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Interdisciplinary systems thinking and the ICT self-concept in higher education

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ABSTRACT: Today's higher education technology-enhanced learning environment presents students with complex challenges that demand holistic approaches. Systems thinking points to a possible educational approach using a whole system perspective for solving complex problems, especially in disciplines where design plays an important role. This study explores relations between interdisciplinary systems thinking and self-concept (SC) related to information communication technology (ICT). For this purpose, an effective sample of 156 undergraduates was collected for an empirical study in teacher education, architecture education and mechanical engineering study programmes. The results indicate significant variations in levels of system thinking and ICT SC based on the study major. Furthermore, multiple regression analysis reveals both positive and negative predictors in system thinking using ICT SC as the explanatory variable. This study provides deeper insights into the integration of systems thinking and ICT competencies to prepare students for the demands of competitive technology-enhanced education for sustainable development.

INTRODUCTION

Successful and sustainable action in a constantly changing society with constant technological progress requires more comprehensive knowledge and skills to understand interconnected systems, and thus ever greater complexity [1]. Important competencies for achieving sustainability include co-operation, problem solving, foresight, critical thinking and, among others, the competence of systems thinking [2]. With the development of information communication technology (ICT) and other digital tools and general digitalisation, the way of living and working has changed all over the world, and education has changed as well. Quality education is presented as a commitment in the fourth Sustainable Development Goal (SDG4) of the Sustainable Development Agenda, which aims to ensure inclusive and equitable quality education across all levels, accessible to all [2].

Educational contexts require learning and development opportunities to develop systems thinking, therefore the integration of systems thinking into curricula is strongly recommended in practice [3]. The use of systems thinking in educational settings is still at an early stage and there are not many well-trained adults in the field of systems thinking [4]. According to some authors [5][6] and the results obtained from bibliometric analysis shown in Figure 1, there is still room for improvement in individuals' systems thinking in higher education, as well as in general education.

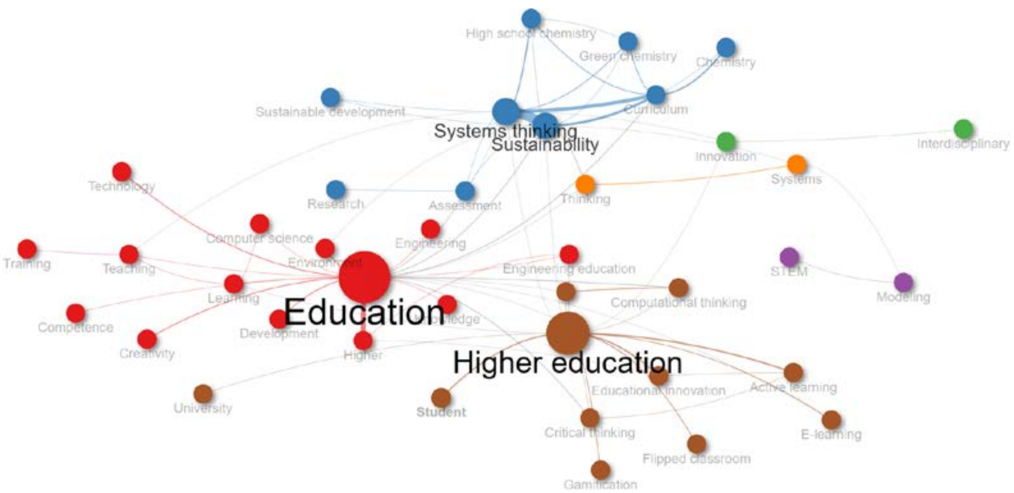

Figure 1: A co-occurrence network of keywords from original articles on the dynamics of higher education systems thinking concept from the Web of Science database, published between 1994 and 2024.

Bibliometrix (ver. 4.1) developed by Aria and Cuccurullo for science mapping analysis was used [7]. A co-occurrence network was generated based on data from the Web of Science database using the search strategy: keywords *((TS = (Systems thinking) AND TS = (higher education) AND (TS = (concepts));* publication time, 1 January 1994 to 15 April 2024. In the literature, systems thinking is mostly mentioned in relation to the concept of sustainability in the broader context of science education. Figure 1 also shows a gap in research on systems thinking in relation to other disciplines in higher education, such as engineering, architecture, education, etc. Furthermore, research that examines the interdisciplinary nature of the approach across disciplines and focuses on the design and increased use of ICT is of additional value.

The increasing use of ICT and digital tools has resulted in easier information sharing, content generation, content access, communication, collaboration, etc. It has transformed educational programmes (e.g. technology teacher, architecture, mechanical engineering) to a great extent and continues to do so today, especially where the focus is on design - designing and making products (physical products, lessons, etc), and the need to use the design thinking approach is essential. Greene et al argue in their research that user-centred design requires a system view [8]. Systems thinking is usually discussed separately from design thinking, although the two approaches have a number of similarities [8][9]. In their work, Greene et al present different conceptual models that consider the differences, connections, integration and inclusion of the two approaches mentioned [8].

SYSTEMS THINKING AND DIGITAL COMPETENCIES IN HIGHER EDUCATION

Systems thinking is defined in different ways as it is applied in different areas [10]. It is based on a holistic view, which, in contrast to a reductionist view, starts from the consideration of the whole from which the properties of the parts are derived. At the same time, systems thinking is based on the principle that the system as a whole is greater than the sum of its parts, and therefore cannot be described by its parts alone [9].

The beginnings of the concept can be found in general systems theory and systems dynamics, which have evolved into systems engineering and engineering systems thinking in the engineering discipline [8]. More recent sources define systems thinking as a technique for considering a problem as a whole that attempts to consider all variables that affect the system and that are affected by the system itself, including social and technological characteristics [1]. Cabrera and Cabrera developed a theory of DSRP rules that demonstrate the application of systems thinking through the application of these rules; namely, distinctions - to distinguish, set boundaries; systems - to identify the system and elements; relationships - to understand the relationships between the elements and the system; and perspectives - to see from a different point of view/perspective, which has also been supported by empirical research [11].

Systems thinking enables the understanding of interrelationships and dynamics in a system and goes beyond linear cause-and-effect thinking. Applying systems thinking to complex systems is a major challenge for the individual, which is why systems thinking is easier to achieve in a group. Groups that work together effectively are considered better able to make decisions because they have more knowledge and experience, and are confronted with more opinions and interpretations [9]. Today, the development of computer science and ICT enables forms of collaboration with the aim of combining the forces of different experts, such as scientists, engineers and researchers to enable more effective collaboration between people around the world. Furthermore, the use of ICT facilitates the visualisation of causal relationships and mental models of systems, which are recommended to cope with the cognitive overload of solving more complex tasks [4]. Diagrams of behaviour over time, causal loops, concept maps and flow state maps are also useful to support systems thinking [3]. Depending on the complexity of the problem, the individual decides which type of collaboration and ICT support they need for the solution and selects these accordingly.

The trend towards the digital transformation of education is increasing after the Covid-19 pandemic and depends on the readiness and digital culture within organisations [12]. In addition, the choice and use of ICT by individuals depends to a large extent on their attitude towards ICT, the appropriate pedagogical approach applied to digital literacy, achievements and their awareness of their ability to use it [13]. In general, self-concept (SC) has a significant impact on cognitive and behavioural outcomes in various domains. A positive SC affects motivation, curiosity, willingness to learn and use, and further research [14]. Being digitally competent does not only mean being able to use smartphone to take photos, make phone calls, send text messages, or a computer to write an essay. The competence and actual use of digital tools and ICT relates to several areas, which Schauffel et al categorise into several dimensions relating to the general SC of ICT, communication, processing and storage, digital content creation and problem solving [14]. In their literature review, Zhao at al found a basic to medium level of digital competence among students and university teachers [13]. The perceived competence is slightly higher in communication, but the level is lower in terms of problem solving and safe use.

This research focuses on examining the technology-enhanced systems thinking approach. The study examined the following three research questions:

1. How do levels of systems thinking and ICT SC vary among students across different academic disciplines?
2. What are the key similarities and differences in systems thinking and ICT SC among students from different academic disciplines?
3. How well does ICT SC predict systems thinking capabilities among students from diverse academic disciplines?

METHODOLOGY

Participants and Data Collection

For the purpose of this study, an empirical research design was used. Empirical research was based on the self-assessment of systems thinking and ICT SC using two questionnaires. Data were collected from undergraduate students at the University of Ljubljana, Slovenia, in years 2023 and 2024. Participating faculties included the Faculty of Education (n = 56), Faculty of Architecture (n = 58) and the Faculty of Mechanical Engineering (n = 42). The participants had an average age of M = 20.73 years (SD = 1.23) (n = 156). The sample included more females (n = 100, 64.1 %) than males (n = 56, 35.9 %). Participation in the study was completely voluntary and all participating students gave informed consent to take part in this research. Since participants were free to withdraw from the study at any stage, only 156 students fully completed the survey out of 267 who entered the on-line 1KA portal for conducting surveys. Three majors from the above-mentioned faculties were selected by the authors of this article, based on the following criteria:

1) design-based learning as a mainstream approach to learning;
2) an amount of transdisciplinary content in the final student projects;
3) extensive and educational use of ICT and digital tools to enhance higher order thinking skills (critical thinking, problems solving);
4) frequency of the SDGs integrated in the study programmes.

Instruments and Validation Measures

Systems thinking in undergraduates was assessed based on measures developed by Moore et al [15] with a 6-point Likert scale (from 1 - never to 6 - always). Scales were adapted by the authors of the present study. An adapted system thinking questionnaire consists of twenty items, which form five constructs based on dimensions of systems thinking [15]:

- STF1: Causal and relational understanding, sequence of events;
- STF2: Patterns of relationships, holistic view and leveraging interdependencies;
- STF3: Casual sequence (casual and dynamic complexity) and feedback loops;
- STF4: Multiple causations possible and variation of different types (random/special);
- STF5: Interrelations and interconnectedness of factors.

All constructs of systems thinking were already validated by the authors in their previous study [6], where results suggest that all constructs of systems thinking demonstrate evidence of convergent and discriminant validity.

ICT SC was measured using adapted questionnaire developed by Schauffel et al [14], where six scales were:

- SCGL: general ICT and data literacy;
- SCCO: communication and collaboration;
- SCPS: process and store (analysing/reflection);
- SCGE digital content creation/generation;
- SCSA: safe and secure application;
- SCSP: problem solving.

For the assessment a 6-point Likert scale was used (1 - strongly disagree to 6 - strongly agree). All variables of ICT SC were also validated in the authors' previous study [6] and all variables demonstrate evidence of high discriminate and convergent validity. Both questionnaires in the present study proved to be moderate to highly reliable, with McDonald's omega values of the constructs between 0.71 to 0.93 (see Table 1 and Table 2) [6].

Data Analysis

The data were analysed using IBM SPSS software (ver. 25). McDonald's omega (ω) coefficient was used to support the reliability of the constructs. In addition, descriptive statistics were used to summarise and describe the main characteristics of a data set, such as the mean and standard deviations of the dependent variable, while multivariate analysis of variance (MANOVA) was used to find and confirm significant differences between groups with an effect size partial eta squared (η^2). Multiple regression was used to analyse the relationships between the dependent variable *systems thinking* and the constructs of ICT SC as explanatory variables.

RESULTS AND DISCUSSION

Students' systems thinking results were obtained using a self-assessment questionnaire on five subscales, see Table 1. Students from all three majors reported above average systems thinking skills on all subscales, with a scale's mid-point of 3.5. To provide a student's total system thinking score, item scores are summed and according to the assessment scale they range from 20-120. Students in technology teacher education programme scored M = 91.23 (SD = 13.27) on average what is comparable with architecture students (M = 89.93, SD = 11.32). Mechanical engineering students scored lower than their counterparts and the average score was M = 83.59 (SD = 11.01). According to the available results in the literature where the same questionnaire was used, mechanical engineering students' scores are similar to medical students' scores, while students in technology teacher education and architecture education seem to be close to public health and nursing students as reported by Moore at al [15].

Table 1: Students' average scores on the systems thinking constructs expressed with a mean (M) and standard deviation (SD) with corresponding McDonald's omega values.

Subscales of systems thinking	Reliability	Technology teacher education		Architecture education		Mechanical engineering education	
	McDonald's ω	M	SD	M	SD	M	SD
STF1	0.83	4.61	0.71	4.67	0.83	4.10	0.67
STF2	0.77	4.31	0.75	4.22	0.73	4.02	0.72
STF3	0.82	4.91	0.79	4.72	0.69	4.40	0.84
STF4	0.72	4.57	0.85	4.56	0.76	4.17	0.74
STF5	0.71	4.42	0.89	4.28	0.86	4.26	0.66

Students' ICT SC results were obtained using a self-assessment questionnaire on six subscales, see Table 2. Students from all three majors reported above average ICT SC on all subscales, with a scale's mid-point of 3.5. The results are consistent with the findings of Zhao et al [13].

Table 2: Students' average scores on the ICT SC constructs expressed with a mean (M) and standard deviation (SD) with corresponding McDonald's omega values.

Subscales of ICT SC	Reliability	Technology teacher education		Architecture education		Mechanical engineering education	
	McDonald's ω	M	SD	M	SD	M	SD
SCGL	0.93	4.11	1.01	4.03	1.13	4.70	0.92
SCCO	0.89	4.58	1.09	4.50	1.02	4.80	0.83
SCPS	0.87	4.06	1.07	4.25	1.02	4.54	0.78
SCGE	0.92	3.58	1.13	4.11	1.01	4.16	0.91
SCSA	0.88	3.69	1.06	3.75	1.16	3.99	1.02
SCSP	0.92	3.59	1.09	3.71	1.10	4.29	0.98

The Shapiro-Wilk test of normality was used for both systems thinking and the ICT SC data set. The test reveals that the data set across different study majors comes from normal distribution ($p > 0.05$). Furthermore, the descriptors of skewness and kurtosis revealed no significant deviations from symmetry and no tails were found that could deviate from the tails of the normal distribution (skewness, kurtosis < 1). Since the normality assumption was met, the parametric tests were performed to reveal the differences between the groups involved in the study.

To answer the second research question, the authors conducted a MANOVA with *Tukey* correction to assess the systems thinking and ICT SC constructs as multiple dependent variables simultaneously. Firstly, Box's M test was used to check assumption of equal covariance matrices and this assumption was met ($p > 0.05$). Secondly, Wilks' lambda test revealed significant differences between the means of groups ($p < 0.05$), and it indicates on high discrimination ability of the independent variable type of study programme. Finally, Levene's test of equality of error variances was used, and for all constructs of systems thinking and ICT SC the authors confirmed the null hypothesis that the error variance of the depended variable is equal across the groups ($p > 0.05$).

The tests of between-subjects effects (see Table 3) show that three of the systems thinking model constructs have significant values less than 0.05 (STF1, STF3, STF4), while two constructs (STF2 and STF5) are not statistically significant $p > 0.05$. An effect size partial eta squared of the type of the group of students on significant differences is regarded as medium effect [6].

Table 3: Tests of between-subjects effects in systems thinking across the groups of students.

Subscales of systems thinking as depended variables	Type III sum of squares	df	Mean square	*F*	*p*-value	Partial eta squared
STF1	9.13	2	4.56	8.08	0.000	0.10
STF2	1.91	2	0.95	1.76	0.177	0.03
STF3	5.96	2	2.98	5.01	0.008	0.07
STF4	4.87	2	2.43	3.90	0.022	0.06
STF5	0.80	2	0.40	0.59	0.554	0.01

The groups of students differ significantly at STF1 where causal and relational understanding and knowing sequence of events is less developed in mechanical engineering students compared to their counterparts from teacher and architecture education programmes. Similarly is at STF4 were also mechanical engineering students have a lack of understanding of possibility of multiple causations and variation of different types in the system itself. Further, one can see from multiple comparisons that casual and dynamic complexity recognition and feedback behaviour is much developed in technology teacher education students compared to mechanical engineering students.

Similarities in systems thinking self-assessed levels can be also found; namely, STF2 and STF5 seem to be evenly developed in all groups of students. This points to an interdisciplinary systems thinking domain which might reflect through understanding of patterns of relationships, having holistic view and leveraging interdependencies together with having knowledge on interrelations and interconnectedness of factors in the systems. Furthermore, the authors examined differences and similarities in the students' ICT SC, whereby some differences and similarities were also identified. The effect size is classified as low to medium [16] (Table 4).

Table 4: Tests of between-subjects effects in ICT SC across the groups of students.

Subscales of ICT SC as depended variables	Type III sum of squares	df	Mean square	*F*	*p*-value	Partial eta squared
SCGL	12.43	2	6.21	5.17	0.007	0.07
SCCO	2.10	2	1.05	1.04	0.355	0.02
SCPS	7.58	2	3.64	3.72	0.047	0.04
SCGE	11.11	2	5.55	5.20	0.007	0.07
SCSA	2.18	2	1.09	0.89	0.410	0.02
SCPS	12.54	2	6.27	5.48	0.005	0.08

Results obtained from multiple comparisons using *Tukey* correction suggests that ICT SC is more developed in mechanical engineering students. Mechanical engineering students outperformed their counterparts from teacher and architecture education at SCGL and SCSP constructs what point towards higher general data in information literacy and higher ability for problem solving using ICT and other digital tools. Moreover, mechanical engineering students reported higher scores against teacher education students in SCPS and SCGE. This result suggests that ability for analysis and critical reflection using digital systems is higher, what might also contribute at the creation of digital material at design-based learning. Architecture education students also outperformed teacher education students at generation of content in design-based work and active learning using real-world cases which is much developed in architecture and mechanical engineering study programmes.

Together with differences also similarities in all three study programmes were found. As it is shown in Table 4, SCCO and SCSA can be evenly developed in all groups of students. It seems that digital competence for communication and collaboration using different portals is well and evenly developed, while handling digital systems considering safe and secure use is also evenly developed in the groups of students, but it needs improvement, since it was reported slightly above the mid-point of the 6-point Likert scale. A similar finding was also made by Zhao et al [13].

The third research question investigates whether constructs of ICT SC have a predicting value in systems thinking. To answer this question, multiple regression analysis was used. First, the tested normality of residuals and values of standardised residuals is less than ±3 (minimum = -1.73, maximum = 1.95), while Cook's distance is less than 1 (minimum = 0.00, maximum = 0.02) what points to no outliers or influential observations which might have influence in predicting have been detected [16]. The authors also performed collinearity statistics on independent variables and tolerance values are less than 1, while VIF's values are lower than the threshold value of 5 proposed by Hair et al [17].

Independent variables are the constructs of ICT SC, while the dependent variable is the total score of systems thinking. The regression model developed in this study is considered acceptable by social science standards [16], where the proportion of the variance in the depended variable accounted for is $R^2_{adj} = 0.21$. As shown in Table 5, the strongest positive predictor in system thinking is the process and store of data, information and content (analysing/reflection) followed by co-operation and communication using digital system, which is consistent with the previous research [6].

Table 5: Effect of ICT SC on systems thinking - multiple linear regression analysis (n = 156).

Variable	Unstand. coefficients		95 % CI for B		Stand. coefficients	*t*-ratio	*p*-value
	B	Std. error	Lower bound	Upper bound	β		
Constant	68.95	4.477	60.10	77.80		15.40	0.000
SCGL	–1.53	1.415	-4.33	1.25	-0.14	-1.08	0.279
SCCO	3.33	1.490	0.38	6.27	0.28	2.23	0.027
SCPS	6.45	1.833	2.83	10.07	0.53	3.52	0.001
SCGE	-3.78	1.677	-7.09	-0.46	-0.32	-2.25	0.026
SCSA	0.23	1.268	-2.27	2.74	0.02	0.18	0.852
SCSP	-0.68	1.628	-3.90	2.53	-0.06	-0.42	0.674

A negative predictor in systems thinking was also found; namely, SC towards the creation of digital content. It might be that mechanical engineering students who reported higher results on ICT SC are rather focused on specific skills or area of expertise and pay less attention to broader systems thinking. It could also be that students who are trained in a particular software programme or digital creation feel very confident about their technical skills, and are therefore unable to see a broader picture of the design-based task or any other task when creating digital content what also confirms earlier findings [6][14]. Sometimes, it could be that the education system through its study subjects does not allow students to manipulate broader context, thus students might not be encouraged to develop systems thinking.

CONCLUSIONS

This study highlights variations in the students' systems thinking and ICT SC across higher education. Students, regardless of their study major, rated their systems thinking and ICT SC as above average. Mechanical engineering students rated systems thinking lower, particularly in relation to recognising sequences of events, the possibility of multiple causes, and causal and relational understanding. However, the ability to recognise patterns of relationships, interrelationships and interconnections was equally well developed by all students, regardless of their major of study. In terms of ICT SC, mechanical engineering students rated their general ICT and data literacy and problem solving higher, but there was also a difference regarding pre-service teachers, who rated the dimensions of processing, storing and creating content lower than the others. The ICT SC of processing and storage, as well as collaboration and communication proved to be positive predictors for systems thinking, while the dimension of digital content creation proved to be an inhibitor of systems thinking. As education continues with the rhythm of time, these competencies might be more vital to sustainable development and technology innovation adaptation in higher education systems.

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