Hamalainen Raimo, P.; Saarinen, Esa; Tormanen, Juha

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Systems Intelligence – a Core Competence for Next Generation Engineers?

Raimo P.Hämäläinen
Systems Analysis Laboratory
Aalto University
Espoo, Finland
raimo.hamalainen@aalto.fi

Esa Saarinen
Department of Industrial Engineering and Management
Aalto University
Espoo, Finland
esa.saarinen@aalto.fi

Juha Törmänen
Department of Industrial Engineering and Management
Aalto University
Espoo, Finland
juha.tormanen@aalto.fi

***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.

References

[1] S. C. Florman, "Non-technical Studies for Engineers: The Challenge of Relevance," *Eur. J. Eng. Educ.*, vol. 22, no. 3, pp. 249–258, Sep. 1997.

[2] D. Q. Nguyen, "The Essential Skills and Attributes of an Engineer: A Comparative Study of Academics, Industry Personnel and Engineering Students," *Glob. J. Eng. Educ.*, vol. 2, no. 1, pp. 65–75, 1998.

[3] C. S. Nair, A. Patil, and P. Mertova, "Re-engineering graduate skills – a case study," *Eur. J. Eng. Educ.*, vol. 34, no. 2, pp. 131–139, May 2009.

[4] S. A. Male, M. B. Bush, and E. S. Chapman, "Perceptions of Competency Deficiencies in Engineering Graduates," *Australas. J. Eng. Educ.*, vol. 16, no. 1, pp. 55–68, Jan. 2010.

[5] P. Lappalainen, "Predictors of effective leadership in industry – should engineering education focus on traditional intelligence, personality, or emotional intelligence?," *Eur. J. Eng. Educ.*, vol. 40, no. 2, pp. 222–233, Mar. 2015.

[6] E. Ramadi, S. Ramadi, and K. Nasr, "Engineering graduates' skill sets in the MENA region: a gap analysis of industry expectations and satisfaction," *Eur. J. Eng. Educ.*, vol. 41, no. 1, pp. 34–52, Jan. 2016.

[7] S. A. Male, M. B. Bush, and E. S. Chapman, "An Australian study of generic competencies required by engineers," *Eur. J. Eng. Educ.*, vol. 36, no. 2, pp. 151–163, 2011.

[8] H. J. Passow, "Which ABET competencies do engineering graduates find most important in their work?," *J. Eng. Educ.*, vol. 101, no. 1, pp. 95–118, Jan. 2012.

[9] R. Boyatzis, K. Rochford, and K. V Cavanagh, "Emotional intelligence competencies in engineer's effectiveness and engagement," *Career Dev. Int.*, vol. 22, no. 1, pp. 70–86, 2017.

[10] M. J. Riemer, "Integrating emotional intelligence into engineering education," *World Trans. Eng. Technol. Educ.*, vol. 2, no. 2, 2003.

[11] J. Walther, S. E. Miller, and N. W. Sochacka, "A Model of Empathy in Engineering as a Core Skill, Practice Orientation, and Professional Way of Being," *J. Eng. Educ.*, vol. 106, no. 1, pp. 123–148, Jan. 2017.

[12] P. Salovey and J. D. Mayer, "Emotional Intelligence," *Imagin. Cogn. Pers.*, vol. 9, no. 3, pp. 185–211, Mar. 1990.

[13] J. Hillier, "The philosophy of engineering: a critical summary," *Proc. Inst. Civ. Eng. - Civ. Eng.*, vol. 163, no. 2, pp. 91–95, May 2010.

[14] J. Heywood, "A historical overview of recent developments in the search for a philosophy of engineering education," in *2011 Frontiers in Education Conference (FIE)*, 2011, p. PEEE-1-PEEE-14.

[15] M. Frank, "Engineering systems thinking and systems thinking," *Syst. Eng.*, vol. 3, no. 3, pp. 163–168, 2000.

[16] M. Frank, "Characteristics of engineering systems thinking - a 3D approach for curriculum content," *IEEE Trans. Syst. Man Cybern. C, Appl. Rev.*, vol. 32, no. 3, pp. 203–214, Aug. 2002.

[17] R. M. Jaradat, C. B. Keating, and J. M. Bradley, "Individual Capacity and Organizational Competency for Systems Thinking," *IEEE Syst. J.*, vol. 12, no. 2, pp. 1203–1210, Jun. 2018.

[18] M. Frank, "Knowledge, abilities, cognitive characteristics and behavioral competences of engineers with high capacity for engineering systems thinking (CEST)," *Syst. Eng.*, vol. 9, no. 2, pp. 91–103, 2006.

[19] P. M. Senge, *The fifth discipline: The art and science of the learning organization*. New York: Doubleday/Currency, 1990.

[20] R. P. Hämäläinen and E. Saarinen, "Systems intelligence - The way forward? A note on Ackoff's 'why few organizations adopt systems thinking,'" *Syst. Res. Behav. Sci.*, vol. 25, no. 6, pp. 821–825, 2008.

[21] F. Camelia and T. L. J. Ferris, "Validation Studies of a Questionnaire Development for Students' Engagement with Systems Thinking," *IEEE Trans. Syst. Man, Cybern. Syst.*, vol. 48, no. 4, pp. 574–585, 2018.

[22] *The future of jobs: employment, skills and workforce strategy for the fourth industrial revolution*, World Economic Forum, Jan. 2016.

[23] R. P. Hämäläinen, J. Luoma, and E. Saarinen, "On the importance of behavioral operational research: The case of understanding and communicating about dynamic systems," *Eur. J. Oper. Res.*, vol. 228, no. 3, pp. 623–634, 2013.

[24] L. A. Franco and R. P. Hämäläinen, "Behavioural operational research: Returning to the roots of the OR profession," *Eur. J. Oper. Res.*, vol. 249, no. 3, pp. 791–795, Mar. 2016.

[25] E. Saarinen and R. P. Hämäläinen, "Systems Intelligence: Connecting engineering thinking with human sensitivity," in *Systems Intelligence*, Espoo, Finland: Helsinki University of Technology, 2004, pp. 1–29.

[26] M. Frank, "Engineering systems thinking: Cognitive competencies of successful systems engineers," in *Procedia Computer Science*, 2012, pp. 273–278.

[27] J. Törmänen, R. P. Hämäläinen, and E. Saarinen, "Systems intelligence inventory," *Learn. Organ.*, vol. 23, no. 4, pp. 218–231, May 2016.

[28] J. L. Hess, J. Strobel, and R. (Celia) Pan, "Voices from the workplace: practitioners' perspectives on the role of empathy and care within engineering," *Eng. Stud.*, vol. 8, no. 3, pp. 212–242, Sep. 2016.

[29] J. L. Hess, J. Strobel, and A. O. Brightman, "The Development of Empathic Perspective-Taking in an Engineering Ethics Course," *J. Eng. Educ.*, vol. 106, no. 4, pp. 534–563, Oct. 2017.

[30] E. Saarinen, R. P. Hämäläinen, M. Martela, and J. Luoma, "Systems Intelligence Thinking as Engineering Philosophy," in *Workshop on Philosophy & Engineering*, 2008, pp. 7–9.

[31] Y. Sasaki, "A note on systems intelligence in knowledge management," *Learn. Organ.*, vol. 24, no. 4, pp. 236–244, May 2017.

[32] E. Saarinen and T. Lehti, "Inducing mindfulness through life-philosophical lecturing," in *The Wiley Blackwell Handbook of Mindfulness*, A. Ie, C. T. Ngnoumen, and E. J. Langer, Eds. Chichester, UK: John Wiley & Sons, 2014, pp. 1105–1131.

[33] P. Lappalainen, "Stirring up Engineers' Systems Intelligence: A Case Study of Life-Philosophical Pedagogy," *Int. J. Eng. Pedagog.*, vol. 7, no. 3, p. 61, Sep. 2017.

[34] J. T. Harviainen, K. Vaajakallio, and H. Sproedt, "Service Design Games as Innovation Tools, Knowledge Creators, and Simulation/Games," *Simul. Gaming*, vol. 47, no. 5, pp. 559–565, 2016.

[35] O. Hannula and J. T. Harviainen, "User Perceptions of Design Games as Settings for Organizational Learning : Case Topaasia," in *ServDes2018*, June 2018.