The model of self-organization in digitally enhanced schools

Eka Jeladze[1], Kai Pata[2]

[1] School of Digital Technology, Tallinn University, Narva mnt. 25, 10120 Tallinn, Estonia
[2] School of Digital Technology, Tallinn University, Narva mnt. 25 10120 Tallinn, Estonia
{ekajel, kpata}@tlu.ee

Abstract. To explain how the innovative changes are maintained in digitally enhanced schools this paper proposes the model of self-organization. We examined the school as complex system focusing systemically at digital components in it. The data were collected from 447 schools in 13 European countries in 2017, using SELFIE instrument that measures schools' digital maturity. Empirical data were used for assessing the goodness of the model and explaining self-organization patterns in different learning ecosystem types. K-Means cluster analysis identified 4 types of schools. In each cluster the regression analysis was conducted to develop the path model between digital components. The findings demonstrated that the proposed model could explain holistically the self-organization in learning ecosystems. The model identified different types of learning ecosystems based on how the innovative changes were maintained in schools: i) organizational learning-driven; ii) digital infrastructure-centered, iii) Mediating loop-centered schools, iv) digital teaching strategies-centered.

Keywords: school, self-organization, system thinking, digitally enhanced learning ecosystem, digital innovations.

1 Introduction

Modern environment in which organizations operate is characterized by high level of complexity, rapid change and technological innovations, to which they have to adapt [1]. Complexity of learning setting is especially accelerated with new technology tools and practices, approaches to teaching and learning spaces, learning transformation with technology [2]. Studies show that technology is a driver that can enhance the education [3, 4, 5]. The policies on national and international level are motivated to leverage technology integration by providing digital infrastructures, respective skills and knowledge to the school community. As a result of improved access to the technology, the changes are expected in teaching. Though there's no clear increase in the learning and teaching outcome, neither substantial change in learning settings [6]. Schools continue to use technology by supporting existing practices [7, 8]. Amid a rapidly changing socio-technical landscape it is important to rely on the model describing how different schools self-organize in order to respond to the requirements of technology-rich environment and the needs of human agents there. For this purpose we focus on a holistic exploration of schools, as well as creation and use of knowledge practices on an organizational level.

So far research has provided a solid base of knowledge for independent factors for technology integration in learning settings [7]. Though explaining separate factors and events leads to event-oriented reactionary approaches that could not solve challenges [9, 10]. Study methodology is missing complex, dynamic and holistic nature of the real world. "A possible reason that technology integration has been difficult to understand is not a lack of data, but limitations of methods used to analyze data" [7].

We need a model that considers dynamic changes of socio-technical innovations and suggests how innovative practices are created and matured through the underlying structures of digitally enhanced learning organizations. To develop the baseline for the model of self-organization in digitally enhanced schools we use the following theoretical assumptions and models. Nonaka [11] describes knowledge creation processes through social formation levels as individuals, groups or organizations, and connects individual knowledge with organizational knowledge system [12]. However, this theory does not expose to the technology innovations [13]. This organizational knowledge conversion model may be complemented with the trialogical learning framework [14] that conceptualizes technology as the mediator to change human behavior and advance the knowledge. This theory describes the work to be organized around collaborative, shared technology-mediated knowledge artifacts and practices. Trialogical learning model does not elaborate how this mediated knowledge is coordinated between individual and organizational levels.

In this paper we propose a model of self-organization in digitally enhanced schools. We explore the schools holistically to understand how they organize for digital innovations, and coordinate for knowledge integration within and between classroom and school level components. We will use empirical data collected with the SELFIE tool [15] to explore the goodness of the model and identify self-organization patterns in different learning ecosystems. The research questions are: How should the self-organization in schools be modeled as digital learning ecosystems? What self-organization patterns in digital learning ecosystems can be found with the SELFIE dataset from European schools? What should be improved in schools' self-organization based on their discrepancy from the self-organization model? We argue that the model can holistically assist the schools to analyze the patterns of self-organization and make steps to improve the organization systemically towards digital maturation.

2 Self-organization in Digitally Enhanced Schools

2.1 Self-Organization in Complex Systems

We use systems approach to explore schools holistically and explain interconnectedness and interdependence of the components there. A system is a functional whole, composed of a set of components, coupled together to function in a way that might not be apparent from the functioning of the separate component parts [16]. The field of system thinking tries to understand the complexity of the system and its behavior by understanding its underlying structure [17, 18]. There are different approaches of systems thinking (cybernetics, viable system management, complex systems, dynamic systems, chaos and complexity and etc.), though they share the following commonalities:

a) Holistic approach of interconnected and interacting elements, where the whole is something more than just the sum of its components [19, 20, 21].

Interactions among the components are more important to determine the system behavior then the separate components.

b) The components are interdependent. They affect each other and depend on each other to achieve the goal [20, 21, 22]. Cabrera (2015) describes the interdependence in terms of hierarchical levels in the system. Different properties and causalities emerge while the components interact within and between levels.

c) Interaction has purpose - that is to maximize the fitness of the agents and the whole system [20, 21]. Individuals acting in the system have different purposes and rationalities [19, 23]. But they follow rules to produce an adaptive response within the system [25, 22].

System's complexity is represented by feedback loop mechanism [21]. Forrester [in 21] describes feedback loop as the closed path that connects an action to its effect on the surrounding conditions, and these resulting conditions inform back and influence further action. The loop is a higher conceptual unit than the variables that make up the circular chain [26]. Loops have purpose and differ in importance or dominance over time [27].

All complex systems have the capability to self-organize and continuously evolve to become better suited to the environment [1, 24]. Self-Organization refers to a dynamically produced (re)-organization where systems change their structure during the operation in order to show more order or pattern, and does it without the imposition of external control [28, 29]. First, we will introduce the general self-organization principles and then associate these principles with the school as a digitally enhanced learning system.

We build our assumptions for developing the self-organization model on the following principles of the self-organization process:

The first principle is synergy [24]. Local elements of the system interact with the close neighbors to create the local synergy [22, 30, 7, 29]. Locally organized elements then spread to faraway regions to create a system level synergy. Components handle, repeat and maintain the same actions to come nearer to the goal [29]. The system co-evolves, its components function simultaneously until they are fit to maximize the synergy for the optimal productivity of the system.

Second, complex systems tend to incorporate certain degree of disorder. They use resources to lower level of entropy. Order is created on macro level (schools in our case) after the energy flux is settled on a micro level [29].

Third, positive and negative feedback loops interplay in the system [22]. Self-organization starts with positive feedback loop. A positive loop occurs when a change in one variable causes a change in the same direction in a second variable, which in turn causes further changes in the same direction in the first [31]. This may be both the transactive or transformative association between the variables. Positive feedback leads to continual growth or decay. Initial fluctuation increases and spreads quickly to achieve the order in the system. System reaches equilibrium when its components align behaviors to the configuration that was created by the initial fluctuation. From this moment further growth for self-organization is no more possible. The system will retain stable condition and suppress any change from the configuration. This is the negative feedback. The mechanism that reinforced the configuration now suppresses the deviation and keeps the system to its stable configuration [29].

Configuration of a new "order-state" is based on the choice of the certain system. This is the fourth principle of self-organization process - selective retention mechanism. It assures that the outcome of the interactions of the system components is not random; it is based on the "preference" for certain situations over the others [29]. In our model different teaching and learning practices evolve or are developed based on the resources, experiences, knowledge or simply preferences of the agents in the ecosystem. The system aligns its behavior to the "preferred" configuration then.

2.2 Model of Self-organization in Digitally Enhanced Schools

In this section we bring the self-organization principles to the digitally enhanced school context. Knowledge is created locally, where tasks are created, problems defined and resolved (classroom level). The challenge is how to coordinate and integrate knowledge inputs from these local activities on an organizational level [12]. Our interest related to the self-organization capability respectively is: how schools coordinate and share knowledge of digital practices created at classroom level to reorganize and establish behavior pattern on a school level.

We identified certain components in the loops, which are embedded in the underlying school structure on a classroom and school level. These components include social behaviors of human agents and technology tools - the mediator to organize knowledge practices and change human activities [14] in the system. Human agents are capable to work with technology tools in order to create the artifacts in a collaborative environment.

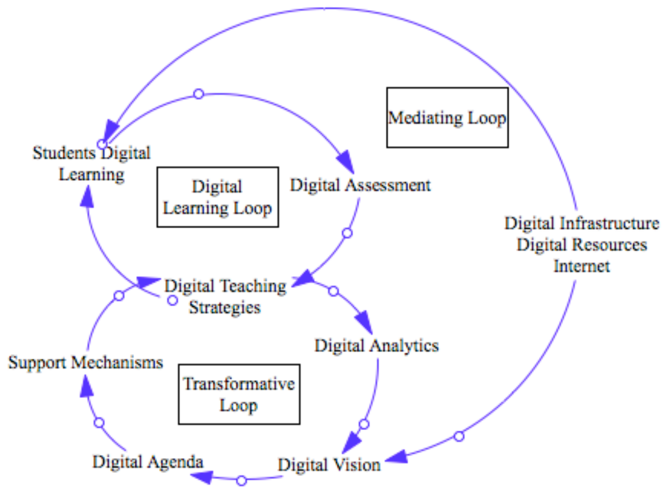

Fig. 1. Model of self-organization in digitally enhanced schools.

We present the model of self-organization in digitally enhanced schools with three groups of underlying structures: mediating, transformative and digital learning [32] loops (Fig. 1). Mediating loop represents digital infrastructure and resources provided from socio-technical landscape to which human agents interact. Digital learning loop represents the interaction of classroom level components. Here the change in personal operating system of activity takes place in a way that supports technology mediated knowledge practices. Transformative loop combines the components with transforming agency that are in place on a school level. Purpose of transformative loop is to identify, enable and deploy the components/conditions in order to restructure/re-organize the system in response to agents' individual needs on a classroom level and to socio-technical landscape.

Synergy of social behaviors of the agents and technical means produce knowledge practices and objects/artifacts in the components. They can be collectively, or individually created artifacts/practices that are shared later, e.g. digital documents, material, behavioral patterns, routines, ways of working with knowledge and knowledge artifacts. E.g. digital teaching strategy is one component in digital learning loop. It includes technology as a mediator to create an artifact in the form of lesson plan, learning scenario, or digital learning material. School's digital vision is another example of component where digital strategy documents are created as artifacts in a collaborative effort of school community.

Shared objects and knowledge practices work as socio-technical scaffolds. Social-technical scaffolds are by nature meta-designed patterns that evolve through feedback loops [33]. These scaffolds support agents, and eventually the system, in the reinforcement cycles in the loops. The system continuously develops through transformation of shared objects and knowledge practices.

In our model we describe self-organization process of digitally enhanced school as follows: New knowledge practices evolve or existing ones are developed in digital teaching strategies. Certain artifacts (e.g. digital material, learning resources) are produced at this point and then shared with students. Activities are enforced in students' digital learning component, where students are engaged to create shared objects with technology tools as mediators (e.g. develop teacher created artifacts, or create new ones on the basis of them). Appropriate digital assessment is synergized with digital teaching and learning strategies that makes a circle in digital learning loop. The loop would inform and reinforce the teaching strategies back to be further developed or tailored to students needs.

Synergy in the digital learning loop generates digital data - or digital analytics (in the model) – that drives spread of innovation on a school level. Digital analytics informs vision, which coherently informs digital agenda and support mechanisms in a transformative loop. Knowledge practices and socio-technical scaffolds produced here (e.g. digital strategy, activities, routines, workshops) reinforce back digital learning loop by expanding the digital innovations in the numbers of engaged teachers and students, as well as in the depth of innovation nature. The system repeats these actions until the negative loop takes place to stabilize the system. It would mean that school has developed a robust knowledge for the particular innovative practice and it is implemented as a regular routine by majority of the teachers. With rapid technology innovations and changing environment, schools have to undergo this positive/negative feedback interplay often and fast.

3 Methods

3.1 SELFIE Instrument

The data was collected through SELFIE (Self-reflection on Effective Learning by use of Innovative Educational Technologies) instrument [15]. It is the tool developed by the European Commission through the partnership of educational experts and schools in Europe. School leaders, teachers and students fill self-reflection questionnaires to assess what works and what needs improvement in the use of technologies for digital teaching and learning in their respective schools. They reflect on planning and implementing the digital strategies on a school level; digital teaching, learning and assessment practices in their classrooms; professional training for digital teaching, collaboration and networking; and the infrastructure that support digital teaching and learning. School leaders, teachers and students answer short statements and questions on a likert-scale from 1 to 5 points. 1 point is the lowest score (school reality does not match the statement description), 5 is the highest (the statement tentatively describes school reality). SELFIE tool then generates school report to showcase to what extent certain components exist in the school, based on the participants' self-assessments.

Questionnaire items cover seven areas of European Framework for Digitally Competent Educational Organizations [34], which is the theoretical basis of SELFIE: leadership and governance practices, teaching and learning practices, professional development, assessment practices, content and curricula, collaboration and networking, and infrastructure.

SELFIE is a useful data-collecting tool for our study. It collects the views from different perspectives: students' learning, teachers' teaching, and school leaders' management perspectives. It enables to construct the system's self-organization behavior from the behaviors of different stakeholders on a classroom and school level.

3.2 Data Collection

In this paper we use the data that was collected from SELFIE tool [15] in 2017. We analyzed data only from primary and secondary schools, total of 447 schools (out of 650) from 13 European countries (Table 1). Total number of participants equals 58525 (schools leaders =2535, teachers=10151, students=45839). School leaders group includes all the teachers holding managerial responsibilities together with their main teaching function. The data was collected from primary school students who were 9 years old or more by the time of participation in the questionnaire.

Table 1. Rate of Participation according to the countries.

Countries	Participant #
Belgium	2056
Estonia	369
Ireland	834
Greece	1086
Spain	7326
Italy	29695
Cyprus	856
Malta	2366
Finland	438
United Kingdom	571
Georgia	2494
Russia	3679
Serbia	6755

3.3 Data Analysis

Data from the questionnaire includes 119 variables. Each variable accounts for the statement in the questionnaire. For the ease of understanding and analysis we used initial 119 variables and transformed them in 13 compound variables. Compound variables are distributed in mediating, transforming and digital learning loops (Table 2). They are used as the components in our model. We divide the components into mediating, transformative and digital learning loops in order to build an ecosystemic model [32] and distribute the constituent components to the classroom and school levels. We hereby acknowledge that each of these components has a role in transformation process.

We investigated the schools holistically as complex systems and tried to map them based on the self-organization patterns. We aggregated the data from teachers, students and school leaders per individual school in order to describe whole school –

as a system. In a final set of the data for the analysis we have 447 cases (schools) and 13 compound variables.

Table 2. Variables Distributed in mediating, transformative and digital learning loops.

Loops	Components	Description of Components
Mediating	Access to technology	Students access technology at school and at home for their learning purposes.
	Digital Infrastructure	Variety and high quality of digital technologies; user-friendly digital environment.
	Digital Resources	Providing high quality digital material for teaching and learning.
	Internet	Reliable connection and speed.
Transformative	Digital Agenda	Digital strategy exists in the school; school protects digital data.
	Digital Vision	Vision includes use of digital technology for: effective teaching and learning practices, active engagement of students, fostering students' creativity.
	Digital Analytics	Collecting and analyzing data on the outcomes of using digital technology at school, also data on individual students for improving their learning experiences.
	Participatory Design	School community involvement in the design of digital strategy; participation in the discussion on the benefits and challenges of using digital technologies.
	Support Mechanisms	Motivating and providing: support to try out new teaching practices and digital tools, technical support, professional development opportunities in-house or organized by third parties, exchange of experiences within schools.
	Networking and Communication	Use of communication tools in and out of schools, participation in online professional networks, collaboration using digital technologies.
Digital Learning	Digital Assessment	Assessing students' knowledge, skills and attitudes, and their learning with digital means.
	Digital Strategies for teaching	BYOD, new pedagogical approaches, personalized learning, engagement in real-world activates, virtual learning environment, cross-curricular/ interdisciplinary teaching, teaching to critically analyze and safely use digital material, special educational needs.
	Students digital learning	Students' use of digital technologies to enhance their learning experience by: creating digital content, self-assessing and peer-assessing, documenting their learning with digital technologies.

We performed K-Means Cluster analysis with an aggregated data. ANOVA identified 4 significantly different clusters among the schools. On the next stage we did stepwise regression analysis for each cluster and path modeling to represent self-organization patterns based on our proposed model.

4 Results

4.1 Different School Clusters

We run K-Means cluster analysis to find the types of digital learning ecosystems across the schools in Europe. We observed the data to identify the groups of schools that differentiate significantly based on the mediating, transformative and digital learning loops. The analysis in this phase does not allow making inferences how the components in loops are related.

According to K-Means cluster analysis the cases where distributed in clusters as follows: 83 cases in the first cluster (18.5%), 96 cases in the 2nd cluster (21.5%), 146 in the 3rd (32.7%) and 122 in the fourth cluster (27.3%) respectively. Cronbach Alpha for the variables (>0.7) proves their internal consistency in the compounds.

ANOVA table shows that the following variables have the highest F meaning and therefore contribute most to cluster solutions: digital strategies (F=359.575), digital infrastructure (F=305.483), digital analytics (F=297.505), support mechanisms (283.774), and digital vision (F=278.504). While Internet (F=93.450) and access to the technology (F=122.879) does not make much difference to distinguish clusters.

Table 3. ANOVA output for clusters.

	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
Mediating, Access to technologies	17.496	3	.142	443	122.879	.000
Mediating, Digital Infrastructure	25.243	3	.083	443	305.483	.000
Mediating, Digital Resources	28.178	3	.131	443	215.581	.000
Mediating, Internet	23.598	3	.253	443	93.450	.000
Transformative, Digital Agenda	18.169	3	.098	443	185.646	.000
Transformative, Digital Vision	14.870	3	.053	443	278.504	.000
Transformative, Digital Analytics	41.590	3	.140	443	297.505	.000
Transformative, Participatory Design of Agenda	20.869	3	.086	443	243.745	.000
Transformative, Support Mechanisms	19.645	3	.069	443	283.774	.000
Digital learning, Networking and Communication	16.192	3	.069	443	235.453	.000
Digital learning, Digital Assessment	31.755	3	.147	443	216.093	.000
Digital learning, Digital Strategies for Teaching	15.212	3	.042	443	359.575	.000
Digital learning, Students Digital Learning	21.103	3	.085	443	249.012	.000

Y-axis (Fig.2) represents average values on 5-point scale, to what level human agents assessed the existence of each variable in the corresponding cluster. In all four clusters schools show higher self-assessment indicator in the digital agenda and digital vision. Though they lay behind on digital analytics to inform the vision and agenda. On the same side, participatory design of agenda has one of the lowest indicators, meaning that stakeholders are less involved in the design of digital agenda of the school.

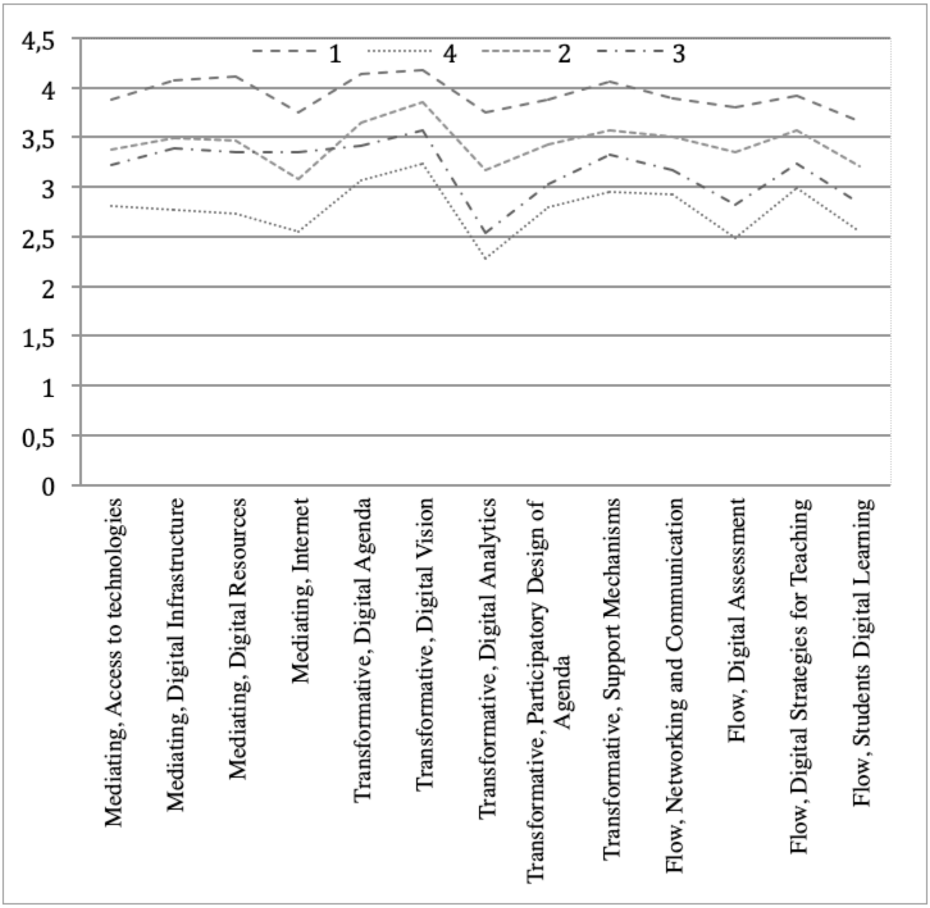

Fig. 2. Map of four clusters. X-axis shows the compound variables. Y-axis shows the value of the compound variables for the clusters.

Values for the components appear to be correlated through mediating, transformative and digital learning groups in different clusters (Fig.2). Higher the participants assess digital infrastructure and organization of digital agenda on a school level, the higher they consider digital learning in their school.

Digital assessment has the lowest value in the digital learning components' group, while digital teaching strategies have the highest values across all clusters. We can observe that using digital technologies in different school clusters is not aligned with the values of the students' digital learning and assessment components.

Using digital data to assess students' immediate learning, as well as using digital analytics to inform schools digital agenda, have lower values compared to other component values in all clusters. We can posit that schools' decisions may be influenced if the changes are not complied with the digital data from a classroom and school level.

Cluster 1 represents digitally most enhanced schools. School community has higher confidence that transformative components are set in their school and digital infrastructure supports them. The values of digital learning components are quite high respectively.

Cluster 2 and cluster 3 are in the middle range with similar indicator in digital infrastructure. We would say that a drop in using digital analytics and participation in agenda design leads to the lower digital learning in the 3rd cluster and forms a major difference between two clusters.

Cluster 4 is the least oriented towards digital activities. Teachers are less involved to design school vision and agenda. They lack support mechanism and digital infrastructure that ends with lower digital learning components. Digital strategies are more or less in place, though it does not change the system because other components do not support the system.

4.2 Types of schools that represent different self-organization models

We analyzed the mediating, transformative and learning loop components in each school cluster separately to identify what actual paths appear between the components. Systems thinking approach highlights that interconnection among the components are more important to determine system behavior then separate components. For this purpose we conducted stepwise regression analysis in each school cluster and mapped the outputs to our self-organized system model. This enabled us to validate our initial model in different types of schools that were detected with k-means cluster analysis. We also observed how certain components in the path models could be viewed as central hubs, since they provide multiple connections with other components. We named the clusters based on these commonalities:

Cluster 1 (Fig. 3) – Organizational learning-driven schools;

Cluster 2 – (Fig. 4) – Digital infrastructure-centered schools;

Cluster 3 – (Fig. 5) – Mediating loop-centered schools;

Cluster 4 – (Fig. 6) – Digital teaching strategies-centered schools

Some commonalities among the clusters (Fig. 3; Fig. 4; Fig. 5 and Fig. 6) could be observed: digital vision is interconnected (two-way connection) with digital teaching strategies in all clusters and it represents the strongest path with high beta value; digital analytics is the weakest component, having no positive correlation with any of transformative loop components (only negative correlation with digital vision in the 3rd cluster).

In the following section we present the path models of school clusters and discuss them in comparison with the self-organization model proposed at Figure 1.

Cluster 1. Organizational Learning-Driven Schools. Based on the path models we can say that 1st cluster is represented with most complex interconnection and interdependencies among the components compared with other clusters (Fig.3).

The components in the *mediating loop* are mutually interconnected. Digital infrastructure has impact on digital learning component. Support mechanisms associate with infrastructure and digital resources. Digital agenda influences the Internet and Digital Resources components, but not the Infrastructure.

The digital learning loop is clearly represented with interconnected 3 components of digital teaching strategies, digital assessment and students' digital learning.

1st cluster also has the best-interconnected *transformative loop* compared to other clusters. There are direct interconnections between digital vision and agenda, support mechanisms and digital teaching strategies. Only the digital analytics does not make connections with other transformative components. Digital vision and agenda seem to influence different aspects. Digital vision relates with support mechanisms and digital teaching strategies, while digital agenda connects with digital learning resources and Internet.

We can see that the system pattern of this cluster is very close to our proposed model.

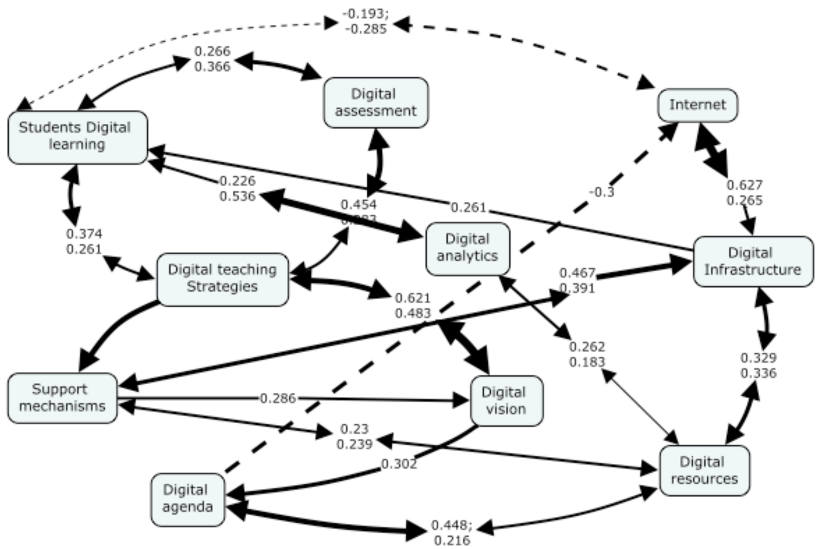

Fig. 3. Cluster 1 – Organizational Learning-Driven Schools. Straight line shows positive correlation, while dotted line describes negative ones. 2-way arrow represents 2-way interdependency between the components. Numbers between the components represent beta values from regression analysis. Thickness of the lines describes the weight of the connections based on the beta values.

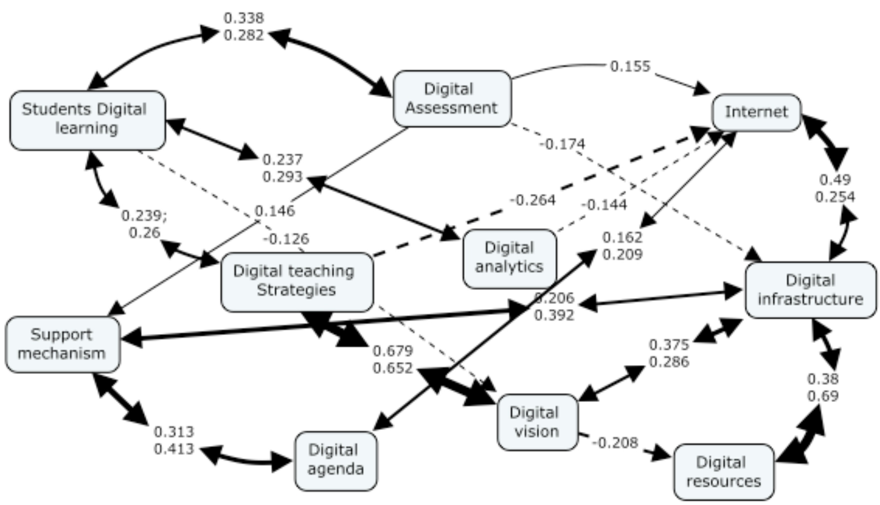

Fig. 4. Cluster 2 – Digital Infrastructure-Centered Schools. Straight line shows positive correlation, while dotted line describes negative ones. 2-way arrow represents 2-way interdependency between the components. Numbers between the components represent beta values from regression analysis. Thickness of the lines describes the weight of the connections based on the beta values.

Cluster 2. Digital Infrastructure-Centered Schools. 2nd cluster (Fig. 4) has the strongest connections around digital Infrastructure and Internet.

The *digital mediating components* are mutually interconnected in these schools, but there are few and weak connections with digital vision and agenda. This cluster represents the schools where actual mediating components do not directly associate with organizational level transformation loop or with the digital learning loop.

Digital learning loop components partially form interconnections. It is connected to transformative loop through digital teaching strategies and digital vision. At the same time the vision creates negative path with students' digital learning.

Support mechanisms are directed to digital infrastructure but not towards students' digital learning or digital teacher strategies.

Overall, the path model in Cluster 2 represents rather separate interconnected digital components that did not form the self-organized system with feedback loops.

Cluster 3. Mediating Loop-Centered Schools. In the 3rd cluster (Fig. 5) we can observe strong interconnections between the *mediating loop components*. These schools are more centered on digital infrastructure and resources (that are provided from outside) than on working with classroom and school level components - that require more self-organization efforts. This cluster also distinguishes with more negative correlations (digital assessment and support mechanisms; digital vision and agenda, digital learning and digital resources; digital assessment to analytics, and digital vision to analytics); the digital learning analytics is not well connected with other loops.

In the *digital learning loop* digital assessment has a low impact on digital teaching strategy and the digital learning strategies do not influence back assessment. Increase in the use of digital assessment on a classroom level is negatively correlated with the support mechanisms and school-level digital analysis of the data. The more schools have digital vision aspects represented, the less they provide support mechanisms or work with digital analytics on a school level. Further analysis of digital vision of this cluster would bring more insight to explain negative paths there.

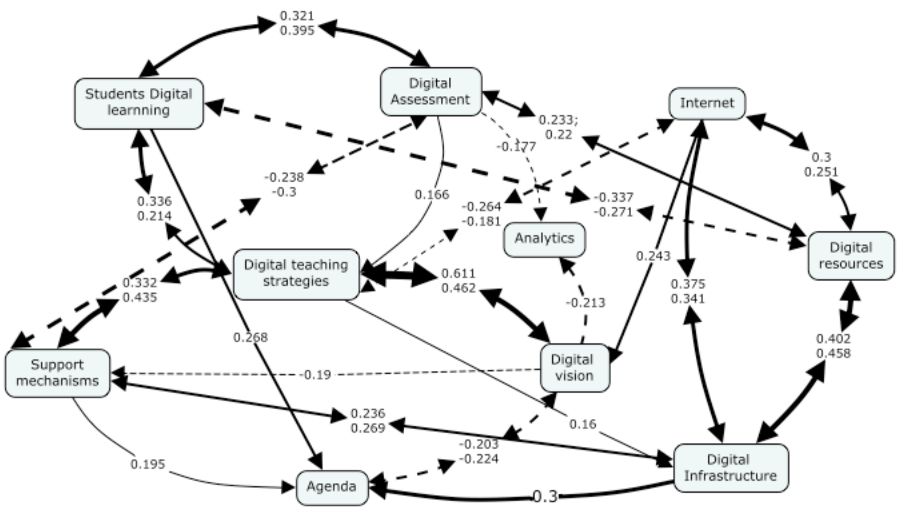

Fig. 5. Cluster 3 –Mediating Loop-Centered Schools. Straight line shows positive correlation, while dotted line describes negative ones. 2-way arrow represents 2-way interdependency between the components. Numbers between the components represent beta values from regression analysis. Thickness of the lines describes the weight of the connections based on the beta values.

Cluster 4. Digital Teaching Strategies-Centered schools. In the 4th cluster (Fig. 6) digital teaching strategy was the most central component that had connections with digital vision and agenda, support mechanisms and students' digital learning, it also impacts digital analytics (one-way communication).

The *mediating loop components* - Internet, digital infrastructure and digital resources - had interconnections with each other as in cluster 1. Only Internet component was directly interrelated with the digital learning loop. Digital resources were interrelated with digital agenda, while digital infrastructure was connected with digital vision. Internet and digital teaching strategies had associations but with opposite directions.

The *digital learning loop components* - Digital teaching strategies, students' digital learning and digital assessment - formed a loop over digital analytics that is a transformative component. Digital teaching strategies impacted the analytics while it did not make connection back to the digital teaching strategies. We could assume that there was no feedback loop in this grouping.

Transformative loop components appeared to be not connected into the loop to make connections to each other. Agenda and vision were not mutually connected. They separately tied with some mediating components (see above), but not with the support mechanisms. Support mechanisms connect mainly with Internet but not with digital infrastructures and resources. Digital agenda creates negative path with students' digital learning.

Particular to this cluster, the school-level factors were not orchestrated to support classroom level of digital learning loop.

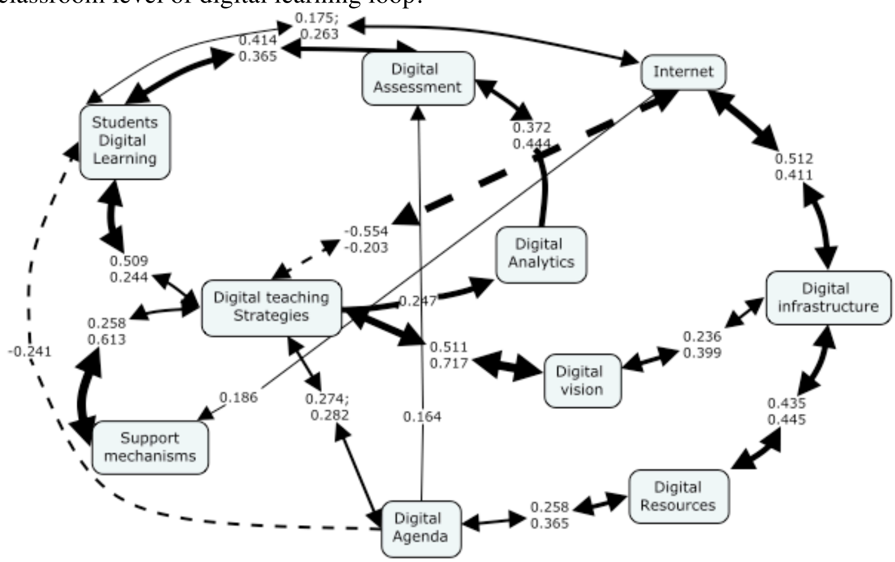

Fig. 4. Cluster 4 – Digital Teaching Strategies-Driven Schools. Straight line shows positive correlation, while dotted line describes negative ones. 2-way arrow represents 2-way interdependency between the components. Numbers between the components represent beta values from regression analysis. Thickness of the lines describes the weight of the connections based on the beta values.

The path models of four clusters indicate the hierarchically successive types of digital learning ecosystems: digital maturity was growing from single classroom level learning-loop in Cluster 4 (Fig. 6) towards integrating it with the mediating loop components in Cluster 3 and 2 (Fig. 5; fig 4) and finally the transformational loop appeared in Cluster 1 (Fig. 3). The most advanced cluster 1 was the closest to the proposed self-organization model in digital learning ecosystems, but yet incomplete in several aspects related with digital analytics.

5 Discussion

In this study we explored schools self-organization to create and coordinate knowledge practices across the underlying structures on classroom and school levels. Self-organization in digitally enhanced schools describes schools' capability to be adaptive to the rapid technological changes in the environment, and respectively restructure/reorganize operations by: deliberately starting to work with technology-mediated artifacts; maturing gained knowledge in a repeated cycle from classroom to school level and back (digital learning and transformative loops) with active participation of school community; providing efficient scaffolds and making knowledge practices visible on a school level.

We proposed the model of self-organization in digitally enhanced schools. Our model identifies the components where knowledge practices and technology-mediated artifacts can be produced, and represents their interactions within and between classroom and school levels in order to determine system behavior [19, 20, 21].

Proposed model can help to map "order-state" of the system: a) which components on the classroom and school level are/are not supported by the mediating digital means; b) does the system generate positive feedback loop on a classroom and school level (based on the analysis of the component connections there); c) what are the strong/weak components in the system that trigger/hinder the synergy within and among the loops. We argue that model has explanatory power for the school "order-state". It also suggests the starting point for further exploration of certain parts of the system and planning its re-organization/re-structure accordingly.

We can see that the self-organization pattern in the first cluster, which represents the most digitally enhanced school structure, follows our proposed model. All the loops are present and connected to each other, which distinguishes cluster 1 from other clusters.

We would like to highlight the following features and needs in school systems based on the findings from the study:

a) Complex interactions among system components (Fig. 3, 4, 5, and 6) reinforce higher digital component values (Fig. 2) on classroom and school levels. These values represent that local agents (students, teacher and leaders) assess development/maintenance of certain components on a higher level in their schools.

b) There's a need to synergize the components in the digital learning loop. It means aligning digital teaching strategies to using digital assessment and students' digital learning (e.g. students produce digital content, or document their learning using digital technologies). System is inclined to decrease entropy level [29]. Higher fluctuation (or deviation from traditional classroom) in the digital learning loop would raise deviation in assessment and students digital learning, thus resulting in the synergy in the loop. We see that schools that declare using new digital teaching strategies tend to more activate students learning by digital technologies and using digital assessment for assessing their skills, knowledge and use of technologies for their learning.

c) Interconnections among the components on the transformative loop need to be enforced. According to self-organization principle order is created on the macro – school level [29]. We assume that this is the main challenge in all clusters.

d) System needs support in knowledge maturing through recursive actions between the loops – classroom and school levels. In our data we cannot depict this recursive actions. We can assume that higher values of the certain component in the system (Fig. 2) shows that more respondents used these components through upscaling already existing knowledge practices on a school level and involving new classrooms; and embracing new creative ideas based on internal or external knowledge and experiences.

e) The system continuously develops through transformation of shared objects and knowledge practices until the components are fit to maximize the synergy for the optimal productivity of the system. Development of shared objects would require links between individual (classroom)/collective (school) knowledge practices by: making knowledge practices visible on a school level (with the help of digital analytics), involving school community in the design of school digital vision and agenda, and supporting iterative processes for artifacts' development. Schools, with higher values on a digital learning loop and complex interactions, verified existence of digital school-wide vision and agenda, as well as school community contribution in its development.

f) We assume that processing the digital analytics is the powerful channel to link classroom to school level. It informs the vision and agenda on a school level, and adjusts knowledge practices between the loops. According to our data processing the digital data of individual students learning and overall system behavior on an organizational level is the weakest link in the cycle.

g) System needs to orient to its future state. We would say that future-orientedness sets the system to new positive feedback loop after stability is achieved from positive/negative feedbacks interplay. It directs organization's openness and responsiveness to the changes in socio-technical landscape, also human agents participation on a school level – to accumulate knowledge practices in digital vision and agenda and then back to classroom level. System gains capability to quickly react and restructure its operation to the changes in the environment.

We can assume that low intensity and interconnection of certain components slow down positive feedback and might cause the decay in the system. It keeps system stable instead of being open and responsive to the socio-technical regime requirement.

In order to support schools' self-organization it is essential to develop their capacity to work on its own: a) to allocate resources to leverage knowledge practices and shared objects, b) expand existing knowledge practices in the iterative cycle between classroom and school level, c) explore and develop new knowledge practices based on the resources.

Configuration of the system is different for individual system. These differences depend on the knowledge practices that evolve during the initial process of self-organization on a classroom level. However, this study did not aim to explore the dominant or characteristic practices (digital teaching strategies) in the school cluster and to find the causalities. Also, SELFIE data does not allow us to validate the knowledge maturing phases across the loops and recursive actions. These are the limitation of this study that will be addressed in the next phase.

6 Conclusions

We explored how schools self-organize to respond to the digital innovations. We built the model of self-organization in digitally enhanced schools. The model identifies and groups school underlying structures across mediating, digital learning and transformative loops, and shows interconnections on a classroom and school levels. We described four types of school ecosystems based on the data from SELFIE tool in order to see how different ecosystems organize for digital innovations. We argue this representation will help policy makers and school community to build schools capacity to reorganize the system in accordance to rapidly changing socio-technical landscape.

References

1. Cabrera D., Cabrera L., Powers E., Solin J., Kushner J.: Applying systems thinking models of organizational design and change in community operational research, European Journal of Operational Research, 268(3), 932-945 (2018)
2. Borko H., Whitcomb J., Liston D.: Wicked problems and other thoughts on issues of technology and teacher learning (2009)
3. European Commission.: Digital Agenda for Europe - Rebooting Europe's economy. European Commission, 1–8 (2014). http://doi.org/10.2775/41229
4. Kampylis P., Punie Y., Devine J.: Promoting Effective Digital-Age Learning - A European Framework for Digitally-Competent Educational Organisations (2015). http://doi.org/10.2791/54070
5. Kools M., Stoll L.: What Makes a School a Learning Organisation? OECD Education Working Papers, (137), 1–89 (2016). http://doi.org/10.1787/5JLWM62B3BVH-EN
6. OECD Centre for Educational Research and Innovation.: Schools at the Crossroads of Innovation in Cities and Regions (2017). http://doi.org/http://dx.doi.org/10.1787/9789264282766-en
7. Howard S. K., Thompson K.: Seeing the system: Dynamics and complexity of technology integration in secondary schools, Education and Information Technologies, 21(6), 1877-1894 (2016).
8. Ertmer P.A., Ottenbreit-Leftwich A.T., Sadik O., Sendurur E., Sendurur P.: Teacher beliefs and technology integration practices: A critical relationship, Computers & Education, 59(2), 423-435 (2012)
9. Sterman J. D.: System dynamics modeling: tools for learning in a complex world, California management review, 43(4), 8-25 (2001)
10. Jeladze E., Pata K.: Smart, Digitally Enhanced Learning Ecosystems: Bottlenecks to Sustainability in Georgia, Sustainability, 10(8), 2672 (2018)
11. Nonaka I. A.: dynamic theory of organizational knowledge creation, Organization science, 5(1), 14-37 (1994)
12. Nonaka I., Von Krogh G., Voelpel S.: Organizational knowledge creation theory: Evolutionary paths and future advances, Organization studies, 27(8), 1179-1208 (2006)
13. Maier R., Schmidt A.: Explaining organizational knowledge creation with a knowledge maturing model, Knowledge Management Research & Practice, 2014(1), 1–20 (2014). https://doi.org/10.1057/kmrp.2013.56
14. Paavola S., Hakkarainen K.: Trialogical approach for knowledge creation, Knowledge creation in education (pp. 53-73). Springer, Singapore (2014)
15. SELFIE, https://ec.europa.eu/jrc/en/digcomporg/selfie-tool
16. Levine R. L., Fitzgerald H.: Analysis of dynamic psychological systems: Basic approaches to general systems, dynamic systems, and cybernetics (Vol. 1), New York: Plenum Press (1992)
17. Richmond B.: System dynamics/systems thinking: Let's just get on with it, In International systems dynamics conference, Sterling, Scotland (1994). Retrieved from http://www.geocities.ws/himadri_banerji/pdf/systhnk.pdf
18. Sweeney L. B., Sterman J. D.: Bathtub dynamics: initial results of a systems thinking inventory, System Dynamics Review, 16(4), 249-286 (2000)
19. Mingers J., White L.: A review of the recent contribution of systems thinking to operational research and management science, European Journal of Operational Research, 207(3), 1147-1161 (2010)
20. Meadows D. H.: Thinking in systems: A primer. Chelsea Green Publishing (2008)
21. Amold, R.D., Wade, J. P.: A definition of systems thinking: a systems approach, Procedia Computer Science, 44, 669-678 (2015).
22. Heylighen, Francis. "Complexity and self-organization." Encyclopedia of library and information sciences 3 (2008): 1215-24.

23. Cabrera D., Cabrera, L.: Systems thinking made simple: New hope for solving wicked problems in a complex world. Ithaca, N.Y.: Odyssean Press (2015)
24. Haken, Hermann. Information and self-organization: A macroscopic approach to complex systems. Springer Science & Business Media, (2006).
25. Okubo A.: Dynamical aspects of animal grouping: swarms, schools, flocks, and herds. Advances in biophysics, *22*, 1-94 (1986)
26. Hirsch G.B., Levine R., Miller R.L.: Using system dynamics modeling to understand the impact of social change initiatives, American Journal of community psychology, 39(3-4), 239-253 (2007)
27. Groff J.: Dynamic systems modeling in educational system design & policy, Journal of New Approaches in Educational Research (NAER Journal), 2(2), 72-81 (2013)
28. Newth D., Finnigan J.: Emergence and self-organization in chemistry and biology, Australian journal of chemistry, 59(12), 841-848 (2007)
29. Tzafestas S.G.: Self-organization. In Energy, Information, Feedback, Adaptation, and Self-organization (pp. 461-488). Springer, Cham (2018)
30. Finnigan J.: The science of complex systems. Australasian Science, 26(5), 32–34 (2005)
31. Senge P.M.: The fifth discipline, the art and practice of the learning organization. Performance+ Instruction, 30(5), 37-37 (1991)
32. Jeladze E., Pata K., Quaicoe J.: Factors determining digital learning ecosystem smartness in schools. Interaction Design and Architecture(s) 35, 1-21 (2018)
33. Fischer G.: Designing socio-technical environments in support of meta-design and social creativity. In: Proceedings of the 8th iternational conference on Computer supported collaborative learning (pp. 2-11). International Society of the Learning Sciences (2007)
34. European framework for digitally-competent educational organizations, https://ec.europa.eu/jrc/en/digcomporg