989), can be.

Publications 2 and 3 build on the work done in Publication 1 by applying the same inventory framework for organizations (Publication 2) and for perceived evaluation of other people (Publication 3). The Organizational Systems Intelligence (OSI) Inventory is discussed within the larger context of developing Learning Organizations, and the perceived inventory is discussed in context of how people perceive each other's performance. Within these two contexts, an item originally in Publication 1 described as "I approach people with warmth and acceptance" first becomes "In my organization, people approach each other with warmth and acceptance"; then "My colleague approaches people with warmth and acceptance".

3.3 Factors of Systems Intelligence

The framework of SI described in Publications 1, 2 and 3 consists of eight factors, or subdimensions, of SI, that are used to describe different aspects of systems intelligent behavior. They are defined as (Hämäläinen et al., 2018, Publication 5):

Systemic Perception: Seeing, identifying and recognizing systems, patterns and interconnections, having situational awareness;

Attunement: Engaging intersubjectively, being present, mindful, situationally sensitive and open;

Positive Attitude: Keeping a positive outlook, not getting stuck on negative impressions and effects.

Spirited Discovery: Engaging with new ideas, embracing change;

Reflection: Reflecting upon one's thinking and actions, challenging one's own behavior;

Wise Action: Exercising long-term thinking and realizing its implications, understanding that consequences may take time to develop;

Positive Engagement: Taking systemic leverage points and means successfully into action with people;

Effective Responsiveness: Taking systemic leverage points and means successfully into action with the environment, being able to dance with systems.

The eight factors and the ways they relate to our everyday life are discussed in depth in the book Being Better Better by Hämäläinen et al. (2014).

Experimentally, when using the set of measurement items presented in Publication 1, individual SI capabilities seem to strongly vary on these eight factors. For example, a person may be highly skilled in Systemic Perception and Effective Responsiveness but be rather weak in Attunement and Positive Attitude.

The same structure has also been confirmed to work when describing behavior at an organizational level (Publication 2); one can discuss not only individual behavior, but also how people in general behave in the organization.

The 32 items for the self-report inventory, for the perceptual inventory, and for the organizational inventory are included within Publications 1 to 3.

3.4 Grouping the Factors

Eight factors are already quite a lot for keeping in mind at the same time; therefore, at least for educational purposes, it is good to group the factors to make communicating and learning about them easier.

Publication 4 presents one such grouping, where the eight factors are combined into four pairs:

Perceiving systems: Systemic Perception, Attunement
Attitude: Positive Attitude, Spirited Discovery
Thinking: Reflection, Wise Action
Acting: Positive Engagement, Effective Responsiveness

There are significant strong correlations between the factors, as described in Publications 1 and 2. Using these correlations and the previous grouping, the factors can be placed to a two-dimensional visualization of the SI inventory so that conceptually and statistically related factors remain close to each other. Figure 1 presents a suggestion for such a visualization.

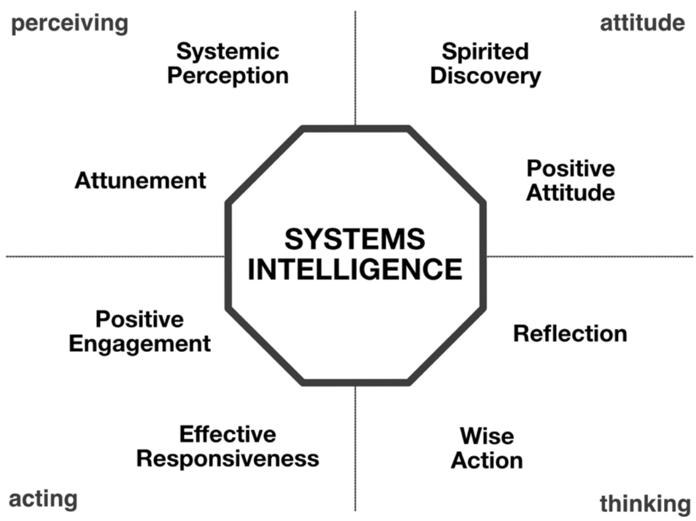

Figure 1. A grouping of the eight SI factors

4. Tools for Developing Systems Intelligence

4.1 Measuring and Reporting Systems Intelligence

In the approaches described in Publications 1 to 3, the eight SI factor scores are calculated as weighted averages of item scores (with items with negative phrasings reversed). For example, the self-report SI inventory calculates the score for Effective Responsiveness as:

$$EFF = \frac{0.494 * SI29 + 0.666 * (6 - SI30) + 0.473 * SI31 + 0.720 * SI32}{0.494 + 0.666 + 0.473 + 0.720}$$

Where SI29, SI30, SI31 and SI32 are responses to items 29-32, respectively, scored from 0 (“never”) to 6 (“always”). As SI30 was a negatively phrased item, it is reversed in the formula. Using these weighted scores allows analyzing the results in a more fine-tuned fashion; for example, here, SI32 (“When things don't work, I take action to fix them”) has the strongest weight, meaning that answers to it affect the Effective Responsiveness score more than the other three items.

The Systems Intelligence Self Evaluation available at http://salserver.org.aalto.fi/sitest/en/ (Törmänen, 2020) reports the results by identifying the factors the participant is relatively strongest in, and the factors the participant is relatively weakest in. This can help the participant both to identify their strengths and to discover his or her most significant opportunities for improvement. For example, a participant might be better than 80% of the participants in six of the factors, better than 60% in Attunement, and better than 95% in Systemic Perception – the evaluation would then highlight Systemic Perception as her strength and Attunement as her opportunity for development.

Figure 2 shows the answer distributions for the eight factors of self-report SI, calculated over all the data gathered from the public self-evaluation questionnaire. Figure 3 shows an example of how an individual’s answers might be reported with respect to these distributions.

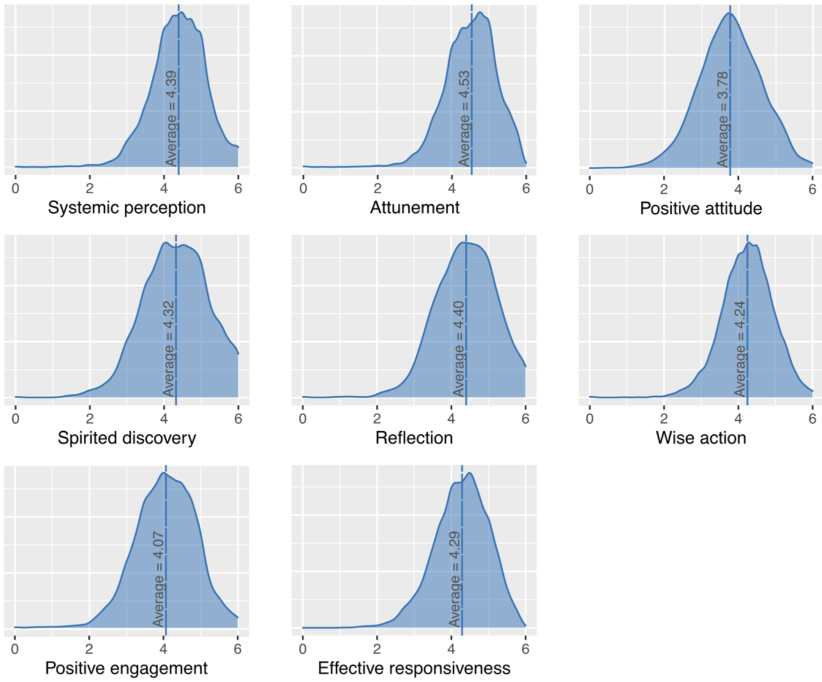

Figure 2. Answer distributions of the self-report SI Inventory dimensions (N=3531)

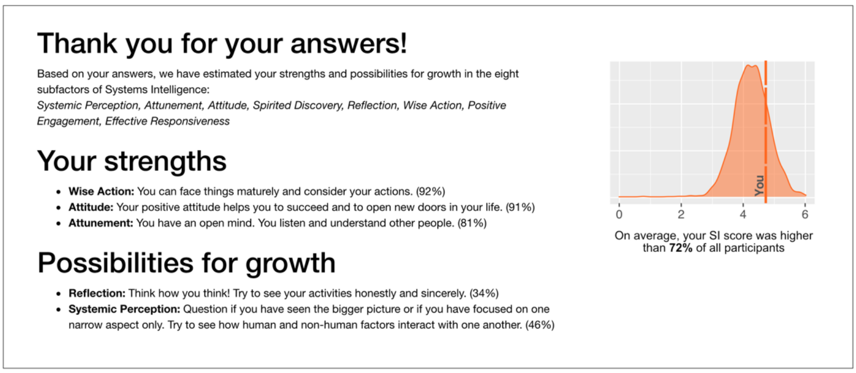

Figure 3. Example of the results page of the self-report SI questionnaire

To date, the Systems Intelligence Self Evaluation has received over 3500 answers that are used to give recommendations to the participant. As Figure 2 shows, the different SI factors have somewhat differing distributions; for example, Positive Attitude has a lower average score and higher variance than Attunement. These differences should be kept in mind when analyzing results from an SI Inventory questionnaire.

Completing one of the SI Inventories consists of answering 32 items with a Likert scale, which takes less than 5 minutes. Thus, the inventories can easily be included as a part of larger questionnaires to incorporate a systems lens to the evaluation.

4.2 Team Visualizations

A typical application of the SI Inventories would be to improve the systems intelligence of a team or an organization. In these cases, the participants may consider their own actions within their working context, and the answer distributions of the entire team are compared to a total distribution of answers. Figure 4 shows one example of such data, with team distributions on all eight SI factors contrasted to the total distributions.

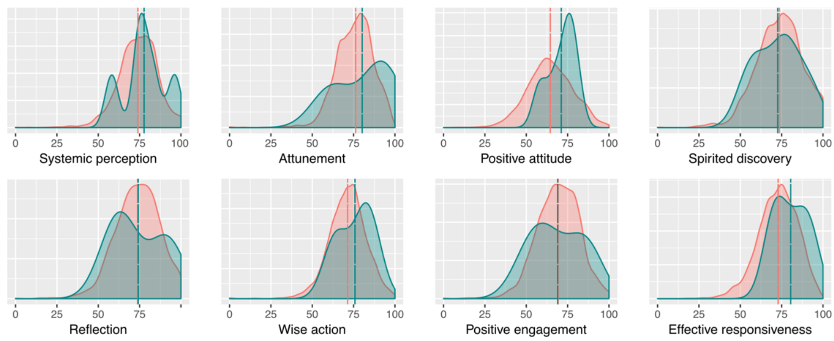

Figure 4. Example of a visualization contrasting smoothed team answer curve (dark teal) to the total answer distribution.

Such a report could help the team identify their relative strengths (in Figure 4's case, Effective responsiveness and Positive attitude) while highlighting possible avenues for improvement (in Figure 4, the high variance in Attunement and Systemic perception might be cause for worry). Notice that when team distributions are smoothed, such as in this example, large variances in answers may result in a distribution that has multiple distinct peaks.

4.3 Gamification

Publication 4 (Tiinanen et al., 2016) describes one way of using simulations to enhance understanding of phenomena related to SI. The PoSITeams web-based multi-agent simulation provides ways for people to study the dynamics of emotions, building on the Broaden-and-Build theory of Barbara Fredrickson (1998, 2004). The approach was also inspired by the mathematical modelling of marital relations by Gottman (Gottman, 2005; Gottman et al., 1998). The simulation lets people explore how emotional dynamics may affect multi-agent environments such as teams and small social networks, and how different parameters or behaviors may affect the entire socio-emotional system.

While the PoSITeams focuses on exploring the interpersonal dimensions of SI and the effect of positive affect, implicitly it also serves as a tool for people to enhance all eight of the SI factors. People can use it as a tool to conduct "what-if" analyses and ways of exploring what would happen if one changed their own behavior. A manager can also ask what could possibly happen if the teams would be reorganized in a new way. Figure 5 shows an example of the PoSITeams user interface.

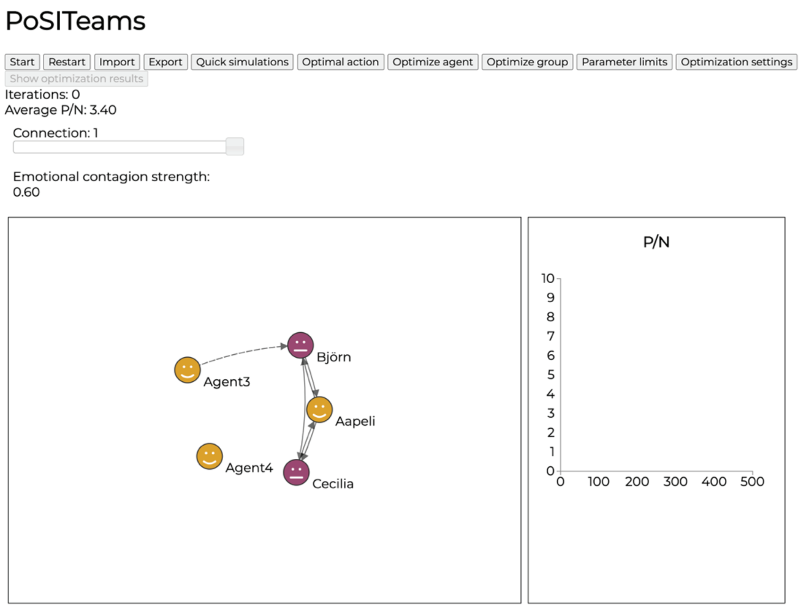

Figure 5. PoSITeams user interface

In addition to these kinds of interactive simulation tools, the SI framework and factor structure can be used in the context of social design games (Harviainen et al., 2016). One such application is the Systems Intelligence Topaasia card deck, shown in Figure 6, which leverages the 8-factor 32-item factor structure of the SI Inventories as a deck of 32 playing cards (Hämäläinen et al., 2020). The card game helps teams reflect on their systems intelligence capabilities and identify ways to develop the teams' behavior.

Figure 6. The Topaasia Systems Intelligence playing card deck

5. Conclusions and Future Directions

The work presented in this thesis consists of tools and approaches that help bring the idea of SI from the laboratory to the real world. With the development of the measurement and simulation tools described in Publications 1-4, it is now possible to bring SI to empirical application in practice, and to use the shared vocabularies of the three SI inventories to discuss SI-related phenomena in a coherent manner between different application and research fields.

Publication 5 suggests that SI can be a core competence in engineering education. While the publication limits the discussion to that specific field, the SI approach is a general one – the same could certainly be said for other disciplines as well, such as business and management in general.

As this thesis has been long in the making, many applications are already underway. The eight SI factors originally presented in Publication 1 have been used in multiple theses, research projects, and interventions, and much of the recent SI research is built on top of the factors. The SI card game described earlier in this article is one example of such an application that has already been used in a large-scale intervention in early childhood education (Hämäläinen et al., 2020).

The SI Inventories (for self-report, organizational, and peer evaluation) provide new tools that are applicable in various fields. Research and interventions on the LO can benefit from the bottom-up, grassroots approach of the Organizational Systems Intelligence Inventory, and the three inventories can work as a parallel development tool to, e.g., the Fifth Discipline Fieldbook (Senge et al., 1994). The inventories can also help human resource development, as they help to discuss both organizational and individual strengths and weaknesses within the organization.

The validation of the inventories described in publications 1-3 has focused mostly on the factorial and content validity of the constructs; it can now be safely said that the constructs are usable as assessment tools, and that the factors produced are intuitive and understandable in everyday life. Future research on the inventories could focus on their reliability, applicability, and predictive value; how stable do the SI inventory results stay over time? Can SI evaluations predict organizational success, or clearly measure how much an individual's SI capabilities are growing? Is it possible to develop a practically useful "intelligence test" based on the SI factors that would avoid the traps articulated by Keith Stanovich (Stanovich, 2010)?

Another valuable future direction could be to study how the SI Inventories behave in various situations and contexts; is it common that a person may be highly systems intelligent in their work life, but completely systems "unintelligent" at their home life? Are there even differences between various work situations? In this way, it might be interesting to relate the SI inventory research to the recent discussion on situation research and situational psychology (Rauthmann et al., 2015).

The contribution of this thesis is the development of novel measurement frameworks and tools that help operationalize and apply SI concepts in everyday life, both individual and corporate. The SI inventories, for self-evaluation, perceptual assessment, and discussing organizational capabilities, allow conducting measurements and presenting results that help communicate essential concepts and possible needs for change. The visualizations and simulations enable efficient communication of systems phenomena and help make abstract or systemic concepts more easily understandable. My wish is that these tools and approaches help make SI applicable to the everyday life of individuals, teams, and organizations.

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Appendix 1: Systems Intelligence Publications and Writings

This appendix contains known publications, essays, and theses that discuss Systems Intelligence. Publications are listed by year, from oldest to newest.

Articles and publications

Saarinen, E., & Hämäläinen, R. P. (2004). Systems Intelligence: Connecting engineering thinking with human sensitivity. In *Systems Intelligence - Discovering a Hidden Competence in Human Action and Organizational Life* (pp. 1–29). Helsinki University of Technology.

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Systems Intelligence Inventory

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Abstract

Purpose

Systems intelligence (SI) (Saarinen and Hämäläinen, 2004) is a construct defined as a person's ability to act intelligently within complex systems involving interaction and feedback. SI relates to our ability to act in systems and reason about systems to adaptively carry out productive actions within and with respect to systems such as organizations, family and everyday life. This paper develops an inventory to measure the SI construct.

Methodology

A combination of exploratory and confirmatory factor analysis using data from self-report questionnaires is used.

Findings

Eight factors labeled Systemic Perception, Attunement, Attitude, Spirited Discovery, Reflection, Wise Action, Positive Engagement, and Effective Responsiveness are identified as the main components of SI. SI has associations with Emotional Intelligence but also captures additional dimensions. People in supervisor positions are found to score higher in a number of the SI factors.

Originality/value

A new measure is developed to evaluate and develop our ability to succeed in systemic contexts. It is suggested to be particularly applicable in organizational contexts. This measure is directly related to the original core disciplines of the learning organization as described by Senge (1990), in particular personal mastery and systems thinking.

Keywords

Emotional intelligence, Systems intelligence, Systems thinking competence, The learning organization

Introduction

Our everyday life is embedded in systems in contexts such as work, organizations, and family. The generic set of abilities involved in the human ability to live successfully in interaction-intensive systemic environments has been conceptualized as Systems Intelligence (SI), which Saarinen and Hämäläinen (2004, p. 3) originally defined as:

"Intelligent behavior in the context of complex systems involving interaction and feedback. A subject acting with Systems Intelligence engages successfully and productively with the holistic feedback mechanisms of her environment. She perceives herself as a part of a whole, the influence of the whole upon herself as well as her own influence upon the whole. By observing her own interdependence in the feedback intensive environment, she is able to act intelligently."

This relatively broad definition integrates conceptual elements that are often held distinct. While pointing to abilities of an individual, it relates to what lies beyond the individual; while referring to an ability that the individual possesses, it points to the operational significance of that ability vis-à-vis the mechanisms of the environment. Being able to function systems intelligently requires that a person is able to take into account the relevant systems and their underlying characteristics so that he or she is able to adopt and function productively in the relevant systems.

Systems Intelligence (Saarinen and Hämäläinen, 2004, 2010) has already been used to describe the generic aspects of the meta-level skills required for succeeding in systemic settings in a number of areas such as organizations and leadership (Hämäläinen and Saarinen, 2008; Luoma et al., 2008, 2011; Saarinen, 2008), emergency management (Seppänen et al., 2013), psychotherapy (Martela and Saarinen, 2013), communications (Jones et al., 2011), and developmental studies and pedagogy (Jones and Corner, 2012; Saarinen and Lehti, 2014). The key assumption of the SI perspective is that human beings harbor abilities to adapt their actions to holistic settings, here conceptualized as systems.

The original core idea in the conceptualization of the learning organization (LO) by Senge (1990) (see also Kofman and Senge, 1993) also relates to the systemic abilities of individuals which allow learning in holistic settings with a systems perspective .There is a relatively wide literature on questionnaires which have been used to measure the learning organization (LO) and in which the focus has been on learning and on the organizational aspects. The most widely used measure is the one developed by Watkins and Marsick (1997), which also has individual level questions with a learning focus. Recently this literature has been strongly criticized by Kim et al. (2015) due to the lack of using proper psychometric analysis and validation methods. Also the earlier literature does not consider in detail the systems competences in organizations or in individuals. There are many constructs to measure organizational learning in general, but very few include the LO perspective as is done in Jerez-Gómez et al. (2005).

This paper presents a new new psychometrically validated measure that could have potential in improving the understanding and development of learning organizations. The paper also analyzes how the construct relates to Emotional Intelligence (Goleman, 1995; Salovey and Mayer, 1989), a competence which has received surprisingly little interest in the LO studies but which is yet considered to be important in organizational behavior (see e.g. Ashkanasy and Daus, 2005). We believe SI is a human core competence in the same way as the well known multiple intelligences described by Gardner (1983). The addition of the SI is motivated by its emphasis of dynamism and systemicity, which are lacking in the earlier constructs.

This paper posits that a scale including the concept of a system provides a new and rich description of people's systemic skills both in different social situations and in different contexts. The scale is suggested to relate directly to the skills required in the LO.

Method

SI is assumed to be a multifactor construct that consists of aspects such as the ability to observe and adjust one's own behavior, the ability to accurately observe and affect the behavior of others, and the abilities to find ways to improve the relevant systems both in the short term and in the long term. To capture all of these aspects, an inventory is generated consisting of a set of statements related to self, to other people, to ways of acting and reacting, and to the cognitive as well as emotional grasp of the relevant systems phenomena.

In order to account for the possibility that SI skills may differ significantly between people in different life situations, occupations, and age groups, participants were gathered from three different contexts: university students, including an open course in Philosophy and Systems Thinking and Applied Mathematics courses; employees of a large engineering company participating in an employee training event; daycare workers and managers; and an open web questionnaire.

The samples are detailed in Table 1.

Table 1. Number of participants by sample and subsample

Sample / *Subsample*	N	female	male
1.Students	459	182	263
Philosophy and Systems Thinking	*284*	*127*	*149*
Applied Mathematics	*175*	*55*	*114*
2.Daycare personnel and managers	463	449	14
Daycare personnel	*385*	*374*	*11*
Daycare managers	*78*	*75*	*3*
3. Company employees and managers	293	135	149
4. Students (following year)	500	224	268
5. Open questionnaire in English	345	173	162

Study 1: Development of the SI inventory factor structure

A list of SI-related items was iteratively worked down from an initial large set of phrases and questions that describe systems intelligent behavior. The list was refined in a series of small-scale tests, improving items that participants found too difficult, problematic, or ones that had very skewed answer distributions. This process resulted in a set of 76 pilot items.

Two data sets were created for developing the factor structure after pooling samples 1-3 together:

- A learning set (N=300), used for exploratory analysis, was formed by sampling 150 females and 150 males randomly among all participants.
- A validation set (N=815) consisted of the complete answers of the remaining participants and was used to validate the factorial validity of the inventory via confirmatory factor analysis.

Participants answered to the pilot items in Finnish with a 7-point Likert-type scale with the labels "never", "very seldom", "seldom", "sometimes", "often", "very often" and "always". In the analyses, the scale was converted to an integer scale of 0-6 respectively. The participants were allowed to leave answers to items empty. The questionnaires were administered over the internet. Participants did not get any compensation for completing the questionnaire.

Participants' SI factor scores were calculated as weighted averages of item responses, using the factor loadings from the confirmatory model.

Relationship between SI and Emotional Intelligence

The SI factor scores were associated with scores on Emotional Intelligence (Goleman, 1995; Salovey and Mayer, 1989) in a separate study with students (Sample 4 in Table 1). The participants answered 47 of the pilot items of the SI inventory in Finnish and the 33-item Schutte Self-Report Emotional Intelligence Test (Schutte et al., 1998), using a Finnish translation of the scale.

The sample size was 500. The participants were motivated by participation in a lottery where 30 winners received two movie tickets each. The questionnaire also provided the participants a summary page that described their relative strengths and weaknesses in SI.

Initial validation of the English language version of the inventory

In addition to the large-scale studies presented above, an English version of the inventory was provided as an open, but not actively publicized web questionnaire. The questionnaire was publicly available on a website, and people were referred to it in a number of public lectures and company training events. There were 345 participants (Sample 5 in Table 1).

Results

Factor structure

Eight of the pilot items were excluded from the analysis for highly skewed answer distributions or due to their low covariance with the rest of the items, and as such, the factor analysis was conducted with 68 items.

Exploratory factor analysis was applied to the learning dataset with the principal factors estimation method and oblimin rotation (allowing the factors to covary). The method does not entail distributional assumptions (Fabrigar et al., 1999), allowing for more robust discovery of factor structure even if some of the items don't follow multivariate normality. The analysis was conducted using the R programming language version 3.1.1 (R Core Team, 2014) and the 'psych' package (Revelle, 2014). Estimates for number of factors to retain ranged from seven provided by Horn's Parallel Analysis (Horn, 1965) to nine provided by Velicer's Minimum Average Partial method (Velicer, 1976). To better understand the factor structure, the Bass-Ackwards method (Goldberg, 2006) was applied to study how the structure develops when the number of latent factors is increased.

Based on the results of the Bass-Ackwards method, the seven-factor solution was found to have good content validity. In the nine factor solution, two factor splits were observed; one splitting attitude-related items to positively and negatively phrased factors, and another splitting interpersonal items to ones related to attuning to other people and ones related to actively changing the social system. The latter split was found to be relevant from a content perspective, and the factor structure was formed by combining the seven-factor solution with the interpersonal factor split to arrive at eight final SI factors.

To maintain good content validity and a balanced inventory, four items were selected to represent each factor in the final SI inventory. The resulting inventory thus has 32 items in total. The items and their factors are shown in Table 2.

Table 2. SI inventory factors and items

Factor	SI Item
Systemic Perception (PER)	1) I form a rich overall picture of situations 2) I easily grasp what is going on 3) I get a sense of what is essential to a given situation 4) I keep both the details and the big picture in mind
Attunement (ATTU)	5) I approach people with warmth and acceptance 6) I take into account what others think of the situation 7) I am fair and generous with people from all walks of life 8) I let other people have a voice
Attitude (ATD)	9) I explain away my mistakes 10) I have a positive outlook on the future 11) I easily complain about things 12) I let problems in my surroundings get me down
Spirited Discovery (DIS)	13) I like to play with new ideas 14) I look for new approaches 15) I like to try out new things 16) I act creatively
Reflection (REF)	17) I view things from many different perspectives 18) I pay attention to what drives my behavior 19) I think about the consequences of my actions 20) I make strong efforts to grow as a person
Wise Action (WIS)	21) I am willing to take advice 22) I take into account that achieving good results can take time 23) I am wise in my judgments 24) I keep my cool even when situations are not under control
Positive Engagement (ENG)	25) I contribute to the shared atmosphere in group situations 26) I praise people for their achievements 27) I'm good at alleviating tension in difficult situations 28) I bring out the best in others
Effective Responsiveness (EFF)	29) I prepare myself for situations to make things work 30) I easily give up when facing difficult problems 31) I'm able to put the first things first 32) When things don't work, I take action to fix them

Confirmatory analysis

Structural equation modeling (Bollen, 1989) was used evaluate the factorial validity of the resulting inventory. A first-order confirmatory factor analysis model, shown in Figure 1, was estimated with the R programming language ‘sem’ package (Fox et al., 2014) and a Generalized Least Squares fitting function. The fit of the model was evaluated with a two-index presentation strategy suggested by Hu and Bentler (Hu and Bentler, 1999), picking the Comparative Fit Index (CFI) and the root mean squared residual (SRMR) as the indices. In addition, the Root Mean Square Error of Approximation (RMSEA) was included.

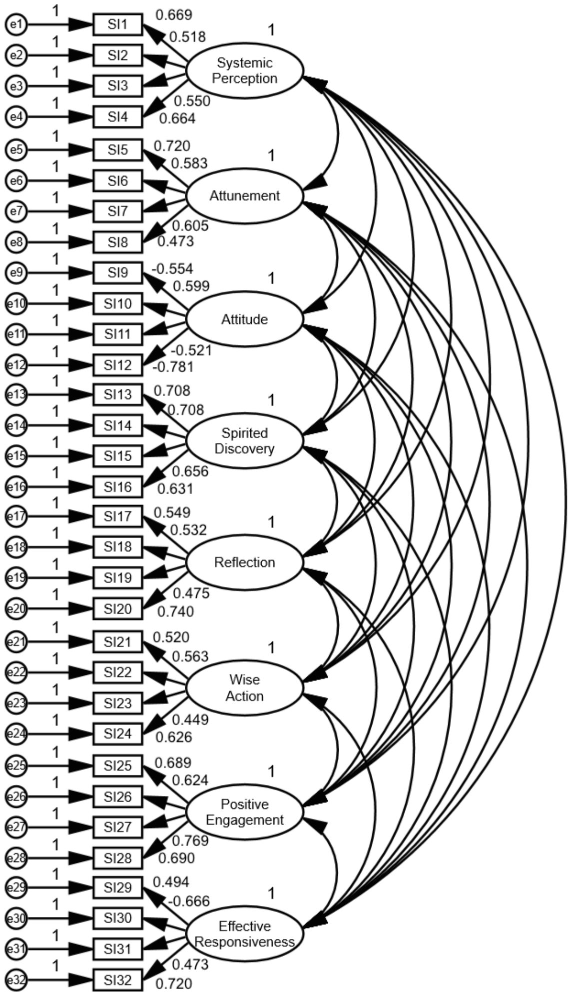

Figure 1. Eight-factor structural equation model of the SI Inventory, with calculated free-weight item loadings shown

With the 32 item loadings and variances and the 28 factor covariances set as free parameters, the model had a χ^2 value of 1257 with 436 degrees of freedom ($p < 0.001$). The fit indices were 0.951 for CFI, 0.068 for SRMR, and 0.048 for RMSEA. All three fit indices indicated good model fit, as they were below conventional cut-off values Hu and Bentler suggested for rejecting badly fitting models (i.e., CFI < 0.95, SRMR > 0.08 and RMSEA > 0.06).

Factor scores

Participants' SI factor scores were calculated as weighted averages of item responses, using factor loadings from the confirmatory model (see Figure 1). Table 3 shows the pairwise Pearson correlations and Cronbach's α internal consistency reliability coefficients for the factors as calculated by R's 'psych' package (Revelle, 2014). The table also includes pairwise correlations with Emotional Intelligence.

Table 3. Pairwise factor correlations for the SI factor scores and the Schutte Self-Report Emotional Intelligence Test. All correlations are statistically significant at level $p < 0.001$. Cronbach's α reliability coefficients are given on the diagonal in parentheses.

	Factor	PER	ATTU	ATD	DIS	REF	WIS	ENG	EFF
PER	Systemic Perception	(0.83)							
ATTU	Attunement	0.49	(0.78)						
ATD	Attitude	0.51	0.46	(0.67)					
DIS	Spirited Discovery	0.61	0.47	0.43	(0.80)				
REF	Reflection	0.58	0.53	0.35	0.57	(0.72)			
WIS	Wise Action	0.61	0.60	0.53	0.52	0.57	(0.64)		
ENG	Positive Engagement	0.55	0.60	0.46	0.58	0.49	0.45	(0.77)	
EFF	Effective Responsiveness	0.63	0.46	0.57	0.52	0.43	0.53	0.50	(0.70)
	Emotional Intelligence	0.54	0.54	0.48	0.46	0.53	0.49	0.67	0.45

The SI factor score correlations were quite high, with a range from 0.351 to 0.632. This is an expected result, as all the factors represented skills related to Systems Intelligence and the factor structure was developed allowing the factors to covary. Internal consistency reliability scores for the factors ranged from 0.64 (WIS) to 0.83 (PER).

The correlations with the Schutte Self-Report Emotional Intelligence Test scale were also high, with a range from 0.46 to 0.67. The most significant correlation (0.67) was between EI and SI Positive Engagement. EI and Positive Engagement correlate with other SI factors similarly, which further indicates that the two scales may be closely linked.

Initial validation of the English language version

With the English answer sample (Sample 5 in Table 1), a 'free weight' eight-factor model, identical to the model used in Study 1, had a χ^2 value of 740 ($p < 0.001$). Its fit indices were 0.968 for CFI, 0.085 for SRMR and 0.047 for RMSEA. Two of the three indices were below the conventional cut-off values, with SRMR being slightly higher than the suggested cutoff value of 0.08.

Group differences in SI factor scores

The Mann-Whitney *U*-test (Mann and Whitney, 1947) was used to study how groups of participants differ with respect to the SI factor scores. Score distributions were compared between males and females, students and people who are working, and employee level and supervisor level participants. For this analysis, all samples were combined to a single (N=2060) data set. The two-sided p-values and means for the groups are shown in Table 4.

Table 4. Two-sided Mann-Whitney U test p scores and means for compared groups

	PER	ATT	ATD	DIS	REF	WIS	ENG	EFF
Sex: p value	0.6915	***	0.035^{*}	0.262	***	0.008^{**}	***	***
Female mean (N=1163)	4.32	4.60	3.93	4.31	4.43	4.22	4.12	4.36
Male mean (N=856)	4.33	4.35	3.83	4.25	4.26	4.30	3.82	4.12
Career status: p value	***	***	***	***	***	***	***	***
At work mean (N=1304)	4.41	4.59	4.02	4.39	4.41	4.32	4.16	4.40
Student mean (N=653)	4.16	4.31	3.64	4.05	4.23	4.14	3.68	3.98
Supervisor status: p value	***	0.4479	0.013^{*}	***	0.004^{**}	0.003^{**}	***	***
Supervisor mean (N=193)	4.58	4.68	4.19	4.58	4.59	4.48	4.43	4.66
Employee mean (N=826)	4.39	4.65	4.04	4.38	4.41	4.34	4.17	4.42

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

There were statistically significant differences in all factor scores between people at work and students, with people at work receiving higher scores. Males and females had statistically significant differences in several of the factors, with females in general providing somewhat more elevated responses than males.

People in a supervisor/managerial position had a higher score than other people at work in most factors. The difference is statistically significant at level $p < 0.001$ in four of the factors, while there was no difference in Attitude scores. People in supervisor positions perceived themselves as better at perceiving and managing systems, more interested and open to new things, and better at engaging with other people in a positive way.

Summary

In today's world, people are increasingly faced with complex and systemic problems. Systems skills are becoming a key competence factor for everyone. Yet, the literature on tools to evaluate people's skills in thinking and acting successfully in systemic settings is very limited. Such tools would be most useful in particular in the development of the learning organization. This paper presents an inventory of 32 items (Table 2) to describe individual differences in SI with an eight-factor model. The factors are labeled Systemic Perception, Attunement, Attitude, Spirited Discovery, Reflection, Wise Action, Positive Engagement, and Effective Responsiveness. The SI factors identified with exploratory analysis are separate in content and are suggested to be representative of the SI concept. The resulting factor model had good factorial validity as judged by confirmatory factor analyses from samples independent from the exploratory factor analysis sample.

The SI Inventory has been designed to measure skills that are important for efficient behavior in systemic settings, rather than the personality of the participant, but it is possible that some personality traits have an effect on the SI skills. The SI factors correlate with Emotional Intelligence, with initial results suggesting that SI Positive Engagement and Emotional Intelligence are closely linked. In our data, people in a supervisor or managerial position scored higher than other people at work, especially in Systemic Perception, Spirited Discovery, Positive Engagement and Effective Responsiveness.

When the SI scale is used in organizational development and in particular in developing the skills needed in the learning organization, it may also be useful to think of the eight factors as belonging to the four general skill dimensions:

- **Perceiving Systems**: Systemic Perception and Attunement

- **Thinking About Systems**: Reflection and Wise Action
- **Systemic Attitude**: Attitude and Spirited Discovery
- **Action**: Positive Engagement and Effective Responsiveness

The SI inventory is available at http://www.systemsintelligence.info/test/. After answering the questionnaire one gets a summary of her SI skills.

A most interesting topic for future research is to study if the SI concept could be extended to describe organizations and teams. Could we talk about organizational systems intelligence? What would be the relationships between individual and organizational SI? Could the learning organization be such that it is able to perform on a higher SI level than the average or lowest scoring individuals in it? It would also be interesting to study if people are likely to perform differently in different contexts, for example, at home as opposed to their work environment. It would also be useful to study differences in the SI scores based on self-report vs. peer-evaluations.

We do believe that introducing the concept of Systems Intelligence to people as one of our generic skills can help us develop our strengths and find ways of "being better better" (Hämäläinen et al., 2014).

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QUANTITATIVE STUDY

WILEY

On the systems intelligence of a learning organization: Introducing a new measure

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Abstract

We introduce and validate the Organizational Systems Intelligence (OSI) scale, a measurement tool for learning organization, and propose the scale as a useful tool for human resource development (HRD) at the individual level. The scale complements the operationalization of Senge's "Five Disciplines" of the learning organization. OSI provides a new perspective that links employees' perceptions of various seemingly mundane everyday practices with the organizationally desirable effects of a learning organization. The model suggests developmental perspectives that highlight micro-level behavioral, informal, interactional, and accessible-to-all aspects of the learning organization as a route to improvement. Operating in the vernacular and focusing on human experience in organizations, the OSI perspective points to improvement possibilities in and among people in contrast to structural manager-level constructs. It contributes to HRD literature that explores developmental outcomes and theoretical understanding from human experience in contrast to rank, status, structure, or hierarchy. With its bottom-up logic as an operationalization of the Sengean learning organization as a form of applied systems thinking, the model introduces an employee-level perspective of systems thinking in action into the field of HRD. It is demonstrated that with respect to perceived performance, the OSI scale performs equally well as the widely used Dimensions of the Learning Organization Questionnaire.

KEYWORDS
competencies/competency, human resource capacity building, learning organization, organizational change and development, organizational performance

1 | INTRODUCTION

Peter Senge's *The Fifth Discipline: The Art and Science of the Learning Organization* (1990), with its lucid prose, concrete examples, and 2 million copies sold, is arguably the most influential presentation of applied systems thinking in the context of leading, developing, and managing organizations. Defining the learning organization as "organizations where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspirations are set free, and where people are continually learning to see the whole together" (1990, p. 3), Senge stressed learning as an essential goal on the way to success.

In the vast literature following Senge's groundbreaking volume, the academic focus has been around the concept of learning as a value in itself, often at the expense of questions of how systems thinking might evolve within organizations, how learning would emerge from the behaviors of people, and how the learning within the organization is linked to performance. In their recent overview of the literature from the point of view of human resource development (HRD) implications, Watkins and Kim (2018) agree that more work is indeed needed "to begin to link specific learning organization strategies to enhanced organizational outcomes" (p. 25).

We propose a new measurement tool that contributes to the understanding of the learning organization by going back to Senge's original vision. Our guiding idea is to enrich the discourse of the learning organization by providing an employee-focused perspective of the learning organization as an intelligent system that successfully finds ways to adapt to its changing environment.

Along with Senge, we approach learning as a phenomenon that serves a purpose rather than as a goal per se. Importantly, we work toward the understanding of the learning organization as a platform for development by using concepts that do not explicitly refer to learning. We thus strongly depart from research that seeks to uncover the "learning organization" by referring to constructs that allude to "learning." The focus will thus not be on structural organizational entities but on the individual, interpersonal and "felt" cultural dimensions of the everyday that employees perceive and influence. In so doing, we shall not focus upon the various constructs that might relate to learning processes, such as leadership guidance and support for learning, discussed for instance by Edmondson et al. (2019), but rather highlight especially Senge's "Personal Mastery," one of the five disciplines and famously emphasized by Senge himself as primary, as foundational to our tool.

While building on Senge, we also pick up motivation for our undertaking from the early empirically grounded book-length works of Watkins and Marsick where they emphasized the role and significance of "informal and incidental learning" (Marsick & Watkins, 1990; Watkins & Marsick, 1993). This is a theme often by-passed in subsequent research on learning organization that has recently picked up the interest of scholars (Decius et al., 2019); see also Nurmala (2014). Furthermore, we seek to address the challenge of Watkins and Dirani (2013) when they called upon researchers to prescribe simple steps to becoming learning organizations and to accumulate evidence of what works. We believe our people-centered, bottom-up suggestions, expressed in a vernacular vocabulary and with an emphasis on the everyday, will "accumulate evidence of what works to create organizations with an enhanced capacity to learn" (Watkins & Kim, 2018, p. 18). We will focus on the mundane reality of people as a route to illuminate potential HRD practices that seek to help employees self-improve and contribute for the benefit of a learning organization.

We shall first seek to articulate the people-centric, bottom-up view of the learning organization by bringing the concept of Systems Intelligence to bear on the theme and develop a new scale for the learning organization that is based on that concept of Hämäläinen and Saarinen (Hämäläinen & Saarinen, 2006; Saarinen & Hämäläinen, 2004). We then take the most commonly used, researched, validated, and practice-informed operationalization of the learning organization, the Dimensions of the Learning Organization Questionnaire (DLOQ) scale of Watkins and Marsick (1993), compare it with a new measure for the learning organization, and demonstrate with empirical evidence that the two scales are closely correlated and work equally well when measured against the parameter of perceived performance. A theoretical and practical discussion of the merits of the proposed OSI scale as a framework for HRD will then follow.

2 | STATEMENT OF THE PROBLEM

The literature on the learning organization is "fraught with conceptual and definitional confusion" (Watkins & Kim, 2018). A host of definitions and operationalizations to "the learning organization" has been presented (S. C. Goh, 2019). While the core construct remains "elusive" (Friedman et al., 2005), it is actively in use as well as promising in its practical and theoretical implications (Hoe, 2019). For HRD, as Chalofsky put in his introduction to the *Handbook of Human Resource Development*, "research and development around the concepts of the learning organization and organizational learning" is a focal point (Chalofsky, 2014).

In their extensive meta-analysis of DLOQ-based research, Song et al. (2013) note that more than 80% of the research studies they reviewed positioned the DLOQ as an input factor. As a result, "there are clear research opportunities to consider alternate positions of the DLOQ. In other words, understanding what factors cause or promote learning cultures would seem equally valuable." They call out for more theoretical justification prior to the empirical research using DLOQ (Song et al., 2013, p. 226).

One such source, Song et al. note, could be Senge's groundbreaking original work in *The Fifth Discipline*. "Senge's (1990) perspective would inform us that systems thinking, personal mastery, mental models, building shared vision, and team learning are the building blocks of any learning organization. It is less clear how any of these elements are most successfully practiced, and more importantly what brings them all together in a systematic way." We believe a return to the roots is indeed in order, particularly for researchers and practitioners of the learning organization with an HRD leaning.

Many of the items presented in the DLOQ use complex managerial language, and often can be challenging to answer for employees on lower levels of the organization. Hasson et al. (2013) have noted that when DLOQ is applied in HRD, managers' perceptions do not necessarily correspond with subordinates' perceptions and suggest that closing this perceptual gap could have a positive effect on employee performance and health. When it comes to the series of questions that consider the knowledge and financial performance of the organization, Marsick and Watkins themselves also note that "often, only middle- and higher-level managers are comfortable answering the performance questions" (Marsick & Watkins, 2003, p. 138).

We pick up from these well-perceived challenges, gaps in research and identified possibilities in order to present a Sengean scale for the learning organization as based on the concept of Systems Intelligence.

3 | SYSTEMS INTELLIGENCE

While Senge's *Fifth Discipline* has been hailed as "almost synonymous with the idea of learning organization" (A. Örtenblad, 2018), the research literature on the learning organization typically builds only on some selected aspects of Senge's vision.

Marsick and Watkins do list "Team Learning," one of Senge's five disciplines, among the seven core "dimensions" of the learning organization, along with "Dialogue and Inquiry" (discussed by Senge and associates in *The Fifth Discipline Fieldbook* [1994]). Senge's constructs "Personal Mastery, "Mental Models," and "Systems Thinking," three out of five, are not addressed as cornerstones of a learning organization, nor is the interplay of the five disciplines. The extant literature of the seven dimensions of the DLOQ (Continuous Learning, Inquiry and Dialogue, Team Learning, Embedded Systems, Empowerment, System Connections, and Leadership) is rich and enlightening, yet remains aloof from Senge's five disciplines. Our key idea is to bridge this gap through the key concept of Systems Intelligence, which integrates Senge's five disciplines.

Systems Intelligence (SI) as a framework draws from Senge's *Fifth Discipline* and the systems sciences (Hämäläinen & Saarinen, 2006; Saarinen & Hämäläinen, 2004). It has been applied to a number of domains including organizational development (Hämäläinen & Saarinen, 2006, 2008; Luoma et al., 2008, 2011), knowledge management (Sasaki, 2017), personal growth (Hämäläinen et al., 2014; Saarinen & Lehti, 2014; Saarinen 2015), therapy discourse (Martela & Saarinen, 2013), engineering education (Hämäläinen et al., 2018; Lappalainen, 2017; Lappalainen et al., 2020), and design thinking (Harviainen et al., 2021; Jumisko-Pyykkö et al., 2021). An approach for the improvement of organizational behavior by an agent-based simulator that uses ideas from SI and positive organizational theory has been suggested by Tiinanen et al. (2016), while Hämäläinen et al. (2020) discuss practical results from using SI-based design games as a way to support teams in early childhood education organizations.

Intuitively, the idea of Systems Intelligence is to capture the phenomenon of succeeding within evolving wholes (conceptualized as "systems"). As a construct intended to do justice to the human endowment for acting and growing from within systems, powerfully witnessed already in infants (Beebe & Lachmann, 2002), SI was originally defined by Saarinen and Hämäläinen (2004, p. 3) as:

> *[…] intelligent behavior in the context of complex systems involving interaction and feedback. A subject acting with Systems Intelligence engages successfully and productively with the holistic feedback mechanisms of her environment. She perceives herself as a part of a whole, the influence of the whole upon herself as well as her own influence upon the whole. By observing her own interdependence in the feedback intensive environment, she is able to act intelligently.*

SI has been operationalized on the individual level, validating the Systems Intelligence Inventory as a self-assessment tool (Törmänen et al., 2016). Taking that earlier work as a point of departure, we believe that the Systems Intelligence perspective, when brought to bear *on one's organization*, yields fresh insight into the functioning of the learning organization. Implicit here is the assumption that whatever a learning organization might ultimately be, we assume that at least a learning organization would have to be an entity that succeeds within wholes that are emergent, in the process of becoming and not yet fixed. Measuring such an entity from within and while operating on the level of an individual is the aim of our Organizational Systems Intelligence (OSI) scale.

4 | OSI SCALE

4.1 | Development of the scale inventory

The original Systems Intelligence Inventory was introduced and validated by Törmänen et al. (2016). The inventory, developed using a combination of exploratory and confirmatory factor analysis, consists of 32 items describing systems intelligent behavior of an individual. The eight factors that emerged were later proposed both shorter and longer definitions (Hämäläinen et al., 2014, p. 19, 2018).

The OSI scale that we here introduce has been created by rephrasing the 32 items of the original Systems Intelligence Inventory to address the organization of the individual by inserting the phrase "In my organization" to the wording of each item. Two pilot studies were used to test the wordings and make small adjustments to their legibility. The final version of the 32-item OSI scale inventory is shown in Table A1. Some examples of the items are:

- "In my organization, people approach each other with warmth and acceptance."
- "In my organization, people like to play with new ideas."
- "In my organization, people are willing to take advice."
- "In my organization, when things don't work, people take action to fix them."

Notice that while introducing the phrase "In my organization," the inventory consciously sticks to what Marsick and Watkins call "individual level," as opposed to what they call "team or group" and "organization" levels. With OSI, the respondent does not evaluate how "my team" or "my organization" operates as a separate entity, but only addresses by vernacular language what takes place "in my organization" among people. There is a very strong mundane, everyday focus to the items of measurement that essentially draws from the experience of the people and from their perceptions of their organization. The organization is evaluated without reference to semi-theoretical constructs or structural entities, the evaluation of which would call for in-depth knowledge about the management processes of the organization. To further highlight the difference between the measurement tools, Table 1 presents the eight factors of Systems Intelligence as described by Hämäläinen et al. (2014), and Table 2 the seven Dimensions of the Learning Organization as described by Marsick and Watkins (2003). The factors clearly refer to different levels of organizational structure and experience.

In the questionnaire used for the empirical part of this study, the OSI scale and the 43-item 7-dimension DLOQ scale (Marsick & Watkins, 2003) were combined and the order of items randomized. Altogether, the combined inventory consisted of 75 questions. All of the items were evaluated on a six-point Likert scale from "Almost never" to "Almost always," following the convention of previous DLOQ questionnaires.

In order to secure an additional point of evaluation for the benefit of comparing the OSI and DLOQ scales, we asked the participants to evaluate how successful they feel their organization is in its field. We chose to ask this with a direct question, evaluated on a 11-point scale, using the wording: "On a scale from 0 to 10, how successful is your organization in its field?" with answer 0 labeled as "Very bad," 5 as "Average," and 10 as "Excellent." This question was asked with a 11-point scale, compared to the six-point scale for DLOQ and OSI, as its answers were used directly in the analysis, instead of as part of a weighted average, and we believed it best to retain more detail in the answer distribution.

4.2 | Data

As our interest was to validate the OSI scale as a tool that is widely accessible and applicable in various contexts, we wanted to approach a wide population of people in work life for our data collection. Accordingly, we decided to

TABLE 1 Descriptions of the factors of Systems Intelligence (Hämäläinen et al., 2014)

1. *Systemic Perception* Our ability to see the systems around us	2. *Attunement* The capability we have to feel and tune into systems
3. *Attitude* Our overall approach to life in systems	4. *Spirited Discovery* Passionate engagement with new ideas
5. *Reflection* Our capacity to reflect on our thoughts and think about our thinking	6. *Wise Action* Our ability to behave with understanding and a long time horizon
7. *Positive Engagement* The character of our communicative interactions	8. *Effective Responsiveness* Our talent at taking timely, appropriate actions

TABLE 2 Descriptions of the Dimensions of the Learning Organization Questionnaire (Marsick & Watkins, 2003)

1. *Create continuous learning opportunities* Learning is designed into work so that people can learn on the job; opportunities are provided for ongoing education and growth	2. *Promote inquiry and dialogue* People gain productive reasoning skills to express their views and the capacity to listen and inquire into the views of others; the culture is changed to support questioning, feedback, and experimentation
3. *Encourage collaboration and team learning* Work is designed to use groups to access different modes of thinking; groups are expected to learn together and work together; collaboration is valued by the culture and rewarded	4. *Create systems to capture and share learning* Both high- and low-technology systems to share learning are created and integrated with work; access is provided; systems are maintained
5. *Empower people toward a collective vision* People are involved in setting, owning, and implementing a joint vision; responsibility is distributed close to decision making so that people are motivated to learn toward what they are held accountable to do	6. *Connect the organization to its environment* People are helped to see the effect of their work on the entire enterprise; people scan the environment and use information to adjust work practices; the organization is linked to its communities
7. *Provide strategic leadership for learning* Leaders model, champion, and support learning; leadership uses learning strategically for business results	

perform the validation of the OSI scale with a large crowdsourced data set, rather than limit the analysis to a sample of only a limited number of organizations. We gathered answers with the Prolific.ac platform from people residing in the United Kingdom or the United States, and who were employed full-time and at last 25 years of age. The participants were compensated for filling out the questionnaire with a 2.00 £ reward. Participants failing to correctly answer two attention check questions requiring the selection of a specific answer, and participants who had spent less than 2 min answering the questionnaire, were removed from the data set. Missing answers were only allowed for background questions.

The resulting data set consists of the answers of 470 people. Statistics for the data are shown in Table 3. The data gathering strategy produced a balanced distribution of males and females, and in addition the data set has close to equal number of residents from the United Kingdom and United States.

5 | RESULTS

5.1 | Model validation

The OSI items are rephrasings of the original SI inventory items. To enable easy use of the OSI scale and the original individual-level inventory together, we thought it would be useful for the OSI to share the factor structure with the SI inventory; this would, for example, allow discussing both the Wise Action of each individual assessing themselves (SI inventory), and the Wise Action of the people in the organization in general (OSI scale inventory). Thus, we decided to use the exact same 8-factor, 4-items-per-factor structure for the OSI items, rather than using exploratory methods to identify a new factor structure. Assuming that the model performs well based on conventional confirmatory factor analysis fit statistics, such as those suggested by Hu and Bentler (1999), the SI factor structure can be retained for the OSI scale.

We applied a first-order model with 32 items loadings on eight OSI factors to the OSI data using structural equation modeling (Bollen, 1989). The model was estimated with the R programming language "sem" package version

TABLE 3 Data statistics

	N	%
Total	470	
Gender		
Male	236	50
Female	233	50
Country of residence		
United Kingdom	255	54
United States	216	46
Age		
Under 40	341	73
40 or older	129	27
Position		
Senior or middle manager	115	24
Supervisor	79	17
Non-managerial	277	59

TABLE 4 Model fit statistics for various models of Organizational Systems Intelligence (OSI) and Dimensions of the Learning Organization Questionnaire (DLOQ)

Model	χ2	*df*	χ2/*df*	CFI	RMSEA	SRMR	Δχ2	Δ*df*	*p*-value
1-factor OSI	900.9	464	1.94	0.979	0.045	0.059	114.6	28	<0.001
8-factor OSI	786.3	436	1.80	0.983	0.041	0.055			
1-factor DLOQ (43 items)	1749.3	860	2.03	0.979	0.047	0.061	67,3	21	<0.001
7-factor DLOQ (43 items)	1682.0	839	2,00	0.980	0.046	0.064			
1-factor short DLOQ (21 items)	512.2	189	2,71	0.975	0.060	0.055	84,6	21	<0.001
7-factor short DLOQ (21 items)	427.6	168	2,55	0.980	0.057	0.051			

3.1–11 (Fox et al., 2020) with a generalized least squares fitting function. The fit of the model was evaluated using three commonly used model fit indices: the root mean squared residual (SRMR), the root mean square error of approximation (RMSEA), and the comparative fit index (CFI). We also ran the analysis for the 43-item full DLOQ scale, and the more commonly used 21-item shortened DLOQ scale that is often used in applications of the DLOQ (Marsick & Watkins, 2003; Yang, 2003).

Table 4 includes the χ2 test statistics, model fit statistics, and χ2 difference tests for the OSI and DLOQ models, in addition to comparing them with single-factor versions of the same models. Both DLOQ models and the OSI model fit statistics indicated a good model fit using the conventional cut-off ranges suggested by Hu and Bentler (1999). The multi-factor versions of each model performed statistically significantly better than the single-factor models ($p < 0.001$ in each case).

These results indicate that the OSI scale has good construct validity when using the SI inventory factors introduced in Törmänen et al. (2016). OSI can be described by eight separate and correlated OSI factors that give rise to "organizational systems intelligence capability." Our results on the DLOQ are in line with recent DLOQ validation studies (Chai & Dirani, 2018; Kortsch & Kauffeld, 2019).

5.2 | Factor scores

OSI scores for the eight factors were calculated as weighted averages of item responses, using factor loadings from the CFA model. DLOQ factor scores were calculated as simple averages, as given by Marsick and Watkins (2003). Table 5 shows the factor score means and intercorrelations for the OSI factors, and Table 6 the means and intercorrelations for the DLOQ factors, both calculated with the R programming language version 4.0.2 (R Core Team, 2020). Both tables also present the Cronbach alpha reliability estimates for the factors, as calculated by the R "pysch" package version 1.9.12 (Revelle, 2020). The Cronbach alpha values for the DLOQ factors and six of the OSI factors were over 0.8, indicating good reliability. The alpha values for OSI Effective Responsiveness (0.73) and Attitude (0.68) were somewhat lower, indicating that these two factors have somewhat lower reliability.

The correlations were very high and statistically significant ($p < 0.001$), indicating that the factors are closely related to each other and share a significant amount of variation. For factors of DLOQ, this seems to be typical; Yang et al. (2004) reported high DLOQ correlations in their validation of the DLOQ questionnaire, and the DLOQ factor means are close to typical values presented by Marsick and Watkins (2003). The results are also in line with the undergoing discussion about high multicollinearity and possible lack of discriminant validity for the DLOQ, as discussed by Kim et al. (2015).

5.3 | Correlation between OSI and DLOQ

Table 7 shows the cross-correlation table for the DLOQ and OSI factors. Many of the correlations are 0.71 or higher, indicating that a linear regression model between the two factors would explain over 50% of the variation (Devore, 2012, p. 510). Thus, it can be assumed that the DLOQ and OSI scales measure, or at least are related to, the same characteristics of the organization. The highest correlations can be found between the individual- and team-level DLOQ factors (Continuous Learning, Inquiry and Dialogue, Team Learning) and OSI factors (Attunement, Positive Engagement, Systemic Perception, Wise Action and Reflection). The correlations were somewhat lower for OSI's attitude and action-oriented factors (Attitude, Spirited Discovery, Effective Responsiveness).

In many cases, the high correlations are as could be expected; for example, the DLOQ dimension of Inquiry and Dialogue and the OSI dimension of Positive Engagement have similarities in content in their item-level formulations. DLOQ explicitly allocates 13 of its 43 items to what it calls "Individual level" and the dimensions not correlating well would signal problems.

We stress the fact that the cross-correlations between DLOQ and OSI are high even if the scales are essentially different. Their theoretical base is different as DLOQ builds on the seven "core dimensions of the learning organization" of Marsick and Watkins, while OSI works from Senge's "five disciplines of the learning organization," as integrated as Systems Intelligence. Even more importantly, the vocabulary that DLOQ and OSI use differ dramatically.

While "Individual level" is present in DLOQ, the main focus of DLOQ (30 out of 43 items) is on teams/groups and the organizational level. With items such as "In my organization teams/groups have the freedom to adopt their goals as needed" (item no. 14), "My organization uses two-way communication on a regular basis, such as suggestion systems, electronic bulletin boards, or town hall/open meetings" (item no. 20), and "In my organization leaders ensure that the organization's actions are consistent with its values" (item no. 43), DLOQ places agency on a team, group, organization or leader. In OSI, in contrast, each of the 32 items evaluates what people are doing "in my organization."

5.4 | Factor scores and perceived organizational performance

HRD seeks to "foster a climate where growth and development of humans in workplaces is addressed holistically and from multiple perspectives" (Werner, 2014, p. 128). This is done for the benefit of performance. Thus "the

TABLE 5 Organizational Systems Intelligence factor means, correlations, and Cronbach alpha values

	Mean	Systemic Perception	Attunement	Attitude	Spirited Discovery	Reflection	Wise Action	Positive Engagement	Effective Responsiveness
Systemic Perception	4.12	(0.81)							
Attunement	4.26	0.81	(0.83)						
Attitude	3.46	0.63	0.65	(0.68)					
Spirited Discovery	3.96	0.72	0.71	0.53	(0.87)				
Reflection	3.98	0.80	0.77	0.61	0.76	(0.82)			
Wise Action	4.13	0.81	0.80	0.67	0.68	0.77	(0.81)		
Positive Engagement	4.12	0.80	0.81	0.61	0.71	0.80	0.79	(0.81)	
Effective Responsiveness	4.19	0.79	0.74	0.61	0.66	0.74	0.75	0.75	(0.73)

Note: All correlation coefficients are statistically significant at level $p < 0.001$.

TABLE 6 Dimensions of the Learning Organization Questionnaire factor means, correlations, and Cronbach alpha values

	Mean	Continuous Learning	Inquiry and Dialogue	Team Learning	Embedded system	Empowerment	System Connection	Provide Leadership
Continuous Learning	3.92	(0.88)						
Inquiry and Dialogue	4.06	0.82	(0.86)					
Team Learning	3.95	0.84	0.88	(0.87)				
Embedded System	3.80	0.78	0.70	0.75	(0.82)			
Empowerment	3.82	0.85	0.81	0.87	0.73	(0.87)		
System Connection	3.98	0.82	0.81	0.83	0.72	0.81	(0.81)	
Provide Leadership	4.01	0.84	0.81	0.84	0.79	0.83	0.81	(0.89)

Note: All correlation coefficients are statistically significant at level $p < 0.001$.

TABLE 7 Organizational Systems Intelligence (OSI) and Dimensions of the Learning Organization Questionnaire (DLOQ) cross-correlations

	Systemic Perception	Attunement	Attitude	Spirited Discovery	Reflection	Wise Action	Positive Engagement	Effective Responsiveness
Continuous Learning	0.79	0.75	0.64	0.77	0.82	0.77	0.80	0.74
Inquiry and Dialogue	0.83	0.86	0.66	0.73	0.82	0.82	0.86	0.76
Team Learning	0.82	0.83	0.69	0.75	0.82	0.80	0.83	0.77
Embedded System	0.73	0.64	0.53	0.65	0.73	0.67	0.70	0.66
Empowerment	0.78	0.77	0.62	0.79	0.81	0.77	0.78	0.73
System Connection	0.80	0.77	0.61	0.70	0.76	0.74	0.78	0.73
Provide Leadership	0.77	0.76	0.63	0.71	0.78	0.74	0.79	0.71

Note: All correlation coefficients are statistically significant at level $p < 0.001$.

learning" of the "learning organization" is not an end in itself. The organization serves a purpose that is intended to benefit from learning. Reflecting this fundamental aspect of organizations, we chose to enrich our analysis of the two scores by asking the respondents also to evaluate their organizations from the point of view of the outcome indicator, "How successful is your organization in its field?"

We studied the relationship between the two instruments by having DLOQ and OSI factors explain perceived organizational success with linear regression models and comparing the share of variation explained by the regression model (based on the coefficient of determination, R^2). Table 8 presents these values for different subsets of the answer data and for three different regression models—one consisting of the seven DLOQ factors, one consisting of the eight OSI factors, and one consisting of the combination of both.

Differences between the two tools were small. DLOQ factor scores had a slightly higher share of explained variation values than OSI, with DLOQ explaining 35% of the variation and OSI 32% of the variation of perceived organizational success. Partial correlations calculated from the combined 15 factor model indicated that only one of the factors, the DLOQ Providing Strategic Leadership for Learning, was statistically significantly distinct from the other factors when taking Bonferroni correction into account. This observation is not surprising, as the factor refers to structural artifacts primarily accessible to managers as opposed to people in the ranks who will not be in a position to influence the items in question.

In our data, people in supervisor roles or non-managerial positions had noticeably higher share of explained variation than people in middle- or senior-level managerial positions. There may be a difference in how organizational success is being perceived depending on the participant. For instance, higher-level managers are likely to be more aware of quantitative metrics of the performance of their organization and are primed to answer with those metrics in mind.

5.5 | OSI and DLOQ in top performing versus lower performing organizations

The participants assessed the performance of their organizations by answering how successful they perceive their organization to be, compared to other organizations in the same field. Using these answers, we can study perceived

TABLE 8 Share of variation explained by different regression models of perceived organizational performance

	N	DLOQ (7 factors) (%)	OSI (8 factors) (%)	Combined (15 factors) (%)
All	471	**35**	32	36
Mid or senior managers	115	**21**	19	23
Supervisors	79	43	**44**	53
Non-managers	277	**40**	36	42
U.K. residents	255	**35**	32	38
U.S. residents	216	**37**	32	39
Retail and sales	52	**45**	37	53
Manufacturing and construction	38	**52**	49	58
Education and research	75	28	**31**	37
Finance, insurance and real estate	35	30	**40**	64
Health care	63	**40**	32	47
Government or public services	37	70	**73**	83
Information technology	56	**36**	15	40
Other services	51	59	**66**	70

Note: Percentages calculated from the coefficient of determination (R^2 value) of the multivariate linear regression model.

organizational performance from the point of view of OSI and DLOQ scores. The hypothesis here is that the stronger an organization is as a learning organization, the stronger is also its success as perceived by its people. For the purposes of our analysis, we singled up organizations that were ranked "top" as compared to "lower performing," according to the evaluation given by the participants in the data. For an organization to qualify as "top" it needed to be rated 10 by the participant. If an organization was scored 0–8, it was classified as "lower performing." In the data, there were 52 organizations that were considered "top" and 340 that were "lower" (79 organizations were rated 9). As described later, the answer distributions of the most successful organizations are overlaid on top of the answer distributions from less successful organizations. Figure 1 shows the distributions for the eight OSI dimensions and Figure 2 for the seven DLOQ dimensions.

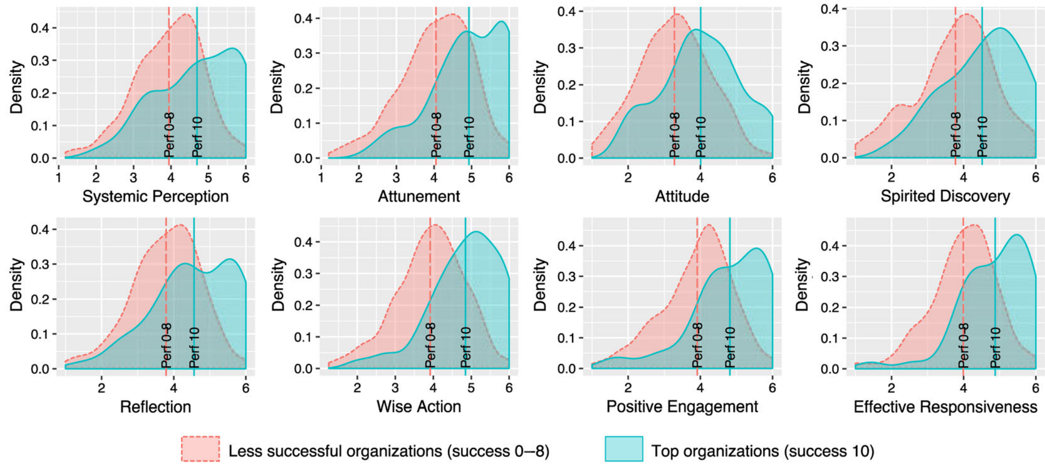

FIGURE 1 Score distributions for the eight Organizational Systems Intelligence factors for top organizations ($N = 52$) and less successful organizations ($N = 340$). Vertical lines indicate averages and areas indicate smoothed answer distributions for both groups

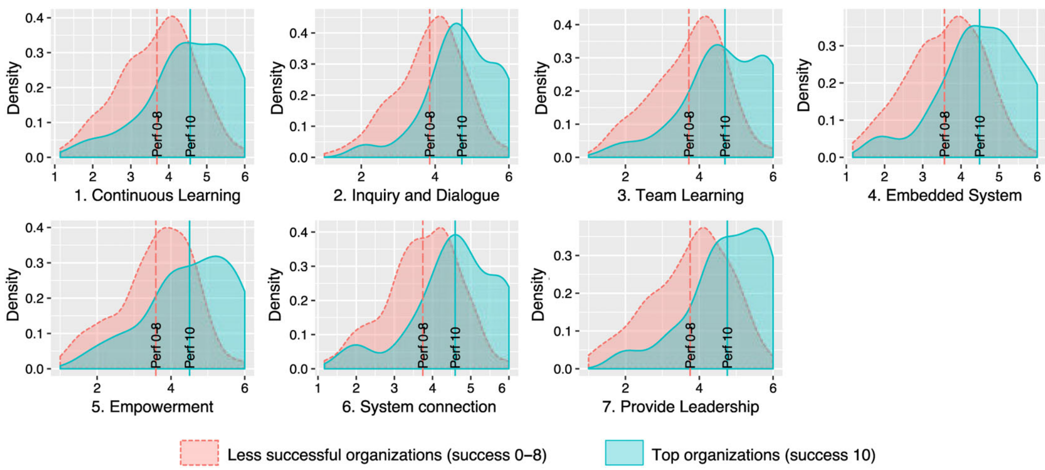

FIGURE 2 Score distributions for the seven Dimensions of the Learning Organization Questionnaire factors for top organizations ($N = 52$) and less successful organizations ($N = 340$). Vertical lines indicate averages and areas indicate smoothed answer distributions for both groups

The data shows that the top organizations score significantly higher in all the factors of both OSI and DLOQ as compared to lower performing organizations. Importantly, the diagrams help to identify points of potential development. To wit, for OSI Systemic Perception and Effective Responsiveness, as well as for DLOQ Provide Strategic Leadership for Learning, the peak of the distribution for high-performing organizations is very close to the maximum score. Having one's organization score in the lower end of the distribution in any of these three factors would signal a clear call for intervention.

6 | DISCUSSION

A pivotal feature of the OSI scale is that it focuses on individuals and only talks about "people" "in my organization." In particular, OSI does not allude to "learning" or organizational structures that might involve "learning." Importantly, the OSI items do not talk about the agency or the functioning of structures only managers could credibly evaluate or influence. We view this as a major advantage of the "serviceability" (Burke, 1984) of our proposal and a key reason for the benefits of the proposed scale for HRD. The communicative applicability of the OSI scale with its generally accessible language suggests broad possibilities for improving performance in an organization from the bottom up. Our perspective joins in the "Copernican turn" described by Rigby and Ryan (2018), where the focus of developing human resources is shifted from institutions to individuals. With this "unprecedented shift of power from institutions to individuals," workplace dynamics are perceived through people and their experience instead of external contingencies and from-without structures.

This shift toward individuals is paramount for HRD professionals that "endeavor to provide learning opportunities that nurture human experience in organizations" (Shuck et al., 2014). Some of the most intriguing issues for scholars and practitioners of HRD concern the gap between the offerings of an organization and the employees' perception of those offering.

Since the groundbreaking work by scholars such as Lee and Bruvold (2003), notions like "perceived investment in employee development" have been recognized as fundamental for HRD, but the employee experience and perception is a slippery slope on which systems are hard to build. In their important study of employee engagement, turnover intentions, and HRD practices, Shuck et al. (2014) bring to focus the generic theme that "for some employees, they can feel unsupported at times or perceive there is little investment from organization for their participation in HRD-related practices" (p. 214). There is need for ways to capture the perception of employees as the entry point for insights into HRD-relevant learning organization processes and constructs.

In the current context of the learning organization, the focus on individuals is theoretically justified in view of Senge's discipline of Personal Mastery, strongly stressed in his original discussion but by-passed in subsequent literature. Senge systematically stresses Personal Mastery as the most important of the five disciplines (Reese, 2020), while also acknowledging its neglect in practice. Personal Mastery applies to everyone in an organization irrespective of her position. If a scale for the learning organization is supposed to work in real life, and if we assume Personal Mastery is one cornerstone of the learning organization, then surely it would be beneficial if a scale for the construct talked about generic human phenomena that anyone can perceive and improve upon. When the relevant developmental possibilities are identified with a vocabulary that does not refer to organizational policies, strategies, or other high-level constructs but maintains the focus on what people themselves can experience, implementation is likely to be more forthcoming. The proposed OSI scale does seem to fill this important criterion for a bottom-up development and increased self-regulation for the benefit of the whole.

There is one intriguing level on which our Sengean perspective strikes a chord with one important original observation of Marsick and Watkins: "Our views of organizational learning began with a mutual observation that significant learning, even transformative learning, was usually *the least structured*." (Marsick & Watkins, 2003, p. 134, italics added). Perhaps organizational structure has less to say than sometimes is assumed in the literature on learning organizations? As Watkins and Kim (2018) put it in envisioning "emerging areas of research," "the role of informal learning in creating a learning culture" looms large (p. 21). We suggest the informal, incidental, and inter-relational human features of people in an organization, as identified by our OSI scale, point to the micro-level cells and molecules from which the organisms of "learning" emerge.

From the point of HRD, the significance of informal learning, along with on-the-job learning, generally acknowledged as highly contributive for the organizational performance, points to what Chalofsky labeled the "humanistic perspective" inherent in HRD that "emphasizes inner growth that is realized through interaction of self, context, and life experiences" and "a holistic approach to human development … [that] recognizes the need to develop the whole person" (Chalofsky, 2014, p. xlv). As Dirkx and Deems put it, what is called for is "an ecological approach to work" that integrates the psychological and the organizational, and views "the 'inner life' as intimately and deeply connected to and embedded within an outer life" (Dirkx & Deems, 1996, p. 276). We suggest that our OSI score strikes new ground to these important effects, with a potential to enrich the discussion that pertains on such deeply human issues as the "incivility" of people (Reio & Ghosh, 2009) that point to cultural factors beyond the structural and managerial while emphasizing what Senge called a key characteristic of the learning organization: "an intense appreciation of interrelationships" (Senge, 1993, p. 5).

7 | IMPLICATIONS FOR THEORY

In his recent comprehensive meta-article of the scores previous to OSI, Goh points out that "the identified dimensions are very similar" in DLOQ and in the other leading scales such as OLS of Goh and Richards (1997), LOM of Sinkula et al. (1997), and OLC of Jerez-Gómez et al. (2005). In the light of the results reported here, the conclusion of the "diminishing returns in the development of new scales to measure the LO construct" is clearly premature.

Instead of being conceptualized as the function of organizational structures, the OSI scale depicts the learning organization as emerging from behaviors and aspirations of people in the everyday of their work, in a way that can be perceived by people themselves. Rather than focusing on abstract processes or structures, the bottom-up perspective of the OSI presents "learning as an activity of interdependent people," using the apt phrase of Ralph Stacey (2003), suggesting theoretically that the contrast between relationality-focused approaches such as Stacey's "complex responses processes" and the "systems" approach such as Senge's is not as sharp as sometimes has been suggested (see also Luoma et al., 2011). Given that no structures of formal learning are alluded to by the items of the OSI, the phenomenon measured seems to fulfill Eraut's criterion for informal learning as something that "takes place in a much wider variety of settings than formal education or training" (Eraut, 2004). We also recall Senge's often bypassed distaste for formal learning to be in line with the current emphasis. As Senge blatantly puts it, "learning is learning, and it has nothing to do with school" (Reese, 2020, p. 9). Theoretically, to the extent the OSI scale does capture an important aggregate phenomenon on the level of the organization, it opens the door for the possibility that employees are more perceptive in their everyday of crucial organizational phenomena than typically is assumed in top-bottom excel-based evaluations of the functioning of the complex whole.

In effect, our OSI perspective tries to deal with important organizational phenomena as emergent, and as reflected on the employee perception level—from within and from bottom-up, as opposed to from without and top-to-bottom. This suggests the theoretical question as to how far essential HRD phenomena can be described without reference to abstract, managerial structures, as opposed to variables that build from the more subjective side of the human experience and intentionality. Minimally, such a perspective is needed as an integral part of the HRD systems story. We are reminded of the question by the grand old man of the systems thinking movement R.L Ackoff, who blatantly asked, with some frustration and characteristic clarity, "Why few organizations adopt systems thinking?" (Ackoff, 2006). Ackoff was struck by the fact that in actual reality, systems discourse has not led to the kind of improvements it should have. To describe a system is one thing, setting it to work with actual people another, as any HRD professional will testify. The people issue needs more focus, and OSI is one attempt in that direction.

Indeed, as a theoretical perspective, Systems Intelligence was designed to overcome the problem that Ackoff identified. It is vital to appreciate the contrast between "truth informers" and "improvement makers" (Hämäläinen & Saarinen, 2008). It is clear that HRD needs from Systems Thinking, not only models of systems, but help with the "feeling of a system" (Hämäläinen & Saarinen, 2008). HRD needs Systems Intelligence where action is primary and drive toward "being better better" (Hämäläinen et al., 2014) the core of the very undertaking. Building from that conceptually perplexing vision that points beyond the dualistic and objectivity-overemphasizing tone is a fundamental aspiration of the Systems Intelligence approach and one that parallels that of HRD.

8 | IMPLICATIONS FOR RESEARCH

The line of thought offered in this paper suggests that holistic perspectives can work in sync with highly contextual and deeply human parameters. "The system" can and should be approached from within and with due respect to the evasive aspects of the human experience especially in its inter-relational functioning. The eight factors of the OSI—Systemic Perception, Attunement, Attitude, Spirited Discovery, Reflection, Wise Action, Positive Engagement, and Effective Responsiveness—could be analyzed in more detail with an eye for cross-fertilization from research in other areas of human interaction.

In therapy discourse and practice, major insights have emerged as a result of research on the mother-infant dyad as brought to bear on relational adult treatment (for an overview, Seligman, 2017). A key to that progress has been the development of techniques to fine-analyze the mother-infant interaction as bidirectional through time-series mathematics and other rigorous techniques (Beebe, 2014). As a field that connects applied systems thinking, practice, discipline, and the everyday demand to make a difference, infant research and psychotherapy suggests perspectives for HRD. Such possibilities of connecting quantitative, qualitative, and mixed methods for the purposes of research and theory building (cf. Reio, 2010a) call for scrutiny, along with rigorous empirical interaction-focused marriage research. Drawing from ingenious video microanalysis methods that may involve also physiological measures, groundbreaking research on couples' interaction has led to stunning progress in the field of marriage research (Gottman, 2015). With impressive predictive results that draw rigorously from the microanalysis of pairs' interaction, the work carries over to themes such as "Attunement" (Gottman, 2011). It is fair to expect that HRD relevant insights are in offing through research into the experience of employees in the context of their birectional everyday interaction at work. One example to that effect is the empirical work of Losada on high-performing teams (Losada & Heaphy, 2004). If a kind of "anthropology" is taken along with systems thinking as fundamental to HRD (Swanson, 2001), and brought to bear on the micro level, then our discussion raises the question whether the study of people in organizations could follow suit, and the generic human factors brought to focus by our model could be investigated within HRD with equal rigor.

Metatheoretically the Systems Intelligence perspective seems to strengthen the employees' experience-focused, behaviorally and culturally informed, and from-within-the-individual orientation of HRD. It can be seen to work in line with the behavioral turn that is changing the landscape of related fields such as economics in the form of behavioral economics and more recently in operations research in the form of behavioral operational research (Hämäläinen et al., 2013).

On the item level, OSI does not commit to abstractions but names individual improvement and personal growth opportunities in a language accessible to laymen and -women. Viewed as potential changes, each of the 32 items name phenomena people can improve without any structural or macro-level changes. This is in contrast to the DLOQ, which uses considerably more abstract language ("My organization creates systems to measure gaps between current and expected performance" and "My organization builds alignment of visions across different levels and work groups"), and which includes many parameters that are beyond the command and control of most employees of an organization. Senge has repeatedly made it clear that he objects to "a tendency of many writers in the field to 'disembody' organizational learning, to talk about 'organizational routines', practices and processes… with no explicit consideration of whether or not 'I am prepared to learn and change' myself." (Senge, 2003, p. 48). We submit OSI is the first measure to meet head on the challenge Senge stresses.

Theoretically, the shift in focus provided by OSI brings to the focus issues that managerial practices often bypass because the effects are too indirect or hard to measure objectively. Consider the four items of the Reflection factor:

- In my organization, people view things from many different perspectives.
- In my organization, people pay attention to what drives their behavior.
- In my organization, people think about the consequences of their actions.
- In my organization, people make strong efforts to grow as a person.

A manager might perceive the items as desirable, but too distant from the company objectives, incentive calculations, bonus plans, and objective deliverables. Yet these items together form a factor of the learning organization. Is it time to open the discussion on the logic of what John Kay aptly called "obliquity" in the context of goal-directed organizational behavior (Kay, 2010)? Such a move from a thinking of predictability and linear cause-and-effect models in favor of the holistic systems- and relationships-based thinking would certainly be in line with Senge's original insights. Recall Senge's words in his landmark essay of 1993 regarding "the core competencies of a learning organization": "At the top of any list of basic capabilities should be the capacity to reflect on and articulate personal vision" (Senge, 1993, p. 19). Given that "most adults have lost their ability to envision what matters to them" (ibid), the stage is set for HRD to find ways to provide for what is lacking.

HRD is also judged by economics, given the "three-legged stool" of the psychological, systems theories, and economics of HRD (Reio & Batista, 2014; Swanson, 2001). While ostensibly people focused, the vision offered by OSI points to developmental perspectives and facilitative interventions that aim at bringing about the learning organization from processes that emerge from the grassroots level with economically relevant effects. In so doing, the OSI works in line with the view on economic dynamism as based on "mass flourishing" envisioned by Economics Nobel laureate Edmund Phelps (2013). Indeed, the perspective offered here provides ways of looking into the possibilities of the "grassroots innovation [that] created jobs, challenge, and change" that Phelps envisions as foundational for economic "mass flourishing."

9 | IMPLICATIONS FOR PRACTICE

As is painfully clear to practitioners of HRD, it is one thing to create an HRD program, and another to make people to engage with the program. Employees might not perceive the benefits of a program, nor experience it as an investment in their learning, growth or well-being. The "humanness of our organizations," as Chalofsky (2014) calls it, is a pivotal part of the HRD for which the discussion above suggests the following implications:

1. *Dialogue with senior management*. Given the pressure for HRD to develop informal and incidental learning programs (Marsick et al., 2014) that may lack clear-cut causal deliverables, the OSI framework with its humane systems language can provide a useful legitimating discourse for HRD to convince managers. HRD needs vocabulary to justify its culturally oriented programs especially against what Ghoshal described as the "gloomy vision" of humanity dominant in much of management thinking (Ghoshal, 2005). The Systems Intelligence framework can help HRD in that vital battle to defend humanity against overtly rationalistic forms of thinking.
2. *Dialogue with employees*. For the purposes of coaching, mentoring, and one-to-one-on developmental discourse, the item-level themes of the OSI provide an opportunity to raise questions of human growth in the context of work. With a discourse distanced from managerial categories that depict employees primarily as resources for performance, OSI items may help HRD to enrich the dialogue within an organization for employees on all levels

to become more aware of their outcome-affecting interrelationships and "to reason about their behavior in new and more effective ways," as Argyris put it in an early description of the learning vision (Argyris, 1991, p. 100).

3. *Boosting the established HRD perspectives with the leverage of the systems discourse*. Much of the groundbreaking research on HRD prevails on connecting humanly relevant constructs like "turnover intention," "work engagement," or "civil behaviors" with HRD programs on the one hand, and with objective organizational outcome categories, on the other. However, even when a correlation can be shown to exist, it can be challenged as a causality. This perpetual dilemma can likely be bypassed with the explicit systems focus of the OSI perspective. By connecting the OSI measure with already existing measures of (say) work engagement, HRD could argue for culturally oriented initiatives on systems ground, a perspective the senior management is held responsible and thus likely to feel compelled to appreciate.
4. *Boosting the holistic positivity inherent in HRD*. Earlier discussions of systems intelligence have emphasized the inbuilt bias toward human growth as a core to the human endowment (Hämäläinen & Saarinen, 2006). Drawing from infant development perspectives, the interrelatedness that is brought to focus is biased to the positive categories of life. Here the perspective points beyond "Systems Archetypes" that stress the patterns where things go wrong ("Tragedy of the Commons," "Fixes that Backfire," "Shifting the Burden," Senge, 1990). While cognitively it is useful to envision complex organizations and their functioning in term such archetypes explored powerfully by Senge et al. (1994), from the HRD point of view it is equally essential to work with insight into "Miracle of the Commons," "Fixes that Fire," and "Sharing Away the Burden." Here the OSI perspective adds an essential interrelational and systemic twist to the humanistic and positive perspective in HRD that "concerns itself with humans' intrinsic motivation to grow" (Reio & Batista, 2014, p. 7). For HRD professionals, it provides a concrete tool to use for the purpose of identifying what particular realms of growth are particularly called for in a given organization.
5. *Identifying industry-specific aspects for improvement*. In some industries, the two measures for learning organization studied here show considerable combined strength. In Finance, Industrial, and Real Estate, the DLOQ and OSI jointly explained 64% of the variation in perceived organizational performance. Thus, the instruments also have potential to complement one another. It remains to be seen what industries in particular benefit from the combined measures.
6. The diagrams presented for the representation of data create a platform on which developmental themes highlighted by the OSI factors can be identified and discussed with personnel irrespective of hierarchy or organizational role. The OSI dimensions address phenomena that concern everyone. Indeed, it is doubtful if people can live in organization without experiencing them. The mundane phenomena the OSI approaches can also be influenced by anybody and arguably will require intrinsic motivation to emerge. Given the increasingly recognized need of HRD to find possibilities for growth and development that come from within people (Rigby & Ryan, 2018), the OSI could be used as an instrument for the benefit of that important cause.

10 | LIMITATIONS OF THE STUDY

The data points for this study have been gathered from individual survey-takers rather than from people in specific organizations. While this allowed validating the OSI scale on the generic level of different organizations, this study did not investigate how the OSI behaves when it is administered to many individuals within a given organization, such as how large a variance the OSI factors would have inside an organization and what the variance would indicate.

Recruiting subjects via online platforms may have an effect on the results. Palan and Schitter (2018) discuss these effects, especially in the context of the Prolific platform used in this study. We believe we were able to successfully avoid the most significant problems described by Palan and Schitter by limiting the effect of "professional survey-takers" on the results by limiting participation to the United States and United Kingdom and vetting answers based on attention check questions and answer time.

Given that any individual in an organization can answer the OSI items and the items still together aggregate on the whole, the scale offered here yields a tool for HRD in its holistic efforts. It remains beyond the scope of the current research, however, as to what counts as "in my organization," and to what extent is the entity that is being evaluated in fact local.

A natural extension of the research introduced in this article would be to study the OSI scale within a single organization, and to study how greatly do the individuals' views on learning differ from each other, and whether any "gaps" between perceptions indicate problems within the organization, such as how perceptual gaps on the DLOQ have been observed to suggest problems with employee well-being (Hasson et al., 2013).

In order to reduce the effect of common method variance (Reio, 2010b), it is also vital to link the OSI to objective measures of performance and wellbeing. The OSI could also be administered in the organization together with the self-report Systems Intelligence Inventory (Törmänen et al., 2016) and its peer-evaluation version (Törmänen et al., 2021) to produce a multi-layered, multi-directional picture of the organization's systems thinking and Systems Intelligence capabilities.

11 | CONCLUSION

From the managerial and HRD point of view to organizational development, the OSI can be seen as a valid alternative measurement tool for the DLOQ. OSI identifies observable behavioral and aspirational characteristics, which are generic and apply to everybody irrespective of position. Anyone can make a change and also perceive the change.

Prior research has provided ample evidence for the pragmatic and theoretical benefits of the DLOQ. We hope to have shown that OSI, with its theoretical roots in Senge's original vision and in the Systems Intelligence perspective, along with its humanly-tuned emphasis and concrete formulations, can usefully supplement the leading measure, well established in its merits. Thus, interventions to develop the LO capabilities of an organization are likely to benefit from the use of both of instruments. The DLOQ can give suggestions for improving organizational capabilities as well as management practices and organizational structures that support learning. The OSI, in turn, raises individuals from the grassroots back to the center, encouraging managers and practitioners to find approaches that apply to all. The OSI, with its emphasis on the LO through individuals, is also likely to benefit from tools developed for individual-level interventions on phenomena such as compassion, prosocial skills, and collaboration. This relates OSI directly to the practice of human resources development.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX A.

TABLE A1 Organizational Systems Intelligence scale

#	Factor	Direction	Item
1	Systemic Perception	+	In my organization, people form a rich overall picture of situations
2	Systemic Perception	+	In my organization, people easily grasp what is going on
3	Systemic Perception	+	In my organization, people see what is essential in a given situation
4	Systemic Perception	+	In my organization, people keep both the details and the big picture in mind
5	Attunement	+	In my organization, people approach each other with warmth and acceptance
6	Attunement	+	In my organization, people take into account what others think of the situation
7	Attunement	+	In my organization, people are fair and generous with people from all walks of life
8	Attunement	+	In my organization, people let others have a voice
9	Attitude	–	In my organization, people explain away their mistakes
10	Attitude	+	In my organization, people have a positive outlook on the future
11	Attitude	–	In my organization, people easily complain about things
12	Attitude	–	In my organization, people let problems in their surroundings get them down
13	Spirited Discovery	+	In my organization, people like to play with new ideas
14	Spirited Discovery	+	In my organization, people look for new approaches
15	Spirited Discovery	+	In my organization, people like to try out new things
16	Spirited Discovery	+	In my organization, people act creatively
17	Reflection	+	In my organization, people view things from many different perspectives
18	Reflection	+	In my organization, people pay attention to what drives their behavior
19	Reflection	+	In my organization, people think about the consequences of their actions
20	Reflection	+	In my organization, people make strong efforts to grow as a person
21	Wise Action	+	In my organization, people are willing to take advice
22	Wise Action	+	In my organization, people take into account that achieving good results can take time
23	Wise Action	+	In my organization, people are wise in their judgments
24	Wise Action	+	In my organization, people keep their cool even under pressure
25	Positive Engagement	+	In my organization, people actively contribute to the shared atmosphere
26	Positive Engagement	+	In my organization, people praise others for their achievements
27	Positive Engagement	+	In my organization, people are good at alleviating tension in difficult situations
28	Positive Engagement	+	In my organization, people bring out the best in others
29	Effective Responsiveness	+	In my organization, people prepare themselves for situations to make things work
30	Effective Responsiveness	–	In my organization, people easily give up when facing difficult problems
31	Effective Responsiveness	+	In my organization, people put first things first
32	Effective Responsiveness	+	In my organization, when things do not work, people take action to fix them

Publication 3

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Perceived systems intelligence and performance in organizations

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Abstract

Purpose – This study aims to introduce the perceived systems intelligence (SI) inventory, developed based on the earlier published self-report SI inventory (Törmänen *et al.*, 2016). It can be used together with earlier managerial level tools for building a learning organization and included in general 360-style evaluations in personnel development.

Design/methodology/approach – The inventory is validated with confirmatory factor analysis with a model based on the self-report SI inventory, using data from full-time used employees and managers in the USA and UK. Perceived SI factor scores are correlated with the perceived study performance of the individual.

Findings – The perceived SI inventory is found to have good factorial validity, and it correlates strongly with evaluations of perceived study performance. Managers perceived high in performance are also found to score high in perceived SI. Perceived SI does not depend on gender, age, organization size or industry.

Originality/value – The perceived SI inventory is the first personnel level peer evaluation tool suggested for developing learning organizations. The new inventory makes peer evaluations possible and provides a new grassroots level tool for personnel development programs in learning organizations.

Keywords Learning organizations, Systems intelligence, Peer evaluation

Paper type Research paper

Introduction

Systems intelligence (SI) is a concept describing our abilities to succeed in complex situations in organizational settings and in our everyday life. Saarinen and Hämäläinen (2004, p. 4) originally defined SI as:

> [. . .] intelligent behavior in the context of complex systems involving interaction and feedback. A subject acting with Systems Intelligence engages successfully and productively with the holistic

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> feedback mechanisms of her environment. She perceives herself as a part of a whole, the influence of the whole upon herself as well as her own influence upon the whole. By observing her own interdependence in the feedback intensive environment, she is able to act intelligently.

SI has been suggested as an essential competence needed in positions of leadership (Hämäläinen and Saarinen, 2006, 2007a) and has been applied for various fields such as organizational development (Luoma *et al.*, 2008, 2011), knowledge management (Sasaki, 2017), personal growth (Hämäläinen *et al.*, 2014; Saarinen and Lehti, 2014), therapy discourse (Martela and Saarinen, 2013), design thinking (Harviainen *et al.*, 2021; Jumisko-Pyykkö *et al.*, 2021) and engineering disciplines (Hämäläinen *et al.*, 2018). For a history of the SI perspective, see Törmänen (2021).

SI draws from Peter Senge's seminal management book The Fifth Discipline (Senge, 1990), which introduced what Senge calls the five disciplines of the learning organization – systems thinking, personal mastery, mental models, building shared vision and team learning. SI seeks to operationalize Senge's vision of the learning organization and integrate it conceptually. To this effect, the original SI inventory of 2016 offered a self-evaluation questionnaire (Törmänen *et al.*, 2016). The more recent organizational SI inventory focused on SI in organizations (Törmänen *et al.*, 2021). The current paper takes the SI perspective yet one more step further, extending it to the peer level.

While Senge's work has been hailed as "almost synonymous with the idea of learning organization" (Örtenblad, 2018), quantitative models of the learning organization have often bypassed key aspects of Senge's vision, especially regarding insights that are difficult to operationalize or control with managerial structures. In her recent overview, Bui highlighted Senge's constructs of personal mastery and systems thinking as ideas that "have powerfully shaped new ways to see the world and act upon" (Bui, 2020). However, in research literature seeking to operationalize the learning organization the two "disciplines" that Bui specifically singles out play in fact only cameo roles. For example, in the arguably most popular measurement scale for the learning organization, Dimensions of the Learning Organization Questionnaire (Marsick and Watkins, 2003), only two out of seven dimensions are focused on the individual. Traditionally, learning organization tools have been top-down with the agency at the leadership of the organization. Recently, however, interest has been rising for also developing bottom-up and multilevel tools and frameworks (Chou and Ramser, 2019).

Rigby and Ryan (2018), in their visionary overview of human resource development (HRD), go as far as to allude to a "Copernican Turn" as an emerging organizational paradigm. In contrast to "'Pre-Copernican' approaches that rely on institutional levers and 'command and control' systems that management can activate to drive the desired behavior", the "Copernican Turn" looks at individuals and their motivational and emotional factors. "For HRD to succeed, tools are needed that tap into the worker's *internal* frame of reference".

In the HRD literature the need that Rigby and Ryan dramatize has indeed been noted for years – the need to link with "key individual variables" such as intention, goals, commitment and satisfaction (Peterson, 2004), "perceived investment in employee's development" (Lee and Bruvold, 2003) and "learning opportunities that nurture human expertise in organizations" (Shuck *et al.*, 2014, p. 239). This emphasis of quintessentially human factors is particularly pronounced when scholars meet head-on the fact, painfully obvious to practitioners, that an HRD program might be excellent as a plan and yet fail to deliver desired outcomes – because employees do not perceive the benefits. Key phenomena such as employee turnover intention or employee engagement hinge on how employees experience their peers, managers and organization, but managers and researcher alike have had a difficult time in conceptualizing and operationalizing the developmentally relevant "human, all too human" parameters. Still, on the abstract level, the situation remains clear enough. As Chalofsky put it in his introduction to the authoritative *Handbook of Human Resource Development,* what is needed in the field is "a holistic approach to human development," one that draws from "inner growth that is realized through interaction of self, context, and life experiences" (Chalofsky, 2014, p. xlv).

The call for more humanly-tuned grassroots-level informed conceptualizations is burning in the context of learning organizations, where the scholarly discourse tends to favor managerial structures that operates from top to bottom. Here the SI approach takes a sharp departure in favor of employees, individuals and human experience. The idea is to approach development through a discourse that does not speak about structures that only managers command but in terms of a discourse employees can understand.

For Senge, systems thinking never was not the cold and objectivistic model building of complex systems from without. As Senge makes clear in his 1993 key paper in *Human Resource Development Quarterly*, "systems thinking" amounts to "seeing relationships" that calls for such deeply human from-within qualities as "genuine caring" and "compassion" (Senge, 1993). It is here where the SI perspective is particularly mindful of Senge's thinking for the benefit of organizational learning as a process. The SI approach takes caution neither to reify employees to objects nor systems to external entities. The SI perspective draws insight from modern relational, systems inspired empirical infant research and from its way of understanding the mother-infant dyad as the paradigmatic context of development (Hämäläinen and Saarinen, 2007b; Saarinen and Hämäläinen, 2010). In the mother-infant context, the baby is an active partner in the dyadic, bidirectional and co-creational system in which intra- and inter-subjective processes of development are intertwined (Beebe and Lachmann, 2005; Beebe *et al.*, 2005; Seligman, 2017).

The guiding intuition of the SI perspective concerns the factors that make humans succeed with and within wholes. With factors such as "systemic perception", "attunement", "positive engagement" and "effective responsiveness", the SI perspective wishes to take the context seriously as a key determinant of successful action. The environment is brought to bear on the subject bidirectionally. In organizations, a key contextual factor is created by one's fellow employees.

There is a long tradition in organizations to develop ways for managers and employees to get feedback of their actions, to avoid self-deception and to get a more realistic view of one's behaviors for the benefit of right-directed development. Indeed, the use of multisource feedback, often called 360-degree feedback, in its various forms, is an established organizational practice (Maylett, 2009; Church *et al.*, 2019). The fact that leaders' perceptions of their behaviors, along with the employees' perceptions generally, might differ from those of others is a source of lively discussion. How the "rater bias" (Holzbach, 1978) and the "self-other agreement" affects various organizational outcomes is an issue that has relevance both theoretically and in practice (Atwater and Yammarino, 1997; Fleenor *et al.*, 2010; Halverson *et al.*, 2005; Lee and Carpenter, 2018). When it comes to leadership, the issue becomes particularly relevant with results such as Jacobsen and Bøgh Andersen (2015) that indicate that at least in some cases, employee-perceived leadership appears to be a more useful metric than the leader's own self-evaluation.

In this paper, we are interested if SI can also be evaluated by peers as perceived competence, especially *vis-à-vis* perceived job performance. We extend the notion of SI to perceptions of one's colleagues in one's organization and introduce a perceived SI measurement scale, adapting the factor structure introduced by the SI inventory of Törmänen *et al.* (2016). We study the relationship between the learning organization and organizational performance (Kim and Lu, 2019) by correlating perceived SI with perceived job performance, with a particular focus on people in a leadership position.

The new inventory is tested and validated by administering it through a web-based questionnaire to people working in the UK and USA. The subjects (N = 569) included employees and managers in various organizations. The subjects were asked to evaluate two of their colleagues – one they felt was a "top performer" in their organization and one they felt was an "average performer." The subjects were asked to evaluate the person in question regarding behaviors and features that related to SI, as well as how the person succeeded in her work performance. The large sample of 1,138 peer-evaluated colleagues allowed analyzing the results obtained in different professions, organizational positions and age groups, as well as for men and women.

Method

Creating the perceived systems intelligence inventory

We chose to develop the perceived SI inventory by adapting the self-report SI inventory developed in Törmänen *et al.* (2016) to a peer-evaluation context. Recognizing that some of the items might be more difficult to address as perceived items instead of self-report items, using the exact same factor structure allows for comparison and contrasting of the self-report and peer perceived SI measurements, and thus significantly widens the applicability of the inventory. Therefore, it was considered desirable to retain as much of the already identified eight-factor SI structure as possible.

The perceived SI inventory was created by revising the phrasings of the original inventory. The original "I [. . .]" format ("I contribute to the shared atmosphere in group situations") was changed to a "My colleague [. . .]" format ("My colleague contributes to the shared atmosphere in group situations"). The resulting inventory of 32 items was screened in a pilot study, whose results were used to ensure that the new perceived versions were understood properly and that their answer distributions were not heavily skewed. Pilot results indicated that direct modification produced a well-functioning inventory with well-behaving items. The resulting inventory, as used in this study, is included in Appendix.

Data and samples

To gather a large, well-sampled set of colleague evaluations, individuals in the academic crowdsourcing platform Prolific.ac were invited to evaluate their own colleagues. The participants received monetary compensation of £1.00–£1.25 for participating in the study. Each participant was asked to evaluate two of his or her colleagues, one who they considered to be among the top 5% of performers in their organization and another who they considered a typical, average performer.

The subject filled the 32-item perceived SI inventory for both colleagues and gave an estimate of how well they felt the colleagues performed in his/her work. The SI questions were answered on a seven-point Likert scale from "never" to "always." Performance was asked with the question "On a scale from 0 to 10, how well do you feel your colleague performs in his/her work?", with the subject answering on a Likert scale. The data set was gathered during a number of smaller-scale questionnaire rounds. In later rounds, the following two additional performance questions were posed with the same scale: "On a scale of 0–10, how much does this colleague help other people succeed?" and "On a scale of 0–10, how much does this colleague contribute to a positive work climate?"

The subjects also described how well they knew the colleague ("We are close friends"; "Quite well"; "Only a little") and how long they had been colleagues ("Less than 1 year"; "1–3 years"; "3–10 years"; "Over 10 years"). The questionnaire also asked for the colleague's gender, age and position in their organization, and the participant's gender and age.

The subjects were selected from a pool of participants who worked full-time, were residents of the UK or the USA and at least 25 years of age. In total, 569 people participated, resulting in 1,138 perceived SI evaluations. The summary statistics from the data set have been collected to Table 1. The sampling strategy resulted in a roughly even split of men and women for both participants and colleagues, with a wide distribution of age groups, and with 44% of the colleagues being in managerial or supervisor positions.

Results

Construct validity of perceived systems intelligence

The self-report SI inventory uses factor scores of the eight SI factors to highlight systems intelligent behavior and to give suggestions and recommendations to the individual. To study whether the same eight-factor model can be used with perceived SI data, we replicate the confirmatory factor analysis process described by Törmänen *et al.* (2016) using our full data sample ($N = 1,138$).

Construct validity is assessed by fitting a confirmatory factor analysis model using structural equation modeling (Bollen, 1989) to the data set, with the same 32-item 8-factor structure as the self-report SI inventory. Using the implementation of the R "sem" package (Fox *et al.*, 2020), the resulting model has a chi-squared value of 1,831.4 with 436 degrees of freedom ($p < 0.001$).

The eight-factor model has a good model fit as indicated by recommendations by Hu and Bentler (1999), with structural fit indices root mean square error of approximation 0.053 and standardized root mean squared residual 0.057. Additionally, the model outperforms a simple single factor model with all items loading to a single SI factor ($\chi^2 = 2{,}241.3$, df = 464, χ^2 difference $p < 0.001$), showing that a multifactor structure is clearly preferable for describing the perceived SI data set.

These results indicate good construct validity for the eight-factor perceived SI inventory and suggest that it can be used with the same eight factors as the self-report SI inventory.

Perceived systems intelligence and perceived work performance

We calculate perceived SI factor scores as weighted averages of the structural equation model coefficients produced in the previous step. Table 2 shows cross-correlations between

Group	Participants	Colleagues
Count		
N	569	1,138
Gender		
Female	298 (52%)	549 (48%)
Male	268 (47%)	586 (51%)
N/A	3	3
Age		
<30	130	260
30–40	221	433
40–50	122	270
50–60	80	149
>60	14	26
N/A	2	0
Role		
Manager or supervisor		501 (44%)
Not manager or supervisor		623 (55%)

Table 1. Summary statistics for participants and peer-reviewed colleagues

Table 2.
Correlations between SI factor scores and peer evaluated work performance

Factor	ATT	ATD	DIS	REF	WIS	ENG	EFF	Perceived performance	Helps others succeed	Contributes to a positive work climate
Systemic perception (PER)	0.70	0.62	0.80	0.85	0.85	0.81	0.87	0.79	0.75	0.74
Attunement (ATT)		0.58	0.65	0.75	0.78	0.82	0.64	0.55	0.65	0.76
Attitude (ATD)			0.58	0.62	0.67	0.63	0.66	0.58	0.55	0.66
Spirited discovery (DIS)				0.83	0.74	0.74	0.76	0.68	0.69	0.68
Reflection (REF)					0.83	0.80	0.79	0.71	0.71	0.72
Wise action (WIS)						0.81	0.81	0.72	0.73	0.80
Positive engagement (ENG)							0.74	0.69	0.75	0.82
Effective responsiveness (EFF)								0.75	0.73	0.69
SI factor average								0.78	0.78	0.82

the SI factors and correlations between SI factor scores and perceived colleague performance. Additionally, the table shows the correlation between the average of all eight SI factor scores and perceived performance. All correlations are statistically significant at a level $p < 0.001$. Table 3 shows the average scores for the SI factors and performance questions.

Correlations are high, both within the SI factors and between SI factors and perceived work performance. This implies that participants see that the factors of perceived SI are closely linked to how they perceive high performance in a work environment. Especially the perceived SI factors of Systemic Perception and Effective Responsiveness have very strong correlations with perceived performance.

The strong link between factor scores and work performance is further highlighted in the scatter plot of Figure 1, which shows the average perceived SI factor score on the vertical axis and perceived performance on the horizontal axis. In general, colleague evaluations follow the regression line quite closely; in only a few cases do the two variables significantly differ.

Alternative perspectives to performance

In addition to the main performance evaluation question, some participants were also asked to answer the following two extra performance questions: "On a scale of 0–10, how much does this colleague help other people succeed?" and "On a scale of 0–10, how much does this colleague contribute to a positive work climate?" Table 2 shows also correlations between SI and these two questions.

In general, the two alternative perspectives show similar results to perceived performance; correlations between perceived SI factors and the performance evaluations are high. Some of the most significant differences related to the more interpersonal factors of perceived SI (Attunement and Positive Engagement), which correlate strongly with contributing to a positive work climate. On the other hand, the more general systems thinking factors of systemic perception and effective responsiveness have a stronger link to direct perceived performance.

Distribution of perceived systems intelligence factor scores for top, high and lower performing individuals

Figure 2 presents histograms of perceived SI scores for managers and non-managers for each SI factor. The histograms are shown as cumulative bar charts with the evaluated

Score	All (N = 1,138)	Managers (N = 501)	Non-managers (N = 637)
Perceived SI (0–6)			
Systemic perception (PER)	3.87	4.22	3.59
Attunement (ATT)	4.08	4.18	4.00
Attitude (ATD)	3.36	3.63	3.15
Spirited discovery (DIS)	3.57	3.89	3.32
Reflection (REF)	3.63	3.90	3.42
Wise action (WIS)	3.86	4.12	3.66
Positive engagement (ENG)	3.69	4.01	3.43
Effective responsiveness (EFF)	3.89	4.27	3.59
Performance (0–10)			
Perceived performance	7.18	7.88	6.63
Helps others succeed	6.49	6.99	6.04
Contributes to a positive work climate	6.66	6.88	6.45

Table 3. Average scores for SI factors and performance questions for all participants, managers and non-managers

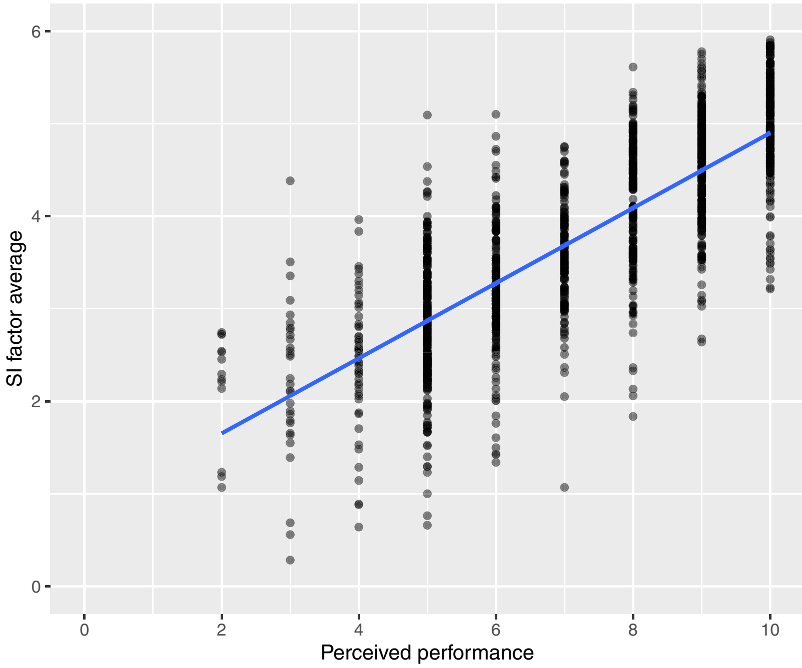

Figure 1.
Colleagues (N = 1,133) evaluated by work performance and SI factor score average. Line shows the linear regression of the two variables

colleagues split into three color-coded groups based on their perceived work performance evaluation (0–5, 6–8 and 9–10).

As the figures show, higher perceived performance and higher SI scores go closely hand in hand in all of the eight perceived SI factors. Especially for systemic perception and effective responsiveness, the two most strongly correlating factors in Table 2, nearly all managers perceived as top performing score in the upper end of the perceived SI subscales.

There are also clear differences between managers and non-managers. Comparatively, a larger portion of managers and supervisors belong to the top and high-performance categories. As shown in Table 3, managers and supervisors score higher in all eight factors of perceived SI and all three performance questions. The largest SI differences, effective responsiveness and systemic perception are also distinct visually in the statistical peaks of the distributions in Figure 2.

Profiles of systems intelligent perceived managers

Figure 3 shows answer distributions to each questionnaire item as violin (distribution) plots for colleagues in supervisory or managerial positions. The figures are laid out so that each perceived SI factor is in its own row. These figures are especially useful to studying which of the questionnaire items seem to be particularly important to top-performing managers, and in which items also lower evaluations are common.

Essentially, these figures show a more fine-grained view of the distributions shown in Figure 2. Some items, such as "My colleague easily grasps what is going on," seem to be strong requirements of high performance; there are virtually no top-performing managers that receive low marks on the question.

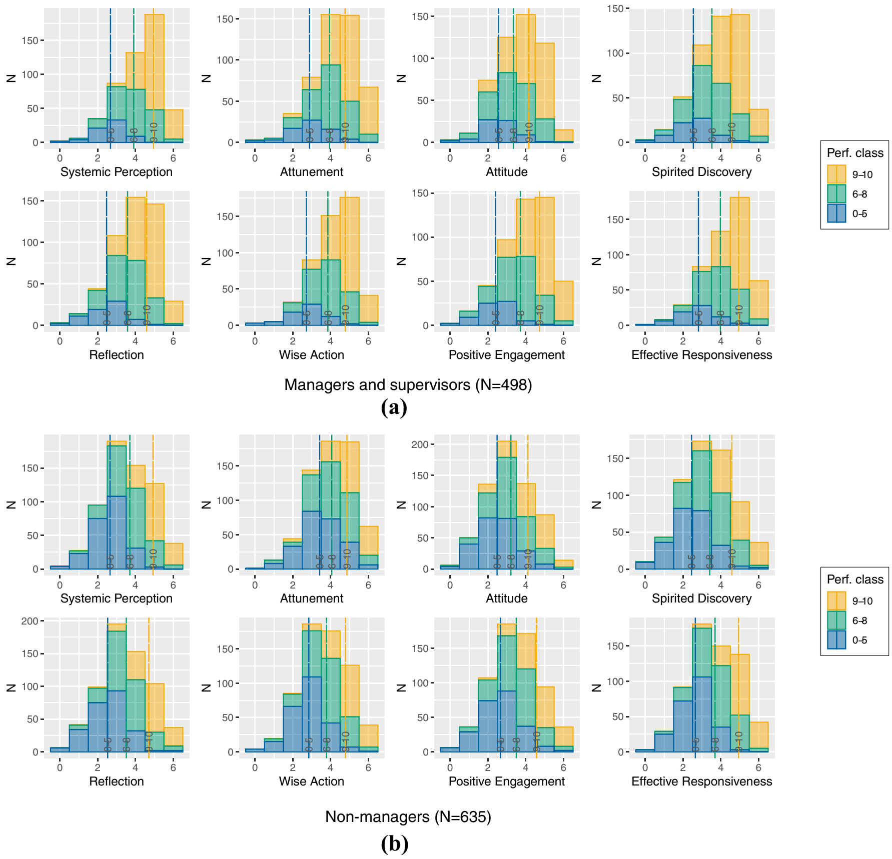

Figure 2.
SI score distributions for colleagues belonging in different performance classes for question "On a scale from 0 to 10, how well do you feel your colleague performs in his/her work?". Horizontal lines denote averages for each performance class

Relationship between background variables and perceived systems intelligence

We use one-way analysis of variance to study whether different answers to background variables are linked to different levels of total perceived SI (calculated as the average of the eight perceived SI factor scores). The rejection of an analysis of variance null hypothesis implies that participants are not sampled from a common population, but rather that perceived SI evaluations and the background variable correlate in some way.

Table 4 shows results for various background variables, including a broad industry grouping of technological, educational, manufacturing and other companies. The analysis of variance tests were carried out with Type III sums of squares using the R "car" package (Fox and Weisberg, 2019).

As Table 4 shows, only a few background variables are linked to the perceived SI assessment. Most notably, colleagues in manager/supervisory position differ greatly from other colleagues, and colleagues that the participant is closely acquainted with are evaluated differently from those the participant is less acquainted with. Additionally, colleague age group and acquaintance time with a colleague have smaller links, though at the level that

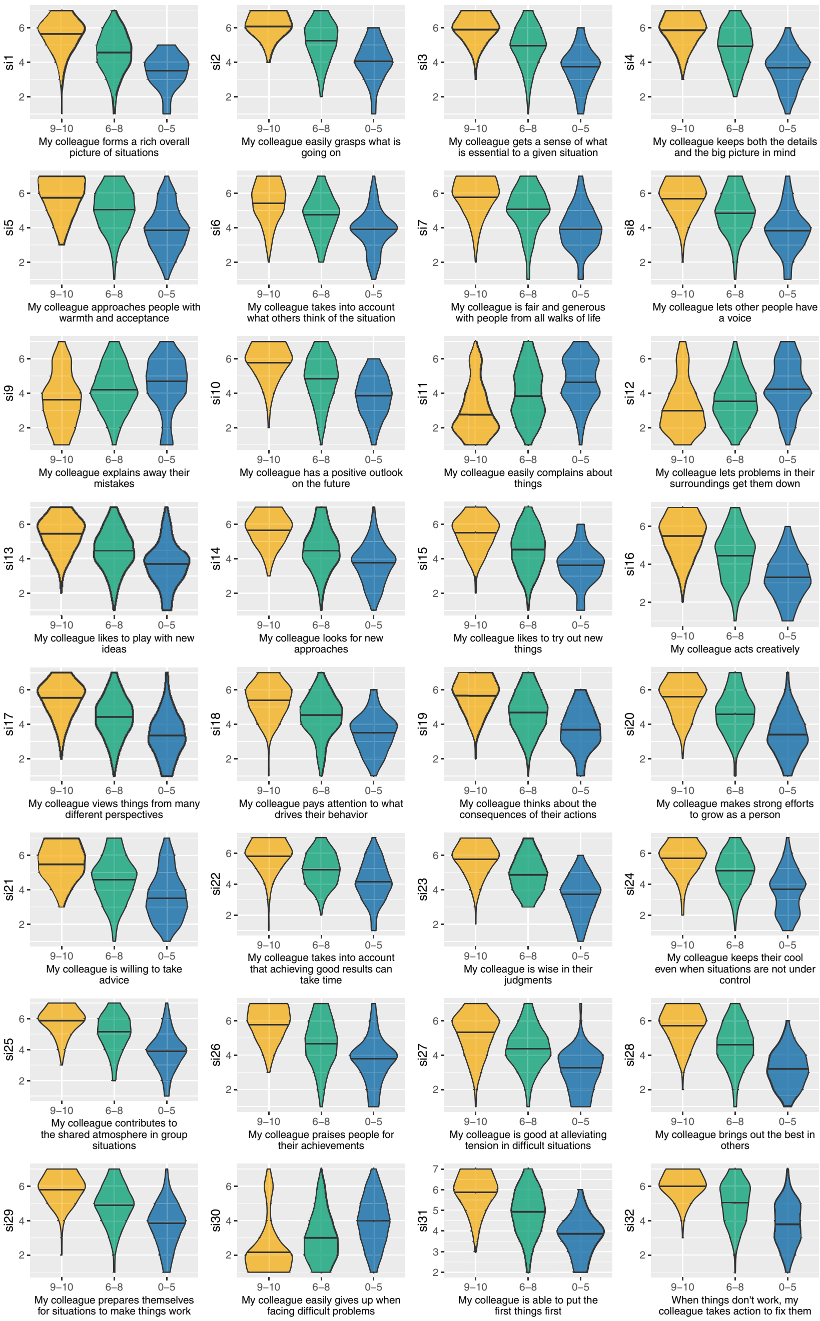

Figure 3.
Item-by-item answer distributions based on perceived performance score classes for managers and supervisors (N = 498)

Bonferroni corrections would be used to avoid false positives, neither would be statistically significant.

The analysis of variance results imply that perceived SI evaluations are not strongly dependent on many common background variables, such as gender, age, organization size or industry, and therefore, perceived SI appears to have generic applicability and similar behavior in most common cases. In applying perceived SI, care should likely only be taken on avoiding close acquaintances from evaluating each other.

Discussion

The perceived SI uses colloquial phrases as opposed to structural or semi-theoretical discourse. As a result, the inventory proposed here supports approaches that seek to develop an organization from people-centered perspectives and look for opportunities at developing the organization from the "bottom up" instead of the more classic "top down" approach. As such, it can serve frameworks such as the multilevel model of organizational learning proposed by Chou and Ramser (2019), which emphasizes the upwards helping, psychological empowerment and voice behavior of employees. As Chou and Ramser note, there are few tools and frameworks available for the "bottom up" and individual-level development of learning organizations. The perceived SI inventory helps to fill this niche as likely the first peer evaluation tool in the field.

The question of leadership in a learning organization was raised already early in the seminal paper by Bass (2000). Empirical evidence in the current paper suggests a strong correlation between high perceived SI scores and perceived performance for managers. The availability of a peer evaluation tool for SI can help the leader in finding improvement opportunities, and to recognize and avoid destructive "systems of holding back" (Hämäläinen and Saarinen, 2007a; Sasaki *et al.*, 2015).

Many aggregates and measurements in organizational and leadership research call for assessments that are difficult for employees to peer evaluate. Based on the results presented here, the perceived SI inventory seems to be one way of evaluating relevant-to-all behavior in a way that is easily discussable and directly comprehensible while at the same time relating to perceived performance. The development could be aided by the stages of SI identified by Jones and Corner (2012). Note that the theory of empathetic leadership by Kock *et al.* (2019) parallels in many respects SI; empathetic leadership has positive effects on job satisfaction and follower performance.

Variable	df	F	*p*	sig
Colleague gender	1	3.7243	0.054	
Colleague age group	5	2.8372	0.015	*
Colleague is a manager/supervisor	1	64.254	0.000	***
Acquaintance level with a colleague	2	40.172	0.000	***
Acquaintance time with a colleague	4	3.4126	0.009	**
My gender	1	2.4075	0.121	
My age group	4	1.2414	0.292	
My time in organization	4	0.2395	0.916	
Organization size	4	0.1136	0.978	
Industry (tech/edu/manufacturing/other)	3	0.1885	0.904	

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. p-values do not have Bonferroni correction

Table 4. Analysis of variance test results for different background variables

The items of SI call out to action and behaviors that anybody irrespective of her position can perceive, appreciate and potentially improve. This indicates that the SI perspective is a useful framework for an organization to adopt for its developmental discourse on any level of the organization. Not only does SI correlate with individual work performance but also it relates to how much a person supports others and the workspace environment; a systems intelligent worker is also one who builds a positive atmosphere in the workplace.

The factors of SI seem to be clearly visible to one's colleagues and at the same time, they closely relate to how employees perceive others' performance. However, the majority of the SI items pointedly talk about the "soft" aspects of performance. This highlights the human dimension called out by HRD professionals and by Rigby and Ryan with their "Copernican Turn." Integrating the SI perspective with more reifying performance indicators, a leader will likely be encouraged to pay attention to SI-related skills in herself and in her personnel. The way employees perceive their peers' performance is certainly a concern for a leader. An employee's performance might be objectively good, but if peers perceive it as weak, self-generated problems can be predicted for the whole. Versatile, well-rounded and humanly rich development thinking will carry an organization further than the narrow performance focus that employee experience as reducing them to objects.

As the perceived SI inventory is a rather lightweight instrument of 32 Likert-scale items, it can have wide applicability for different organizational development and improvement purposes. For example, the perceived SI inventory could be included as a component of a 360-degree feedback questionnaire, providing a viewpoint to how an employee's organizational and systems skills are perceived. The evaluation could also be relatively easily repeated later with the same individuals to study changes in perceived SI factor scores.

The perceived SI inventory provides many opportunities for developing organizations and teams. For example, it can be used as an organization-wide or team-wide intervention, where all members give perceived SI evaluations on their closest colleagues, helping individuals identify their strengths and weaknesses on the eight SI factors. The results could be further connected to the self-report SI inventory of Törmänen *et al.* (2016), highlighting possible differences between self-perceptions and colleague perceptions of SI. Figures 2 and 3 show two suggestions to how SI factor score distributions can be visualized and allow for the easy showing of how an individual's own scores are positioned next to the overall distribution.

In the results reported here on SI, it is very rare for there to be a person who scores low in perceived SI and still is perceived to generate good performance or vice versa. Managers receive higher evaluations in all perceived SI factors and based on the analysis-of-variance test, and managerial position is the strongest background variable affecting an individual's perceived SI evaluation.

Thus, the perceived SI inventory can have the potential to serve as a powerful tool for leadership development. The inventory and its factors can be used as part of coaching programs, for example, by focusing on any gaps an individual has in his/her SI capabilities or they can be taken as concepts and vocabulary for more informal dialogue within the workplace, optionally supported by other tools such as design games (Hämäläinen *et al.*, 2020).

Conclusions

Based on confirmatory factor analysis results, the perceived SI inventory has good factorial validity using the original self-report SI inventory factor structure. Thus, the eight SI factors can thus be used to describe perceived SI.

The results show that all perceived SI factors correlate strongly with subjective evaluations of work performance. When studying top-performing individuals and especially top-performing managers, the effect is especially pronounced with the perceived SI factors Systemic Perception and Effective Responsiveness.

When comparing managers to other employees, managers tend to have higher perceived SI. perceived SI is also strongly linked to perceived performance in managers, and thus seems to be equally or even more important for managers than for other employees. Thus, results indicate that managers and leaders could benefit from coaching and tools that help them develop their SI capabilities.

Based on the relationship between the perceived SI factors and background variables perceived SI seems to be generic; there are only minor differences between genders, age groups or between different industry sectors. This result is maintained for both employees and managers. Indeed, it seems that systems intelligent behavior and leadership is similar no matter the place.

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Appendix

Table A1. Perceived SI inventory items and factors

#	Factor	Direction	Item
1	Systemic perception	+	My colleague forms a rich overall picture of situations
2	Systemic perception	+	My colleague easily grasps what is going on
3	Systemic perception	+	My colleague gets a sense of what is essential to a given situation
4	Systemic perception	+	My colleague keeps both the details and the big picture in mind
5	Attunement	+	My colleague approaches people with warmth and acceptance
6	Attunement	+	My colleague takes into account what others think of the situation
7	Attunement	+	My colleague is fair and generous with people from all walks of life
8	Attunement	+	My colleague lets other people have a voice
9	Attitude	−	My colleague explains away their mistakes
10	Attitude	+	My colleague has a positive outlook on the future
11	Attitude	−	My colleague easily complains about things
12	Attitude	−	My colleague lets problems in their surroundings get them down
13	Spirited discovery	+	My colleague likes to play with new ideas
14	Spirited discovery	+	My colleague looks for new approaches
15	Spirited discovery	+	My colleague likes to try out new things
16	Spirited discovery	+	My colleague acts creatively
17	Reflection	+	My colleague views things from many different perspectives
18	Reflection	+	My colleague pays attention to what drives their behavior
19	Reflection	+	My colleague thinks about the consequences of their actions
20	Reflection	+	My colleague makes strong efforts to grow as a person
21	Wise Action	+	My colleague is willing to take advice
22	Wise Action	+	My colleague takes into account that achieving good results can take time
23	Wise action	+	My colleague is wise in their judgments
24	Wise action	+	My colleague keeps their cool even when situations are not under the control
25	Positive engagement	+	My colleague contributes to the shared atmosphere in group situations
26	Positive engagement	+	My colleague praises people for their achievements
27	Positive engagement	+	My colleague is good at alleviating tension in difficult situations
28	Positive engagement	+	My colleague brings out the best in others
29	Effective responsiveness	+	My colleague prepares themselves for situations to make things work
30	Effective responsiveness	−	My colleague easily gives up when facing difficult problems
31	Effective responsiveness	+	My colleague is able to put the first things first
32	Effective responsiveness	+	When things don't work, my colleague takes action to fix them

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POSITEAMS – POSITIVE SYSTEMS INTELLIGENT TEAMS, AN AGENT-BASED SIMULATOR FOR STUDYING GROUP BEHAVIOUR

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ABSTRACT

Systems intelligence is the ability to act intelligently within complex systems involving interaction and feedback. Organizations and social groups are typical examples of everyday systems. The dynamics of social systems can be difficult to understand because of their systemic nature. This makes positively affecting the state of the system a challenging problem. The effects of positive emotions have been linked with increased performance in social groups and individuals. Thus simulating emotion dynamics can be used to better understand how to act more constructively within organizations. PoSITeams is a web-based multi-agent simulator to study the dynamics of emotions. We present a novel agent-based emotional contagion model based on psychological research to study the dynamics of positive and negative emotions in organizations. The purpose of the simulator is to let the user explore the effects of different behavioural and structural changes in organizations. This facilitates perceiving the organization as a system and also lets the user recognize the potential of changing the system from within, thus promoting systems intelligent behaviour in the organization. The presented emotional contagion model is also considered as an optimization problem to let the simulator suggest systems intelligent actions. The behaviour of the model and the optimization methods are examined with example simulations.

Keywords: systems intelligence, agent based modelling, social systems, emotional contagion

INTRODUCTION

Organizations and social groups can be naturally perceived as systems, i.e. wholes consisting of multiple mutually interacting parts, where the interactions often include non-linearities and feedback loops. Such systems are seldom observed from the outside, but rather we are surrounded within them. Acting constructively within a social system and positively affecting its state is a complex problem since the effects of the system, such as non-linearities, feedbacks and time delays, are difficult or even impossible to understand. Consequently, tools that would facilitate perceiving the systemic nature of the problem could be beneficial to our understanding of the everyday systems, ultimately leading to a more productive behaviour within them.

Although the dynamics of social systems can be difficult to understand, humans do have a remarkable capability to act intelligently within systems, a concept known as systems intelligence (Saarinen & Hämäläinen, 2007). A systems intelligent person perceives the system as a whole and recognizes herself as an active part of the system, who is both able to affect the state of the system and is reciprocally influenced herself by the system. She can act productively inside the system and is able to recognize and take advantage of different feedback mechanisms. Some individuals are more proficient than others in acting intelligently within systems such as different social groups, but it is a skill that can be developed. To study systems intelligence within social groups, we have developed a simulator called Positive Systems Intelligent Teams (PoSITeams). PoSITeams is a web-based multi-agent social simulator that simulates the dynamics and evolution of positive and negative affect in a team. Agent-based simulations have been used extensively to model social systems and they can provide useful insights into the underlying systems and introduce ideas to improve their performance.

We are social animals and we are greatly influenced by the emotions of others. Emotions have been widely studied in psychology (Frijda, 1986) and a lot is known about their effects on individuals and social groups. Positive emotional contagion has been linked to increased performance in social groups (Barsade, 2002). In particular, the ratio of positive and negative affect has proven to be an especially useful parameter. It has been successfully applied to predicting effective organizations and successful marriages (Losada & Heaphy, 2004; Gottman, 2002). Positive emotions have been studied in the field of positive psychology, which focuses on human flourishing and how to improve our lives contrary to the traditional fields of psychology, which concentrate on the remedies to psychological problems (Seligman & Csikszentmihalyi, 2000). Also on the individual level the characteristic difference between flourishing and non-flourishing individuals has been observed to be the ratio of experienced positive and negative emotions (Fredrickson, 2013). Positivity ratios can therefore be used as indicators of the overall performance and well-being of both social systems as well as its individuals, which has been the motivation behind PoSITeams.

The purpose of PoSITeams is to enable the user to simulate social groups of her own and explore the effects of different behavioural changes. The focus is especially in engaging the user in reflective thought-processes and facilitate seeing the system as a whole and let the user recognize herself as an active part of the system. In this sense, the simulator could be used to promote systems intelligent behaviour in a social context.

BACKGROUND

Systems Intelligence

The concept of systems intelligence was introduced by Professors Raimo P. Hämäläinen and Esa Saarinen of Aalto University in 2004. Systems intelligence can be defined as the ability to act intelligently within complex systems, i.e. wholes consisting of different parts with complicated interactions, dynamics and feedback loops (Saarinen & Hämäläinen, 2007). The conceptual basis of systems intelligence has been greatly influenced by systems thinking, especially by the highly acclaimed work of (Senge, 1990). Both of these systems approaches emphasize the holistic view of perceiving the world through interconnectivity and interdependence of its components rather than reducing the whole to its parts. They share the tenet that the whole is greater than its parts and that there are emergent phenomena that are not reducible to the properties of these parts. However, systems intelligence focuses on human behaviour within systems, rather than attempting to understand the system from the outside, which is characteristic for systems thinking. In systems intelligence, a person is recognized as an active part within the system with some power to affect its state, while being reciprocally influenced by the system. It is recognized that everyday systems have uncertainties, but they might still require taking action. Systems intelligence therefore strives to be an intuitive concept that brings new perspectives to everyday issues, leading to concrete actions.

Systems intelligence is conceptually related to the theory of multiple intelligences (Howard, 1983) and emotional intelligence (Goleman, 1995). Systems intelligence is, however, considered to be a higher level competence, which is not directly reducible to these forms of intelligences (Saarinen & Hämäläinen, 2010). Since systems intelligence also looks for opportunities for improvement within systems, it is also connected to positive psychology (Seligman & Csikszentmihalyi, 2000), a field of psychology focusing on how to live better rather than finding remedies to psychological problems. Systems intelligence is considered to be a combination of eight distinct capabilities: systems perception, attunement, reflection, positive engagement, spirited discovery, effective responsiveness, wise action and positive attitude (Hämäläinen, et al., 2014). These dimensions can be grouped roughly into four categories: perceiving, attitude, thinking and acting, as shown in Table 1.

Table 1. The eight dimensions of systems intelligence

Perceiving	Systems Perception	Attunement
Attitude	Positive Attitude	Spirited Discovery
Thinking	Reflection	Wise Action
Acting	Positive Engagement	Effective Responsiveness

Organizations can be naturally considered as systems, which makes systems intelligence a particularly useful concept to leadership and organizational life (Hämäläinen & Saarinen, 2008). Most organizations have a clearly defined goal, and systems intelligent behaviour in such a context is therefore finding actions within the organization that make it more effective at reaching its goals. Especially in leadership positions the potential to influence the system is large, which makes systems intelligence a key competence of a successful leader.

Organizations are examples of social groups. An important feature of social groups is that one seldom has an opportunity to view them from the outside, but rather one is an active part of the system with some power to affect its state. Social groups are therefore a great environment for the analysis of systems intelligence. For example a simple encouragement might have a surprisingly significant effect depending on the group. Humans are social animals, so we have a fairly developed innate ability to understand social systems. However, systemic features such as non-linear interactions, feedbacks, accumulation and time delays can be difficult to grasp intuitively. Therefore humans can have difficulties to see the potential that a simple act, such as an encouragement, might have on the group. Similarly it can be difficult the see the extent to which negative behaviour is detrimental for the group. Systems intelligence in a social context therefore requires an understanding of emotion dynamics.

Effects of positive and negative emotions

Since an encouragement or a criticism can have a great impact on individuals, and therefore on the whole group, it is no surprise that negative and positive affect may serve as an indication of how well a group of people function together.

The broaden-and-build theory in positive psychology suggests that positive emotions have a much larger role than merely to make one "feel good" or indicating emotional well-being (Fredrickson, 1998; Fredrickson, 2001). There is empirical evidence that experiencing positive emotions increases awareness and openness to consider a wider selection of thoughts and actions (Fredrickson & Branigan, 2005; Schmitz, et al., 2009). Contrary to negative emotions, that are often associated with narrow thought-action repertoires which are quite specific to cope with event that induces the negative reaction (e.g. fear tends to elicit a fight-or-flight response), positive emotions such as joy promotes playfulness, curiosity and interest, which can turn into a wide selection of different thoughts and actions. Through such positivity-induced actions, a person then builds her cognitive, social, psychological, emotional and physical resources that will be long lasting, unlike the fleeting emotions evoking this process (Fredrickson, 1998; Fredrickson, 2001).

Since experiencing positive emotions broadens one's thought-action repertoires and builds personal resources, positive emotions increase flexibility and ability to cope with adversities (Garland, et al., 2010; Fredrickson, et al., 2003). Therefore people experiencing positive emotions are more resilient against negative emotions and they are more likely to experience more positive experiences in the future, creating a positive feedback loop towards emotional well-being (Fredrickson & Joiner, 2002). Negative emotions also have a potential to turn into feedback loops, as is often observed in depression (Garland, et al., 2010).

An important concept in positive psychology is *flourishing*, which is "*to live within an optimal range of human functioning, one that connotes goodness, generativity, growth, and resilience*" (Fredrickson & Losada, 2005). The characteristic difference between flourishing and non-flourishing individuals appears to be the ratio of experienced positive and negative emotions (Fredrickson & Losada, 2005). A commonly used estimate for this tipping point has been 3:1, although it might not be universally applicable to all demographics (Fredrickson, 2013). People have a tendency to experience negative emotions more strongly than positive ones (Baumeister, et al., 2001; Rozin & Royzman, 2001), which might explain the asymmetry seen in the positivity ratio. This negativity bias seems to be relatively weaker for the flourishing individuals, who have a stronger reaction to positive everyday events (Catalino & Fredrickson, 2011). Another asymmetry between positive and negative emotions is the positivity offset, which is tendency to experience most neutral situations as mildly positive (Cacioppo, et al., 1999).

People have a tendency to be influenced by the emotions of others, known as emotional contagion, which has been defined by (Hatfield & Cacioppo, 1994) as:

> "*a tendency to automatically mimic and synchronize expressions, vocalizations, postures, and movements with those of another person's and, consequently, to converge emotionally*"

That is, people do not experience emotions and moods in isolation, but they are largely affected by the surrounding people, often unknowingly. Groups can experience collective emotional states, which are not directly reducible to the individuals of the group. This is referred to as the "top-down" view of group emotions, where the group is seen as an emotional entity that shapes the emotional responses of its individuals (Barsade & Gibson, 1998). However, it is argued that group emotions should also be viewed from a "bottom-up" perspective, where the composition of the individuals construct the emotional state of the group (Barsade & Gibson, 1998).

Positive emotional contagion has been linked to increased performance in social groups (Barsade, 2002). For example successful marriages tend to have a ratio of positive and negative interactions around 5:1 (Gottman, 2002). Similarly high performance business teams seem to have a positivity ratio of 5:1 (Losada & Heaphy, 2004). Thus the positivity ratio is a useful concept also in social groups. High positivity ratio also increases the number of strong connections in the group, referred to as *connectivity* (Losada & Heaphy, 2004). Similar observation has also been noted in (Waugh & Fredrickson, 2006), where positive emotions were shown to increase the feeling of "oneness" in the group, which could be interpreted as a form of connectivity. There is also empirical evidence that positive emotions increase sociability (Whelan & Zelenski, 2012), also a means to increase connectivity of the group.

Modelling the effects of emotions

Representing emotions

Computational processing and simulation of human emotion has been studied in the field of *affective computing* (Picard, 1997). There have been several attempts to identify a discrete set of fundamental basic emotions that are cross-culturally recognized and that can explain more complicated emotions (see e.g. (Ekman & Friesen, 1971; Jack, et al., 2014; Plutchik, 2001)). Although there is no consensus on the number of basic emotions (Ortony & Turner, 1990), one approach to modelling emotions could be to select a subset of them to be represented separately. Emotional contagion of different basic emotions has been studied in (Doherty, 1997). However, it is more common to represent emotions with different dimensional models, which usually have two to three different dimensions to describe the emotions (Marsella, et al., 2010). Typical parameters for these models are valence, which represents emotion in the negativity-positivity continuum, and arousal, which indicates the intensity of the subjective emotion parameters. For example, hate is a highly aroused state with negative valence, whereas boredom would be a state with negative valence and low level of arousal. Examples of dimensional models of emotion are, for example, the circumplex model (Russell, 1980), which uses valence and arousal dimensions, and the PAD model (Mehrabian, 1980), which also incorporates dominance-submissiveness dimension. For instance, hate and fear are examples of dominant and submissive emotions.

The dimensional models of emotions are mostly concerned with representing different emotions. However, the interest of this work is the effects of positivity and negativity in social groups, so there is no need to represent different emotions and it is natural to model them only in terms of their impact on positivity and negativity. This also greatly simplifies the model since the complex interplay of different emotions and also their arousal/dominance aspect can be omitted. Therefore only models that concentrate on positivity and negativity are considered in this work.

One interesting note is that it is common to represent mood by its positivity, so the simplification of modelling emotions by classifying them into positive and negative might capture some other affective phenomena such as mood. The main distinctive difference between mood and emotion is that mood is generally a much longer lasting phenomenon, whereas emotions usually only last at most a couple of hours (Frijda, 1993).

Emotional contagion models

Although John M. Gottman does not use the term "emotional contagion", his research on marital happiness is highly relevant (Gottman, 2002). Gottman models the interaction between husband and wife with equations

$$W_{t+1} = I_{HW}(H_t) + r_1 W_t + a \tag{1}$$

$$H_{t+1} = I_{WH}(W_t) + r_2 H_t + b, \tag{2}$$

where W_t and H_t represent the emotional states of the wife and the husband respectively at time t. Husband and wife affect each other through their influence function I_{HW} and I_{WH}, which are bilinear functions of the influencing partner's current emotional state. The rest of the equation represents the uninfluenced part, which describes the behaviour of the spouse when there is no interaction between the partners. Parameters r_1 and r_2 are called emotional inertia that describe how quickly the emotional states approach their steady states. The parameters a and b do not have an intuitive interpretation, but they affect the dynamics of the model. Gottman has also extended the model with additional correction terms (Gottman, 2002).

Agent-based simulations have been used extensively to model phenomena in social sciences (see e.g. (Gilbert, 2004)), so it is no surprise that agent-based modelling has been used to model emotional contagion. (Bosse, et al., 2009a) suggest a model where the emotional contagion strength between agents i and j is represented by

$$\gamma_{i,j} = \varepsilon_i \alpha_{i,j} \delta_j, \tag{3}$$

where ε_i is the strength by which the agent i expresses its level of emotion. This can be understood as the degree of introversion/extroversion of the agent. Parameters $\alpha_{i,j}$ represent the connection strength between agents i and j, which can be understood as how close the social relationship between the agents is and how much they are interacting with each other. δ_j represents how easily the emotions of agent j are affected by the emotions of others, which can be interpreted as emotional sensitivity.

The overall emotional impact directed towards agent j is then

$$q_j^* = \sum_{i \neq j} \frac{\gamma_{i,j} q_i}{\gamma_j}, \tag{4}$$

where q_i is the emotion level of agent i and

$$\gamma_j = \sum_{i \neq j} \gamma_{i,j} \tag{5}$$

is the overall emotional contagion strength. The interaction model in (Bosse, et al., 2009a) is then

$$q_j(t + \Delta t) = q_j(t) + \gamma_j \left(q_j^*(t) - q_j(t) \right) \Delta t. \tag{6}$$

In this model the emotional level of agent j is updated towards the overall emotional impact directed at the agent. The magnitude of the update depends on the overall emotional contagion strength of the agent.

(Bosse, et al., 2009b) extends the model by introducing a bias term β_j representing whether the agent is more susceptible to positive or negative emotional impacts. The interaction formula of this model is then

$$q_j(t + \Delta t) = q_j(t) + \gamma_j \left(\beta_j PI(t) + \left(1 - \beta_j\right) NI(t) - q_j(t) \right) \Delta t. \tag{7}$$

This has again been extended in (Hoogendoorn, et al., 2011), where the parameter η_j was introduced, representing the tendency of agent j to amplify or absorb the received emotion impacts, leading to an equation

$$q_j(t + \Delta t) = q_j(t) + \gamma_j \left[\eta_j \left(\beta_j PI(t) + \left(1 - \beta_j\right) NI(t) \right) + \left(1 - \eta_j\right) q_j^*(t) - q_j(t) \right] \Delta t. \tag{8}$$

MODELLING THE CONTAGION OF EMOTIONS

A new model is proposed to capture the essential dynamics of emotional contagion in groups. Since this work focuses on positivity ratios and its effects on organizations and social groups, elaborate models aiming to accurately reproduce the variety of different emotions are not considered. The model focuses only on the level of positivity and negativity of emotions. However, since there are some qualitative differences between positive and negative emotions, such as broadening and narrowing of awareness and the negativity bias, positive and negative emotions are represented as separate variables. Similarly to Gottman's model in (1) and (2), the proposed model is of the form

$$P_j(t+1) = a_j P_j(t) + b_j + \sum_{i \neq j} I_{i,j}^P(t) \tag{9}$$

$$N_j(t+1) = c_j N_j(t) + d_j + \sum_{i \neq j} I_{i,j}^N(t). \tag{10}$$

As in Gottman's model, the positive and negative states can be separated into the influenced and uninfluenced components. The influenced components are represented by the influence functions $I_{i,j}^P$ and $I_{i,j}^N$, which characterize the interaction and emotional contagion between the agents i and j, whereas the remaining terms of the model represent the uninfluenced part of the emotional state of agent j. That is, the uninfluenced part represents the emotional state of the agent when there is no interaction between any other agents. When the influence functions are set to zero and the agents are only affected by the uninfluenced component of the model, then

$$P_j(t+1) = a_j P_j(t) + b_j \tag{11}$$

$$N_j(t+1) = c_j N_j(t) + d_j. \tag{12}$$

From this we get the following stable steady states for the model

$$P_j = \frac{b_j}{1 - a_j} \tag{13}$$

$$N_j = \frac{d_j}{1 - c_j}. \tag{14}$$

Therefore it follows, that the stable steady state for the positivity ratio in the uninfluenced case is

$$\frac{P_j}{N_j} = \frac{b_j(1 - c_j)}{d_j(1 - a_j)}. \tag{15}$$

The general positivity of the agent can be characterized by setting proper values for these parameters, e.g. a flourishing person might have the ratio $\left(b_j(1 - c_j)\right)/\left(d_j(1 - a_j)\right)$ of 3:1. Gottman calls a_j and c_j emotional inertia parameters (Gottman, 2002), which indicate how quickly the agent returns to its steady state. Positive emotions tend to be more fleeting and short-lasting than negative emotions (Baumeister, et al., 2001), so for most people it would be expected that $a_j > c_j$. It is also worth noting, that the uninfluenced case in (11) and (12) have solutions

$$P_j(t) = a_j^t P_j(0) + \frac{b_j\left(1 - a_j^t\right)}{1 - a_j} \tag{16}$$

$$N_j(t) = c_j^t N_j(0) + \frac{d_j\left(1 - c_j^t\right)}{1 - c_j}. \tag{17}$$

Therefore $\frac{P_j}{N_j} \rightarrow \frac{b_j(1-c_j)}{d_j(1-a_j)}$ when $t \rightarrow \infty$, only if $|a_j| < 1$ and $|c_j| < 1$.

The positivity ratio of the model in (9) and (10) increases, when

$$\frac{P_j(t)}{N_j(t)} < \frac{P_j(t+1)}{N_j(t+1)} = \frac{a_j P_j(t) + b_j + \sum_{i \neq j} I_{i,j}^P(t)}{c_j N_j(t) + d_j + \sum_{i \neq j} I_{i,j}^N(t)} \tag{18}$$

$$\Rightarrow \frac{P_j(t)}{N_j(t)}\left[c_j N_j(t) + d_j + \sum_{i \neq j} I_{i,j}^N(t)\right] < a_j P_j(t) + b_j + \sum_{i \neq j} I_{i,j}^P(t) \tag{19}$$

$$\Rightarrow \frac{P_j(t)}{N_j(t)} < \frac{\left(a_j - c_j\right)P_j(t) + b_j + \sum_{i \neq j} I_{i,j}^P(t)}{d_j + \sum_{i \neq j} I_{i,j}^N(t)}. \tag{20}$$

Assuming $a_j = c_j$, the inequality is further simplified to

$$\frac{P_j(t)}{N_j(t)} < \frac{b_j + \sum_{i \neq j} I_{i,j}^P(t)}{d_j + \sum_{i \neq j} I_{i,j}^N(t)}. \tag{21}$$

This shows that the change of P/N depends both on the agent's personal characteristics of b_j and d_j and the external influences determined by the influence functions. Since it is assumed that $a_j = c_j$, the uninfluenced steady state of the agent is simply b_j/d_j as seen from the equation (15). Therefore if the values of b_j and d_j are large compared to the influence functions, P/N converges towards the uninfluenced steady state of the agent. In other words, by changing the absolute values of b_j and d_j the behaviour of the model can be adjusted to either emphasize the impact of the influence functions or the agent's general positivity determined by the uninfluenced steady state. This is analogous to the "top-down" and "bottom-up" view of group emotions in (Barsade & Gibson, 1998). The parameters b_j and d_j also keep P/N within a finite positive range, avoiding both zero and infinity. This suggests that adjusting the b_j and d_j parameters also affects how volatile the behaviour of P/N is.

Influence functions

The proposed form for the influence functions is

$$I_{i,j}^{P}(t) = \gamma_{i,j}(1-\beta_j)P_i^{rel}(t) \tag{22}$$

$$I_{i,j}^{N}(t) = \gamma_{i,j}\beta_j N_i^{rel}(t). \tag{23}$$

It is known that the ratio of positive and negative emotions is the distinctive difference between flourishing and non-flourishing individuals (Fredrickson, 2013; Fredrickson & Losada, 2005), so it is assumed that the agents interact with the other agents according to their positivity ratios. Instead of directly using the positivity ratio *P*/*N*, relative positivity and negativity ratios are used, defined as

$$P_j^{rel}(t) = \frac{P_j(t)}{P_j(t)+N_j(t)} \tag{24}$$

$$N_j^{rel}(t) = \frac{N_j(t)}{P_j(t)+N_j(t)} \tag{25}$$

to limit the interaction values within the range [0,1] and to avoid issues caused by the singularity of *P*/*N* when $N \to 0$.

The parameter β_j describes the negativity bias effect, i.e. a negative event has more impact than a corresponding positive effect (Rozin & Royzman, 2001). Accordingly, the effects of negative events are emphasized when $\beta_j > 1 - \beta_j$. Negativity bias can be also interpreted as the different slope parameters in the bilinear influence function of Gottman's model in (1) and (2). The models (7) and (8) also take the negativity bias into account by weighting the positive and negative emotional impacts with β_j and $1 - \beta_j$. Parameter $\gamma_{i,j}$ describes the strength of emotional contagion. As in (3) , it is expressed as

$$\gamma_{i,j} = \varepsilon_i \alpha_{i,j} \delta_j. \tag{26}$$

Here ε_i describes how strongly agent *i* expresses her emotional state to the other agents, $\alpha_{i,j}$ represents the level of interaction between agents *i* and *j* and δ_j describes how greatly the emotional level of agent *j* is affected by the emotional influence of other agents.

Broaden-and-build extension

The broadening effect of positivity is one of the main tenets of the broaden-and-build theory (Fredrickson, 2001). This is implemented by increasing both δ_j, which represents the emotional sensitivity of the agent, and ε_i representing extroversion. Increasing either of these parameters also increases the total emotional contagion strength and thus increases the connectivity of the group as stated in (Losada & Heaphy, 2004). As the value of δ_j is increased, the effect of the group on the emotional state of the agent also increases. Thus the coupling between the agent and the whole group becomes stronger. This is consistent with the results of (Waugh & Fredrickson, 2006), which states that increased positivity affects the feeling of "oneness" in the group. Increasing the extroversion parameter ε_j as the positivity ratio increases is also consistent with (Whelan & Zelenski, 2012), which states that positivity has a favourable effect on sociability.

The increase of δ_j and ε_j is implemented with simple linear models

$$\delta_j(t) = P_j^{rel}(t-1)\left(\delta_j^{MAX} - \delta_j^{MIN}\right) + \delta_j^{MIN} \quad (27)$$

$$\varepsilon_j(t) = P_j^{rel}(t-1)\left(\varepsilon_j^{MAX} - \varepsilon_j^{MIN}\right) + \varepsilon_j^{MIN}. \quad (28)$$

It is assumed that $\delta_j^{MIN} < \delta_j^{MAX}$ and $\varepsilon_j^{MIN} < \varepsilon_j^{MAX}$ to ensure that δ_j and ε_j increase as the positivity ratio of the agent increases.

The broaden-and-build theory states that experiencing positive emotions facilitates coping with adversity (Fredrickson, et al., 2003; Garland, et al., 2010). Using the same approach as with δ_j and ε_j parameters, the parameter β_j is modelled with a linear model depending on the level of relative positivity P_j^{rel}. That is

$$\beta_j(t) = P_j^{rel}(t-1)\left(\beta_j^{MIN} - \beta_j^{MAX}\right) - \beta_j^{MIN} + 1. \quad (29)$$

This makes the agent less susceptible to negativity when its positivity ratio increases. Again it is assumed that $0 \leq \beta_j^{MIN} < \beta_j^{MAX} \leq 1$ so that the negativity bias decreases as the positivity ratio increases. This also ensures that β_j and $1 - \beta_j$ are non-negative.

Selecting the model parameters

The presented emotional contagion model has several free parameters, and some choices were made regarding which of these should be adjustable by the user and which of them should be given a fixed value. Granting the user too much freedom can be overwhelming and make it more difficult to obtain insights from the application. Therefore the following choices have been made.

- *Emotional inertia*. This is denoted by parameters a_j and c_j, which are given a fixed value of 0.9. Although negative emotions tend to be longer lasting than positive ones, these parameters are given the same value since the impact of negative emotions is already emphasized by the negativity bias parameters. A shared value also facilitates the reasoning of the model behaviour as shown in (21).
- *General positivity*. This corresponds to the positivity ratio in the uninfluenced steady state of the agent given by equation $P_j/N_j = \left(b_j(1-c_j)\right)/\left(d_j(1-a_j)\right)$. That is, how positive the agent is when there is no interaction with any other agents in the system. Since $a_j = c_j$, the general positivity is determined by the parameters b_j and d_j. The sum of b_j and d_j is given a fixed value of 0.1 and this is divided between the parameters so that the agent will have the general positivity level set by the user. Also the initial P_j and N_j levels are determined so that their sum is 10, which is divided between P_j and N_j so that the P_j/N_j equals to the given general positivity value.
- *Extroversion*. This is the parameter ε_j and can be interpreted as the tendency to express one's emotional level to others. In the simulator this is implemented as a linear function as defined by equation (28) to take into account the increase in connectivity as the positivity ratio increases. The user is allowed to adjust ε_j^{MIN} between $[0, 0.8]$ and ε_j^{MAX} is fixed at $\varepsilon_j^{MIN} + 0.2$. That is, the extroversion parameter is determined by

$$\varepsilon_j(t) = 0.2P_j^{rel}(t-1) + \varepsilon_j^{MIN}, \quad \varepsilon_j^{MIN} \in [0,0.8]. \tag{30}$$

- *Emotional sensitivity*. This corresponds to δ_j, the tendency of agent's own emotional level being affected by the emotions of others. This is implemented similarly to extroversion using the linear equation (27) and the user is allowed to change δ_j^{MIN} within range $[0, 0.8]$ and δ_j^{MAX} is fixed at $\delta_j^{MIN} + 0.2$. This corresponds to equation

$$\delta_j(t) = 0.2P_j^{rel}(t-1) + \delta_j^{MIN}, \quad \delta_j^{MIN} \in [0, 0.8]. \tag{31}$$

- *Connection strength*. Determined by parameters $\alpha_{i,j}$, which represents how strong the social relationship is between the agents i and j. The user is allowed to change this parameter between $[0, 1]$.

- *Negativity bias*. As stated in the broaden-and-build theory, experiencing positive emotions increases the capability to cope with negative emotions and therefore the negativity bias is changed according to the equation (29). The user is allowed to change β_j^{MIN} between $[0, 0.5]$ and β_j^{MAX} is set to $\beta_j^{MIN} + 0.5$. Negativity bias is therefore determined by

$$\beta_j(t) = -0.5P_j^{rel}(t-1) + 1 - \beta_j^{MIN}, \quad \beta_j^{MIN} \in [0, 0.5]. \tag{32}$$

PoSITeams presents these parameter ranges as sliders with values between $[0, 1]$ and they are internally mapped to the aforementioned ranges. This makes the user interface more consistent for the user. The only exception to this is the general positivity parameter, since it has a direct interpretation as a positivity ratio.

HOW TO BEST IMPROVE TEAM BEHAVIOUR

Considering the emotional contagion model as an optimization problem, there are a number of interesting problems to investigate, such as

- find the optimal behaviour that maximizes the individual or collective positivity ratio
- find the optimal structure of the organization
- what kind of a team member would be the best addition to the team in terms of maximizing the positivity ratio of the team

Simulated annealing

The optimization of the emotional contagion model is performed with simulated annealing for its simplicity. Simulated annealing is an approximate global optimization technique that emulates the process of slowly cooling a heated metal and thus minimizing its thermodynamic free energy (Kirkpatrick, et al., 1983). A typical example of its application is the traveling salesman problem, a classic NP-hard problem (Černý, 1985).

To use simulated annealing, each value combination of free parameters of the system is defined as a state. For simplicity, all the parameters are considered to be discrete values within a predefined interval. A neighbouring state is obtained from the current state by randomly changing the value of each parameter p with a probability of

$$P(|\Delta p| > 0) = \min\left(\frac{1}{2}, 1 - \frac{S-2}{S}\right), \tag{33}$$

where *S* is the number of parameters in the state. The expected number of parameters to be changed is therefore 2, when $S \geq 4$. This is motivated by the assumption that good solutions are located near other good solutions. After a number of iterations the current solution is presumably better than a randomly selected state and by doing a minor change in the current state, the obtained neighbouring state is also likely to be good. Minor alterations to the current state hopefully improve the poor parts of the solution while keeping the good parts mostly unchanged.

If a parameter value *p* is changed, its new value *p*' is selected uniformly from range

$$p' \in [\max(l, p - 0.1N), \min(u, p + 0.1N)]. \tag{34}$$

where *l* and *u* define the lower and upper bound of the parameter interval of length *N*. Each state *s* has an associated energy defined by the energy function *E*(*s*). The algorithm attempts to find the state with the lowest energy. The transition from state *s* to its neighbouring state *s*' is accepted with probability

$$P(e, e', T) = \begin{cases} 1 & if\ e' \leq e \\ \exp(-(e' - e)/T) & if\ e' > e, \end{cases} \tag{35}$$

where *e* and *e*' are the energies of the states *s* and *s*' respectively. *T* is the temperature parameter, which is initially set to $T_0 = 10^{10}$ and cooled according to $T_{n+1} = 0.999T_n$ until $T < 0.01$. This corresponds to 27618 iterations, which has been found out to be sufficiently quick and accurate in practice.

The energy function can be chosen rather freely. It can be for example the negative P/N of a single agent or the negative mean P/N of all the agents. The P/N value can be evaluated by performing simulations for each parameter combination until convergence. However, reaching convergence can be slow in practice, so a predefined number of simulations is used to evaluate P/N approximately. A value of 100 is used to provide satisfactory results in reasonable time. Other interesting energy functions could be negative of the minimum P/N of the group, so that the objective is to maximize the lowest P/N in the group.

The energy functions can incorporate costs associated with changing a parameter value. The motivation behind this is that there is always some effort required in changing one's behaviour or social connections. Also some changes are easier than others, for example increasing extroversion can be easier for someone than decreasing negativity bias.

The actual cost functions for Δp are unknown, so it is assumed that each parameter *p* has a cost c^- for a negative change of one unit and a cost c^+ for a positive change of one unit. This corresponds to a bilinear cost function g_p as shown in Figure 1.

Including the costs in the optimization turns the problem into a multi-objective optimization problem. A common approach to multi-objective optimization is to optimize a weighted sum of all the objectives (Marler & Arora, 2004). The costs are therefore combined with an energy function *E*(*s*) by

$$E'(s) = (1 - w)E(s) + \frac{w}{M}\sum_{p \in s} g_p(\Delta p), \tag{36}$$

where $w \in [0, 1]$ is the trade-off between minimizing the original energy function and minimizing the costs associated with changing any of the parameters. M is the number of agents in the system, hence the total cost is divided between all the agents (i.e. it is easier for two agents to do one behavioural change each than for one agent to do two changes).

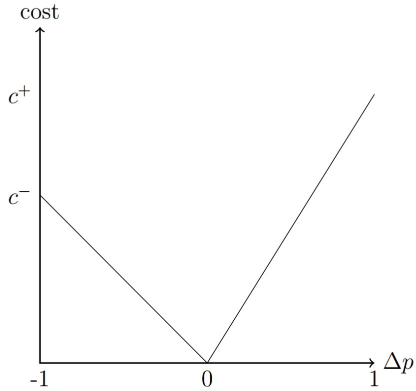

Figure 1. An example of a bilinear cost function g_p of changing the value of parameter p.

EXAMPLE SIMULATIONS

The following examples simulations are performed with the PoSITeams simulator, which can be found at http://systemsintelligence.aalto.fi/positeams. Most of the simulator view is dedicated for visualizing the agents and their connections as seen in the figures of the example simulations. The agents change their color from deep blue to bright yellow depending on their positivity ratio. Similarly the facial expression of the agent varies dynamically from sad to happy depending on its current positivity ratio. The positivity ratios are also drawn as a function of iterations next to the agent graph. The connections between the agents are shown as links in the directed graph and their opacity is directly proportional to the total emotional contagion strength $\gamma_{i,j}$ between the agents. The length of the links also indicates the level of interaction and the strength of the social relationship between the agents described by the parameters $\alpha_{i,j}$, which enforces clustering of socially connected groups.

A simple group

The first simulation example consists of three agents, one positive and two negative. The agent parameters of the example are shown in Table 2. The agent parameters of the first simulation example. All the connections have a strength of 1, except there is no connection from Cecilia to Bob. Figure 2 shows the simulation at its steady state after around 200 iterations. The average positivity ratio in this steady state is only 0.14, which is much lower than the general positivity of any of the agents. Similar behaviour can be observed in (Bosse, et al., 2009b) using the model (7), where the authors model emotion contagion spirals inspired by the broaden-and-build theory. The behaviour in this simulation example can be considered an example of a negativity spiral and it is also an example of a collective emotional state, which is not a sum of its parts, consistent with the "top-down" view in (Barsade & Gibson, 1998). This is a consequence of fixing $b_j + d_j$ to a small value of 0.1. The agents are affected both by their individual characteristics and their neighbouring agents. This balance can be adjusted by the b_j and d_j parameters of the model as shown in (21). When this sum is set to a larger value, the behaviour of the agents is largely determined by their general positivity rather than their environment. The sum of these parameters is therefore set to a small value in the simulator, since it shows more interesting behaviour by incorporating both the "top-down" and "bottom-views" of collective emotions as stated (Barsade & Gibson, 1998). This also allows the model to describe behaviour analogous with emotional contagion spirals.

Table 2. The agent parameters of the first simulation example.

Name	General positivity	Extroversion	Emotional sensitivity	Negativity bias
Adam	5	1	1	0.6
Bob	1	0.8	0.8	0.7
Cecilia	1	0.8	0.8	0.7

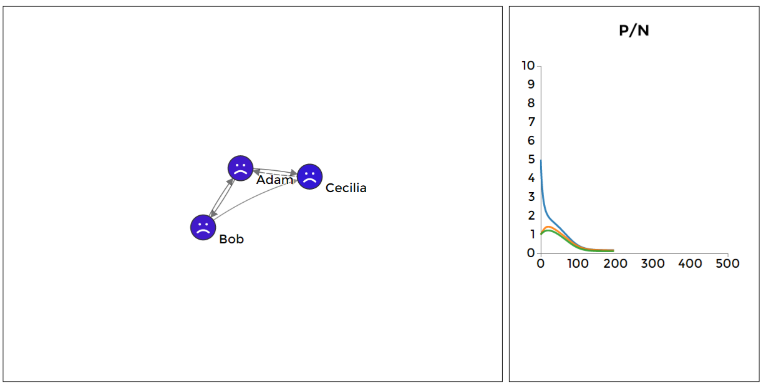

Figure 2. The first simulation example after reaching its steady state.

The behaviour of Adam is then optimized, restricting the optimization only to adjustment of emotional sensitivity and extroversion. This leads to a change in emotional sensitivity from 1 to 0, whereas the level of extroversion stays unchanged. Since Adam is the most positive of the three agents with general positivity of 5, it is natural to adjust the emotional sensitivity to a low value to self-generate positivity and increase resistance to external negativity. Also having a high level of extroversion is beneficial to spread positivity in the system. This adjustment leads to an average P/N of 5.53 as shown in Figure 3.

Now the average positivity ratio is larger than the general positivity of any of the agents. Again, this is similar to the model in (Bosse, et al., 2009b) being an example of a positive spiral. The main difference is that (Bosse, et al., 2009b) have a stricter interpretation of the emotional contagion as converging to the same shared emotional state. In the example shown in Figure 3, the agents have different steady states caused by individual differences, but they still represent a collective emotional state and an example of a positive spiral. This is also consistent with the view in (Barsade & Gibson, 1998), where the authors argue that studying group emotion should include both views, the "top-down" view where the emotions of the individuals arise from the group and the "bottom-up" view, where the group emotion is determined by a composition of the emotions of the individuals.

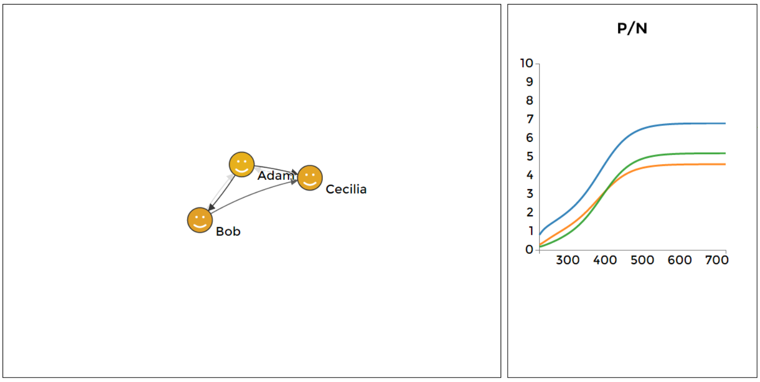

Figure 3. The state of the system after optimizing the emotional sensitivity and extroversion parameters of Adam.

An interesting behaviour happens when the emotional sensitivity and extroversion parameters of Adam are optimized again, starting from the state shown in Figure 3. As a result of this, the emotional sensitivity is set from 0 to 1, which increases the average P/N to 8.22 as shown in Figure 4. Interestingly, the emotional sensitivity and the extroversion parameters of Adam are exactly the same as in the initial negative steady state. One might expect that setting the parameters to their original values would have a negative effect, returning the system to its original state. However, the difference is that the system is not the same anymore and whereas in the beginning Adam was surrounded by negative agents, now he is surrounded by positive ones. Being emotionally sensitive is a positive quality in a positive environment since it lets one be influenced by the surrounding positivity. Conversely, being emotionally stoic is beneficial in a negative environment. This example also demonstrates that it is not necessarily possible to reach the global optimum of the system using a single optimization step, since the optimal behaviour in the global optimum might not suffice to escape the initial negative steady state.

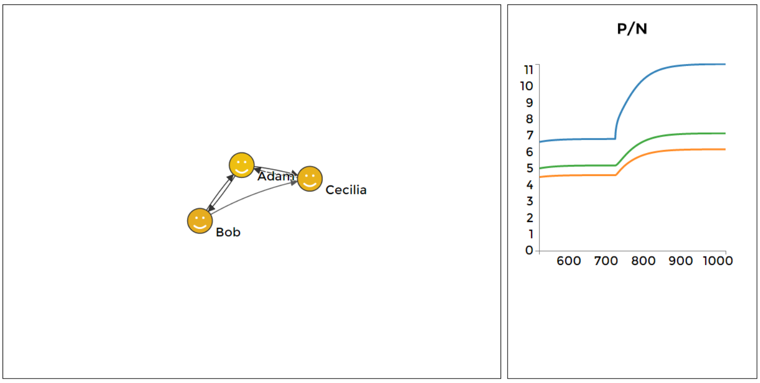

Figure 4. The state of the system after optimizing the emotional sensitivity and extroversion of Adam for the second time starting from the state shown in Figure 3. This demonstrates that it can be impossible to reach the global optimum of the system with a single optimization. Also, changing the parameters to their original values does not necessarily return the system to its original state.

A small organization

Optimization with zero costs

A more complicated example is shown in Figure 5, which consists of two small teams with a shared supervisor. The agent parameters of the example are shown in Table 3. All the connections shown in the figure have a strength of 1. Team A consists of Adam, Albert and Anna, whereas team B is formed by Barbara and Bob. Cecilia is the supervisor of the two teams. To enforce the team structure in the simulation, the parameter limits are set so that connections within each team must be in range [0.5, 1] and between the teams within [0, 0.1]. Cecilia must have connection strengths in the range [0.2, 1] with all the members in the organization. The general positivity of all the agents is also constrained between [0, 5] and the negativity bias must be within [0.5, 1]. The whole group is then optimized without parameter costs, which leads to a steady state shown in Figure 6 with an average positivity ratio of 34.66. Detailed optimization results can be found in the Appendix.

Table 3. The agent parameters of the organization simulation example.

Name	General positivity	Extroversion	Emotional sensitivity	Negativity bias
Adam	2	0.2	0.2	0.6
Albert	5	0.8	0.8	0.6
Anna	3	0.2	0.8	0.6
Barbara	2	0.3	0.3	0.6
Bob	2	0.3	0.3	0.6
Cecilia	1	0.9	0.4	0.8

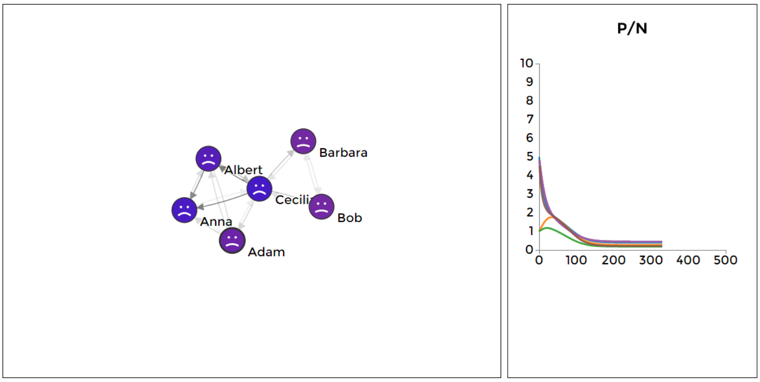

Figure 5. Steady state of the small team before optimization.

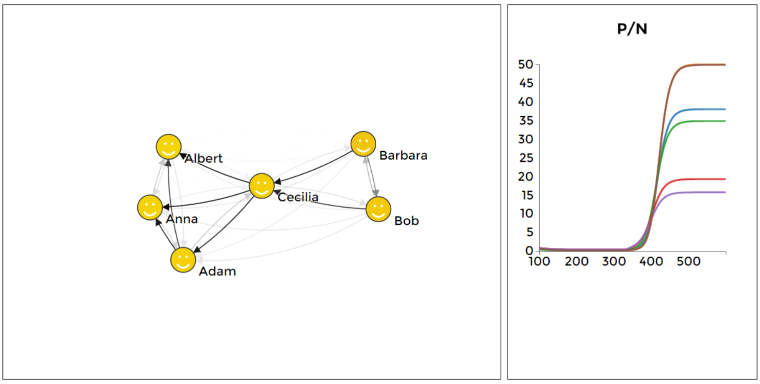

Figure 6. The result of optimization with no parameter costs.

Although the exact solution varies between subsequent runs, since simulated annealing is an approximate global optimization method, the general trend is minimizing negativity bias, maximizing general positivity and strong emotional connection strengths. However, the "trivial solution" of setting extroversion, emotional sensitivity and general positivity to maximum and negativity bias to minimum fails to escape the negative steady state, eventually reaching a steady state with an average P/N of 0.12. In the solution Cecilia draws positivity from team B and spreads it to team A, which seems to enable escaping the negative steady state, while keeping a fairly strong level of connectivity.

Optimizing connection strengths

Another type of solution can be obtained by only optimizing the connection strengths, attempting to find an optimal organizational structure. Again no parameter costs are used and the limits are kept the same as for the previous example. This leads to a solution in Figure 7 with an average P/N of 3.37. Detailed optimization results can be found in the Appendix.

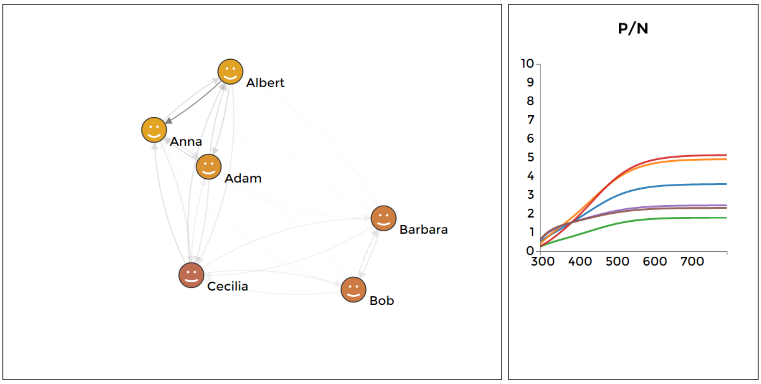

Figure 7. The results of optimizing the connection strengths of the group.

The main characteristic of the obtained solution is that the connection strengths from Cecilia to other agents are minimized. According to the general positivity parameter, Cecilia is the most negative person in the group. Thus the solution is to restrict the flow of negativity originating from her by decreasing emotional contagion strengths.

Optimization with costs

PoSITeams allows assigning costs for changing each of the agent and connection parameters. This takes into account the effort associated with changing one's behaviour or social relationships. For the following simulation example, these costs (both c^+ and c^-), are assigned so that for each agent the cost of changing general positivity or negativity bias is set to 10 and the cost of changing any of the other parameters is set to 1. Since the solution of the optimization without costs invariably maximizes general positivity and minimizes negativity biases, large costs are assigned to these parameters to moderate their effect. The trade-off parameter w in equation (36) is set to 0.5. The solution with an average P/N of 12.46 is shown in Figure 8. Detailed results can be found in the Appendix.

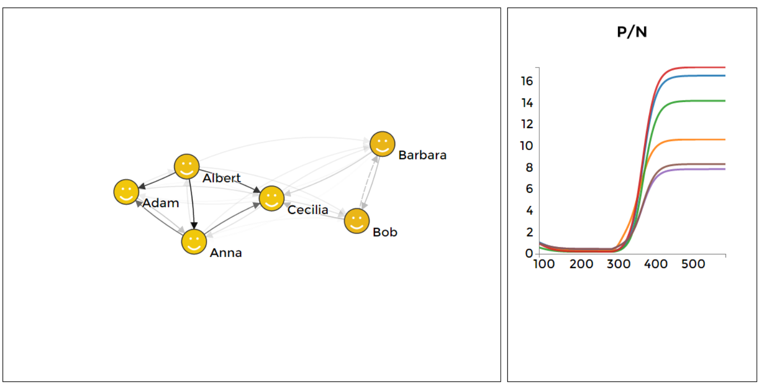

Figure 8. The solution of the optimization with costs.

Two interesting aspects of the obtained solution is the weak connection strengths from Cecilia and strong connection strengths from Albert, who is the most positive agent based on general positivity. Albert is given a more central role to benefit from his positivity, while Cecilia's role is diminished.

Adding a new team member

The last example examines the possibility of adding a new member, Brian, to the team B. The question is, what kind of person Brian should be and what should be his role so that the average positivity ratio of the group is maximized? The connection strengths between Brian and team A are limited within range [0, 0.1] to enforce the structure of two separate teams. Other connections are left unconstrained. All the parameters are given zero costs to give different solutions equal weights. In this example, Brian is to be considered a pseudo member rather than an actual team member with personal characteristics. Thus changing the parameter values does not correspond to changing the behaviour of an actual team member and there is no cost associated with changing one's behaviour. Instead, we are interested in the characteristics that an optimal team member would have. The solution of the optimization is shown in Figure 9, with an average P/N of 7.82. Detailed optimization results are found in the Appendix.

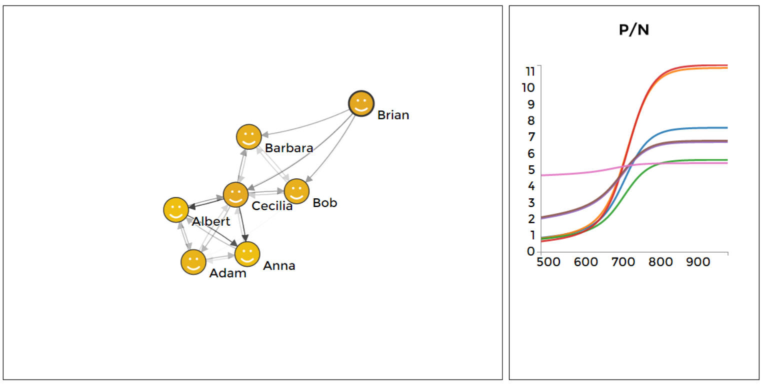

Figure 9. The solution of adding an optimal team member, Brian, to the group.

The solution is to give Brian a role where he strongly communicates towards his team members, while keeping a certain distance so that he is not himself affected by the negativity of the group. This rather one-sided communication channel might not be especially realistic in practice, but alternative solutions can be found by adjusting the costs and parameters limits and exploring different outcomes. One possibility is to set the lower bound of the total incoming connections to 1. This leads to a solution shown in Figure 10. The solution takes hundreds of iterations to escape the negative steady state, but eventually a steady state with a mean P/N of 8.85 is reached. This is even higher than in the previous example, but qualitatively the solutions are quite similar. Detailed results can be found in the Appendix. The incoming connections are divided between Bob and Barbara since they are more positive than Cecilia. However, the emotional sensitivity of Brian is set to zero and therefore hardly any emotional contagion occurs, allowing Brian to spread positivity in the network without being affected by the negativity of the organization.

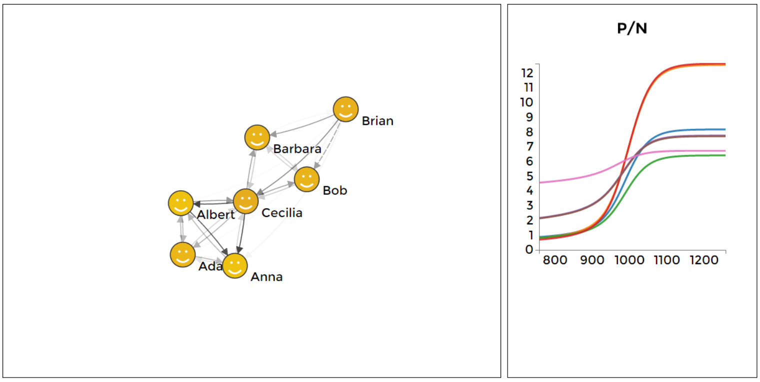

Figure 10. The solution after optimizing Brian with the lower bound of the total incoming connection strengths set to 1.

DISCUSSION

The simulation examples demonstrate how PoSITeams can introduce ideas for a more constructive behaviour in social systems, such as when being emotionally sensitive can be beneficial and when not, or what kind of interventions and structural changes might improve effectiveness of organizations. Obviously, the underlying model described in this work has not been yet validated with any real world data, so any predictions and quantitative values that the model gives remain theoretical. Nevertheless, we consider that there are still several potential applications for PoSITeams.

For example, PoSITeams could be used to facilitate perceiving organizations as systems and demonstrate plausible systemic effects that can occur within them. Exploration of different behavioural and structural changes may promote reflective thinking, allowing the user recognize herself as an active part of the system with potential to change the system from within. Therefore PoSITeams could be used as a tool to promote systems intelligence. Considering the eight dimensions of systems intelligence (Hämäläinen, et al., 2014), we can reflect on how well each of these dimensions is accounted for in PoSITeams:

- *Systems perception:* the simulator presents the organization as a graph, which draws the attention to the relationships between the members of the organization. The graph presentation also focuses on the holistic view of the organization by providing a view of the whole organization at once.

- *Attunement:* The simulator draws attention to how our own behaviour can affect the whole organization. Therefore it encourages the user to be more aware of her behaviour. Also the simulations themselves can be rather engaging and perceiving oneself visually as a part of the whole can increase awareness of the systemic nature of social groups and possibilities that may ensue.

- *Reflection:* The user is encouraged to reflect on her own behaviour and relationships with others as she provides parameter values to the model.
- *Positive engagement:* Since the application simulates emotional contagion and focuses on the positivity ratios and their effects on organizational performance, the user is encouraged to interact positively with other people.
- *Spirited discovery:* The simulator offers possible scenarios, promoting "what-if" thinking and providing food for thought. The focus is also on embracing change and finding concrete actions to change the system for the better.
- *Effective responsiveness:* The simulator can identify leverage points in the organization either by letting the user to explore various behavioural and structural changes or by using the optimization functionality provided by the simulator.
- *Wise action:* By using the simulator, the user hopefully obtains a better understanding of the organization as a whole and how it can be affected by our own behaviour. The systems perspective also attempts to demonstrate typical features of systems, which ideally transforms into deeper understanding of systems and therefore wiser actions.
- *Positive attitude:* Again, the simulator focuses on the effects of positivity, which encourages an overall positive attitude.

It would be therefore an interesting direction for future research to evaluate whether using PoSITeams leads to more systems intelligent behaviour. This relates to a growing interest of developing technology to promote well-being (see e.g. "positive computing" by (Calvo & Peters, 2014)). Instead of promoting mental faculties such as mindfulness, empathy or compassion, it would be interesting to develop ways to improve systems intelligence. Applications that focus on increasing mental well-being are often designed to resemble games (see e.g. (McCallum, 2012)), a concept known as gamification, which aims at making the application highly engaging and fun. Perhaps a potential use case for PoSITeams would be to make it more game-like. For example the user could be given different social groups and corresponding tasks, such as maximizing the overall positivity of the given group. The approach of posing the user problems that she must solve could be more beneficial in terms of promoting systems intelligence. Also the user would be dealing with "imaginary" social groups, which might make it easier to consider actions that do not come naturally to the user. In actual social groups there can be reservations, e.g. "my workplace does not allow me to be more introverted", which might make the user more reluctant to consider alternative behavioural modes.

Another interesting question is whether using the simulator actually leads to better actions at the organizational level. Peter Senge identifies five key features of learning organizations in his book The Fifth Discipline (Senge, 1990): personal mastery, mental models, shared vision, team learning and systems thinking. These disciplines are promoted in PoSITeams in following ways:

- *Personal Mastery:* The simulator promotes personal growth by demonstrating how changing each of the personal characteristics can improve both personal well-being and organizational performance.

- *Mental models:* The systems perspective presents a new way to visualize and think about the organization, which can challenge old ways of thinking and acting.
- *Shared vision:* Improving positivity ratios provides a shared goal for the organization. Since improving the positivity ratio within the organization has also individual benefits, it is an easy goal to commit to.
- *Team learning:* Using the simulator in collaboration can promote discussion and challenge old assumptions about the organization.
- *Systems thinking:* The systems philosophy is deeply ingrained within the simulator and using the simulator highly promotes thinking about the organization as a system. The simulator can even considered to be a tool to promote systems thinking itself.

Using PoSITeams in organizations would be highly interesting to see whether it can generate change and support organizational decision making. Also designing better organizations could be also one potential direction for research. Perhaps organizations that are robust to adversities share some structural characteristics that can be explored with the simulator. Most organizations are not designed to support individual well-being. However, since positivity and effective organizations are connected, designing the organizations to embrace the effects of positivity seems like a worthwhile endeavour.

In (Bosse, et al., 2009b) an ambient agent model is proposed for an emotional contagion model, where the model would be given emotional level inputs from a group, for example by analysing facial images, and it would give action proposals to the team leader in case group emotion level drops below a certain level. That is, the emotional contagion models could be utilized to help regulate emotions in organizations. In a similar manner the emotional contagion model could be combined with sentiment analysis, which would make information channels such as e-mail and social media attainable for emotional contagion modelling. Emotional contagion has been observed in social media (see e.g. (Kramer, et al., 2014)) and by modelling and simulating the phenomenon it could be possible to design social media platforms to better support mental well-being. For example the visibility of content that promotes contagion of positive emotions could be adjusted.

CONCLUSIONS

We all live in a world of systems. In this work we have explored the possibility of using interactive agent-based emotional contagion simulations to support systems intelligent behaviour in social systems. By emphasizing the systemic view of social groups and by providing a means to explore different behavioural and structural changes, we hope to engage the user in reflective, more holistic way of thinking to obtain insights of more constructive ways of acting. We have presented a novel mathematical model for emotional contagion based on psychological research. The model can incorporate individual characteristics, such as general positivity, extroversion, emotional sensitivity, negativity bias and strength of social connections. The model is also capable of reproducing phenomena such as collective emotional states. The example simulations show potential use cases for PoSITeams and how optimization can be used to provide ideas and insights for a more productive behaviour within social systems. However, PoSITeams still lacks user experiences in the real-world and it would be interesting to see the actual effects of using the simulator in organizations. It would be also interesting to test whether using the simulator can actually increase systems intelligence. Validation and further development of the emotional contagion model are also subjects of future research.

APPENDIX: OPTIMIZATION RESULTS

The optimization results of the small organization examples are presented here in detail.

Optimization with zero costs

The results of the example shown in Figure 6.

Adam: Emotional sensitivity set from 0.20 to 0.93
Adam: Extroversion set from 0.20 to 0.98
Adam: Negativity bias set from 0.60 to 0.50
Adam: General positivity set from 2.00 to 5.00
Connection between Adam and Albert set from 1.00 to 0.80
Connection between Adam and Cecilia set from 1.00 to 0.20
Connection between Adam and Barbara set from 0.00 to 0.02
Connection between Adam and Anna set from 1.00 to 0.92
Albert: Emotional sensitivity set from 0.80 to 1.00
Albert: Extroversion set from 0.80 to 0.01
Albert: Negativity bias set from 0.60 to 0.50
Connection between Albert and Adam set from 1.00 to 0.52
Connection between Albert and Cecilia set from 1.00 to 0.29
Connection between Albert and Barbara set from 0.00 to 0.07
Connection between Albert and Anna set from 1.00 to 0.58
Cecilia: Emotional sensitivity set from 0.40 to 0.98
Cecilia: Extroversion set from 0.90 to 1.00
Cecilia: Negativity bias set from 0.80 to 0.50
Cecilia: General positivity set from 1.00 to 5.00
Connection between Cecilia and Adam set from 1.00 to 0.97
Connection between Cecilia and Albert set from 1.00 to 0.98
Connection between Cecilia and Bob set from 1.00 to 0.23
Connection between Cecilia and Barbara set from 1.00 to 0.29
Connection between Cecilia and Anna set from 1.00 to 0.99
Bob: Emotional sensitivity set from 0.30 to 0.37
Bob: Extroversion set from 0.30 to 0.99
Bob: Negativity bias set from 0.60 to 0.50
Bob: General positivity set from 2.00 to 5.00
Connection between Bob and Adam set from 0.00 to 0.10
Connection between Bob and Albert set from 0.00 to 0.07
Connection between Bob and Cecilia set from 1.00 to 0.88
Connection between Bob and Barbara set from 1.00 to 0.91
Connection between Bob and Anna set from 0.00 to 0.09
Barbara: Emotional sensitivity set from 0.30 to 0.13
Barbara: Extroversion set from 0.30 to 1.00

Barbara: Negativity bias set from 0.60 to 0.50
Barbara: General positivity set from 2.00 to 5.00
Connection between Barbara and Adam set from 0.00 to 0.08
Connection between Barbara and Albert set from 0.00 to 0.02
Connection between Barbara and Cecilia set from 1.00 to 0.96
Connection between Barbara and Bob set from 1.00 to 0.96
Connection between Barbara and Anna set from 0.00 to 0.09
Anna: Emotional sensitivity set from 0.80 to 0.99
Anna: Extroversion set from 0.20 to 0.03
Anna: Negativity bias set from 0.60 to 0.50
Anna: General positivity set from 3.00 to 5.00
Connection between Anna and Adam set from 1.00 to 0.69
Connection between Anna and Albert set from 1.00 to 0.96
Connection between Anna and Cecilia set from 1.00 to 0.28
Connection between Anna and Bob set from 0.00 to 0.07
Connection between Anna and Barbara set from 0.00 to 0.07

Optimizing connection strengths

The results of the example shown in Figure 7.

Connection between Adam and Albert set from 1.00 to 0.56
Connection between Adam and Cecilia set from 1.00 to 0.72
Connection between Adam and Anna set from 1.00 to 0.59
Connection between Adam and Barbara set from 0.00 to 0.08
Connection between Adam and Bob set from 0.00 to 0.10
Connection between Albert and Adam set from 1.00 to 0.59
Connection between Albert and Cecilia set from 1.00 to 0.24
Connection between Albert and Anna set from 1.00 to 0.77
Connection between Albert and Barbara set from 0.00 to 0.07
Connection between Cecilia and Adam set from 1.00 to 0.23
Connection between Cecilia and Albert set from 1.00 to 0.20
Connection between Cecilia and Anna set from 1.00 to 0.20
Connection between Cecilia and Barbara set from 1.00 to 0.20
Connection between Cecilia and Bob set from 1.00 to 0.20
Connection between Anna and Adam set from 1.00 to 0.95
Connection between Anna and Albert set from 1.00 to 0.53
Connection between Anna and Cecilia set from 1.00 to 0.58
Connection between Anna and Barbara set from 0.00 to 0.07
Connection between Barbara and Adam set from 0.00 to 0.09
Connection between Barbara and Albert set from 0.00 to 0.02
Connection between Barbara and Cecilia set from 1.00 to 0.34
Connection between Barbara and Anna set from 0.00 to 0.05
Connection between Barbara and Bob set from 1.00 to 0.67
Connection between Bob and Albert set from 0.00 to 0.03
Connection between Bob and Cecilia set from 1.00 to 0.30
Connection between Bob and Anna set from 0.00 to 0.06
Connection between Bob and Barbara set from 1.00 to 0.79

Optimization with costs

The results of the example shown in Figure 8.

Adam: Emotional sensitivity set from 0.20 to 0.84
Adam: Extroversion set from 0.20 to 0.28
Adam: Negativity bias set from 0.60 to 0.50
Connection between Adam and Albert set from 1.00 to 0.94
Connection between Adam and Cecilia set from 1.00 to 0.33
Connection between Adam and Anna set from 1.00 to 0.58
Connection between Adam and Bob set from 0.00 to 0.06
Albert: Emotional sensitivity set from 0.80 to 0.00
Albert: Extroversion set from 0.80 to 1.00
Albert: Negativity bias set from 0.60 to 0.50
Connection between Albert and Adam set from 1.00 to 0.93
Connection between Albert and Cecilia set from 1.00 to 0.93
Connection between Albert and Anna set from 1.00 to 0.99
Connection between Albert and Barbara set from 0.00 to 0.08
Connection between Albert and Bob set from 0.00 to 0.10
Cecilia: Emotional sensitivity set from 0.40 to 0.84
Cecilia: Extroversion set from 0.90 to 0.01
Cecilia: Negativity bias set from 0.80 to 0.50
Connection between Cecilia and Adam set from 1.00 to 0.32
Connection between Cecilia and Albert set from 1.00 to 0.64
Connection between Cecilia and Anna set from 1.00 to 0.62
Connection between Cecilia and Barbara set from 1.00 to 0.44
Connection between Cecilia and Bob set from 1.00 to 0.82
Anna: Emotional sensitivity set from 0.80 to 0.98
Anna: Extroversion set from 0.20 to 0.76
Anna: Negativity bias set from 0.60 to 0.51
Connection between Anna and Adam set from 1.00 to 0.86
Connection between Anna and Albert set from 1.00 to 0.63
Connection between Anna and Cecilia set from 1.00 to 0.87
Connection between Anna and Barbara set from 0.00 to 0.09
Connection between Anna and Bob set from 0.00 to 0.04
Barbara: Emotional sensitivity set from 0.30 to 0.91
Barbara: Extroversion set from 0.30 to 0.27
Barbara: Negativity bias set from 0.60 to 0.50
Connection between Barbara and Adam set from 0.00 to 0.08
Connection between Barbara and Albert set from 0.00 to 0.03
Connection between Barbara and Cecilia set from 1.00 to 0.56
Connection between Barbara and Anna set from 0.00 to 0.04
Connection between Barbara and Bob set from 1.00 to 0.82
Bob: Emotional sensitivity set from 0.30 to 0.81
Bob: Extroversion set from 0.30 to 0.29
Bob: Negativity bias set from 0.60 to 0.50
Connection between Bob and Albert set from 0.00 to 0.09

Connection between Bob and Cecilia set from 1.00 to 0.77
Connection between Bob and Barbara set from 1.00 to 0.69

Adding a new team member with no constraints

The results of the example shown in Figure 9.

Connection between Adam and Brian set from 0.00 to 0.04
Connection between Anna and Brian set from 0.00 to 0.05
Connection between Bob and Brian set from 0.00 to 0.05
Brian: Emotional sensitivity set from 0.80 to 0.14
Brian: Extroversion set from 0.80 to 1.00
Brian: Negativity bias set from 0.80 to 0.50
Brian: General positivity set from 3.00 to 5.00
Connection between Brian and Adam set from 0.00 to 0.07
Connection between Brian and Albert set from 0.00 to 0.09
Connection between Brian and Cecilia set from 0.00 to 0.93
Connection between Brian and Barbara set from 0.00 to 0.88
Connection between Brian and Bob set from 0.00 to 0.98

Adding a new team member with constrained incoming connections

The results of the example shown in Figure 10**.**

Connection between Adam and Brian set from 0.00 to 0.07
Connection between Albert and Brian set from 0.00 to 0.02
Connection between Anna and Brian set from 0.00 to 0.03
Connection between Barbara and Brian set from 0.00 to 0.34
Connection between Bob and Brian set from 0.00 to 0.59
Brian: Emotional sensitivity set from 0.80 to 0.00
Brian: Extroversion set from 0.80 to 0.99
Brian: Negativity bias set from 0.80 to 0.50
Brian: General positivity set from 3.00 to 5.00
Connection between Brian and Adam set from 0.00 to 0.05
Connection between Brian and Albert set from 0.00 to 0.02
Connection between Brian and Cecilia set from 0.00 to 0.99
Connection between Brian and Anna set from 0.00 to 0.05
Connection between Brian and Barbara set from 0.00 to 0.99
Connection between Brian and Bob set from 0.00 to 0.95

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Systems Intelligence – a Core Competence for Next Generation Engineers?

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***Abstract*—We discuss Systems Intelligence (SI), a competence related to one's ability to succeed in wholes, i.e., in systemic settings which are complex and challenging. There is special emphasis on social systems and people skills. We believe this competence needs to be included in the skillset of engineers in a modern society. The SI competence can be measured and developed, and it relates to the skillset for professionals suggested by the World Economic Forum in 2016.**

Keywords—systems intelligence; systems thinking; engineering education; engineering competence

I. Introduction

It is obvious that engineer's basic competencies are the technical skills, which draw from various special engineering disciplines and mathematics. However, it has long been acknowledged that in a modern society, the hard engineering skills are not enough – social skills, communication, and attitudes count as well. This fact has been seen as a challenge for the design of engineering education and curricula. The theme has been raised by many authors. There are early papers, e.g. [1] and [2], which advocate the need for non-technical subjects in engineering studies. Subsequently, many studies have shown that the skills of engineering graduates do not always meet the expectations of the job market [3]–[6]. This fact has also been recognized in engineering accreditation programs [7][8].

II. Widening the Requirements for Engineering Competences

Over the years, there have been efforts to describe the benefits of "soft" capabilities in the engineering profession, such as emotional and social intelligence [9][10] and empathy [11]. These skills are shown to be relevant in the workplace. Riemer [10] also suggests that a person's emotional intelligence can have an impact on learning. Boyatzis et al [9] found that emotional and social intelligence predicted engineer effectiveness. They suggest that engineering education should include emotional intelligence and relationship building training. Emotional intelligence was defined originally by Salovey and Mayer [12] as the ability to monitor one's own and others' feelings and emotions to discriminate among them and to use this information to guide one's thinking and actions. There is also growing interest in engineering philosophy and engineering thinking which is relevant here, see e.g. [13][14].

The need to widen the scope of engineering competencies naturally suggests a systems perspective. In the discipline of systems engineering, systems thinking is, indeed, seen as a key competence [15]–[17]. The capacity for engineering systems thinking (CEST) is a characterization developed by Frank [18]. It consists of the following cognitive characteristics:

- Understanding the whole system and seeing the big picture
- Understanding interconnections; closed-loop thinking
- Understanding systems synergy
- Understanding the system from multiple perspectives
- Thinking creatively
- Understanding systems without getting stuck on details; tolerance for ambiguity and uncertainty
- Understanding the implications of proposed change
- Understanding a new system/concept immediately upon presentation
- Understanding analogies and parallelism between systems
- Understanding limits to growth

The origins of CEST go back to the landmark management book, The Fifth Discipline, by Peter Senge [19], where the fifth discipline is Systems Thinking. In contrast to Senge's generic vision, CEST was developed as an engineering-only oriented competence program. Teamwork is included in CEST, yet only briefly. In the suggested curriculum [16], behavioral competences are mentioned, but only marginally. The systems engineer should be able to relate to others and establish trustful relations with different parties. Overall, the general perspective in CEST is still very strongly limited to technical engineering skills. The ability to recognize social systems in the workplace receives very little attention. We should focus more on the process of systems thinking, including the emotional and subjective dimensions, and not only on the product description. This also relates to the discussion about why systems thinking has not been widely adopted in organizations [20]. However, quite recently Camelia and Ferris [21] have taken steps to relate and analyze the affective dimension with a modified CEST.

III. The Future of Job Skills

The Word Economics Forum produced a report in January 2016 on the future of job skills [22]. A quote from the executive summary of the report:

> *"Overall, social skills – such as persuasion, emotional intelligence and teaching others – will be in higher demand across industries than narrow technical skills, such as programming or equipment operation and control. In essence, technical skills will need to be supplemented with strong social and collaboration skills."*

The above conclusion covers all industries and professions, including engineering. The report also lists the following ten skills you need to have in the Fourth Industrial Revolution: *Complex Problem Solving, Critical Thinking, Creativity, People Management, Coordinating with Others, Emotional Intelligence, Judgement and Decision Making, Service Orientation, Negotiation,* and *Cognitive Flexibility*.

It is useful to reflect these skills against the engineering competencies discussed in section II. The trend is clear. The importance of non-technical skills is increasing, which was, indeed, identified early in engineering but did not receive wider attention. These skills have now become the core of the general skills needed in all jobs. In particular, one can say that systems engineering competencies should be much more related to complex problem solving, critical thinking and creativity, as well as to judgement and decision making, than is suggested in the related literature so far. Here it is also interesting to note recent developments in the discipline of Operations Research (OR), which is very close to systems engineering, as it also uses modelling for problem solving and to support decision making. In OR, the behavioral perspective has recently been acknowledged to be of essential importance [23][24]. It is recognized that the modeler's personal actions and cognitive biases can have an impact on the outcome of the problem-solving process. In the above list of competences, skills 4-9, people management, coordinating with others, emotional intelligence, service orientation, and negotiation, deal directly with different ways of engaging with people.

A natural conclusion to be drawn here is that these new competence requirements need to be taken into account when developing engineering education programs for the next generation.

IV. Systems Intelligence

The concept of Systems Intelligence was first introduced by Saarinen and Hämäläinen in 2004 [25] and was defined as:

> *"By Systems Intelligence (SI) we mean intelligent behaviour in the context of complex systems involving interaction and feedback. A subject acting with Systems Intelligence engages successfully and productively with the holistic feedback mechanisms of her environment. She perceives herself as part of a whole, the influence of the whole upon herself as well as her own influence upon the whole. By observing her own interdependence in the feedback intensive environment, she is able to act intelligently."*

Systems Intelligence is assumed to be a key form of human behavioral intelligence. SI integrates the action-based bias of the human condition, along with the fact that all life takes place in systemic environments and with respect to, as well as from within "wholes". The evolution of human beings has taken place in systemic social contexts and relation-intensive environments. For human life to survive and flourish, communication and interaction with others has been pivotal. It has required skills that relate the individual to wholes from within, and in ways that lead her to attune to systems in real time, irrespective of the question whether the systems are constructed, technical, or social and human.

Systems Intelligence draws ideas from a variety of disciplines, ranging from traditional systems thinking to the Socratic tradition in philosophy, emphasizing conceptual thinking for the purpose of good life. The work of Senge is a special inspiration and a natural link to engineering competencies. In particular, two of the Five Disciplines of Senge, Personal Mastery and Systems Thinking, are seen crucial for SI, yet often overlooked in the applied literature. While CEST refers to Senge's ideas [18][26], its emphasis is on technical contexts. Personal mastery as an ability to deal also with humanly intensive social contexts is not brought to focus.

In CEST, systems are seen from outside as objective entities. In Systems Intelligence, the actor sees systems from inside and sees herself as being part of the whole. She acts from within the system, whether the system represents an engineering design challenge or the social environment in the workplace. This brings in the Senge's first discipline, Personal Mastery, and integrates it with systems thinking. In social contexts, also engineers need Emotional Intelligence (EI) skills [12]. These can be seen as abilities embedded in Systems Intelligence, which also takes into account the structures of the system, both organizational and social.

V. Measuring Systems Intelligence

The Systems Intelligence Inventory [27] is a way of evaluating one's level in the competence. The inventory was developed and validated with a combination of exploratory and confirmatory factor analysis, using a total sample of 2060 university students, engineering company employees and daycare workers and managers.

The self-report test consists of 32 items, some of which are *"I quickly get a sense of what matters," "I critically evaluate my ways of thinking," "I view things from many different perspectives," "I praise people for their achievements," "I am willing to take advice,"* and "*I successfully manage problematic situations."*

The SI Inventory has eight factors, which the authors describe as:

- **Systemic Perception**: Seeing, identifying and recognizing systems, patterns, and interconnections, having situational awareness
- **Attunement**: Engaging intersubjectively, being present, mindful, situationally sensitive and open.
- **Positive Attitude**: Keeping a positive outlook, not getting stuck on negative impressions and effects
- **Spirited Discovery**: Engaging with new ideas, embracing change
- **Reflection**: Reflecting upon one's thinking and actions, challenging one's own behavior
- **Wise Action**: Exercising long-term thinking and realizing its implications, understanding that consequences may take time to develop
- **Positive Engagement**: Taking systemic leverage points and means successfully into action with people
- **Effective Responsiveness**: Taking systemic leverage points and means successfully into action with the environment, being able to dance with systems

The SI measure correlates with EI, but, importantly, SI includes systems- and action-oriented dimensions not covered by EI. Empirical findings show that people in supervisor and managerial positions score higher in SI. Furthermore, preliminary unpublished results from our recent study on peer evaluation of SI indicate that there is a positive correlation between high SI and job performance. Higher job performance, as perceived by your colleagues, seems to go hand in hand with a high peer-evaluated SI score. This is observed for professions in general, but it also holds for people employed in technical fields and information technology. These results suggest that SI can be a core skill for engineers.

VI. Systems Intelligence as an Engineering Competence

The common theme in required engineering competencies and job skills in general is the emergence of competences related to human interaction and systemic problem solving. Today's engineers need to be able to engage with people in different contexts. Quite recently, empathy is also suggested to be a core skill in engineering [11][28][29]. The dimensions of the construct of empathy include self and other awareness, perspective taking, and the ability to switch modes between empathic and analytic cognitive mechanics. The way we have articulated systems intelligence includes and integrates these new engineering competence areas. Thus, it is natural to propose that SI could be a core practice-oriented engineering competence in addition to the technical skills of the profession.

In the field of Engineering Philosophy, Systems Intelligence has also been used to describe engineering thinking. A quote from [30]:

"Engineering thinking is fundamentally an orientation to one's environment from the point of view of improvement, rationality and action. The question of the availability of models and representations is only secondary. Engineering thinking, in other words, is systems intelligence. It combines the sensitive, passionate, instinctual, pre-rational and subjective aspects of the human endowment with cognitive, rational and objectivity-related epistemology in the service of improvement with the means that are available."

The existence of a validated measurement scale for SI [27] makes the competence particularly attractive from the educational perspective. The ability to measure improvements helps to design development processes and a means to evaluate an engineer's SI skills in different contexts. One key feature of the SI concept is that the term is easy to use and grasp, perceived as neutral, and people find it empowering. It invites an engineering mind to want to improve upon. Constructs like emotional intelligence and empathy can more easily be seen as nonrelated to the engineering profession. Systems Intelligence has also been suggested to be useful in understanding knowledge management [31].

The ways of introducing Systems Intelligence into an engineering education program remains still a developing area. In Aalto University in Finland, professor Esa Saarinen has delivered a very popular general life philosophical lectures series for more than fifteen years [32]. The contents of the course have been designed to also instigate systems intelligence thinking in the students. Evaluating the student responses does, indeed, suggest that this has been successful [33]. So, one approach is to introduce students to general themes such as philosophy of life, ethics, self-leadership and organizational behavior with a systems thinking perspective and strong emphasis of a Sengean Personal Mastery.

A SI self-evaluation test is available freely on the internet at http://salserver.org.aalto.fi/sitest/en/. The test shows how the respondent scores compare to the whole population that has done the test previously. It also provides information on the person's strengths and developmental opportunities in SI. Thus, the test can easily be used as an element in any course.

Gamification has recently become a topic of strong interest in learning process design and in educational practices [34]. One easy approach for introducing gamification is the use of educational playing cards. A Finnish company, Gälliwashere, has developed a family of organizational learning games called Topaasia [35] that is played in multiple short sessions over a long period of time. Research shows that the results have been very positive [35]. There is a pilot test set of cards for Systems Intelligence based on the items in the SI Inventory. Preliminary responses of this learning mode in real organizations have been extremely positive. The game has inquired people and teams to initiate learning and improvement processes without a formal instructor. These kind of gaming exercises would, no doubt, be easy to organize in different courses in engineering education.

VII. Summary

An understanding of the core competences needed in engineering practice is essential for the improvement of engineering education. The necessary competence profile in engineering, as well as in many other professions, has widened essentially in recent years. Narrow technical professional skills are not sufficient anymore. New suggested competences discussed in engineering education literature emphasize abilities to manage complex settings and engage with people. We see that the concept of Systems Intelligence captures many of these dimensions quite well and we suggest that SI could be included as one of the core engineering competencies. As a concept, it stimulates systemic thinking, and there are tools to include it in educational programs.

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Systems Intelligence (SI) refers to intelligent behavior in the context of complex systems involving interaction and feedback. Systems intelligent individuals and organizations are able to successfully and productively engage with the holistic feedback mechanisms of their environment. This study operationalizes the concept of SI by providing measurement and modelling tools and approaches that help take Systems Intelligence from the laboratory to the real world.

The measurement and modelling tools presented in this work can help to stage interventions for improving individual and organizational capabilities to be more productive within and with respect to systems. The tools also serve as useful instruments for building learning organizations and human resource capabilities.

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