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Modelling of information flows in the Software Carpentry environment

Introduction. The level and speed of development of modern information technologies, the aspiration of modern society to informational unification necessitate the creation and implementation of a new model of the educational and scientific community interaction to ensure free, operational and effective access to the information resources being required for the purpose of implementing innovative means of studying and utilizing information processing tools.
Key goals. The educational and scientific community is looking for new approaches that can ensure the necessary level of education efficiency under the condition of severe limitations of resources, where time is the first of them. Therefore, an urgent problem today is the formulation of the principles of construction, modelling, and systematization of the properties of the information environment as an interactive educational and scientific platform. In this work we consider the problem using the Software Carpentry as an example.
Methods and Materials. To solve the formulated problem, we have conducted an analysis of the paradigms of informational educational environments, classifying the most widespread and available in the Ukrainian educational and research community such as Coursera, edX, Prometheus, Udemy. Another interesting direction to consider is the so-called microlearning. At the same time, the use of the above types of educational online resources for the purposes of organizing and conducting scientific research, as well as selecting and implementing new tools for processing information about objects of scientific research is difficult or impossible.
Results. The ideology of Software Carpentry is considered as one of the most successful implementations in this direction. The authors are participating in the project implemented by University of St. Andrews (Scotland) on translation the «Python programming language» course from English to Ukrainian as volunteers.
Conclusion. We propose generalized set-theoretical model of such an information environment for educational and research community interaction.

Keywords: *modeling, online learning, open science, effectivity of education, resourcing.*

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Моделювання інформаційних потоків у середовищі Software Carpentry

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Актуальність. Сучасний рівень і швидкість розвитку інформаційних технологій, прагнення суспільства до інформаційної уніфікації зумовлюють необхідність створення та впровадження нової моделі взаємодії освітньої та наукової спільноти для забезпечення вільного, оперативного та ефективного доступу до інформаційних ресурсів.
Мета. Освітня та наукова спільноти шукають нові підходи, які можуть забезпечити необхідний рівень ефективності навчання в умовах жорсткої обмеженості ресурсів, де на першому місці стоїть час. Тому актуальною проблемою сьогодення є формулювання принципів побудови, моделювання та систематизації властивостей інформаційного

середовища як інтерактивної навчально-наукової платформи. У даній роботі розглядається розв'язання цієї проблеми на прикладі Software Carpentry.

Методи дослідження. Автори використовують такі методи дослідження – системний аналіз, теоретико-множинний аналіз, багатокритеріальна оптимізація, методи обробки експертної інформації. Для розв'язання поставленої задачі проведений аналіз парадигм інформаційних освітніх середовищ та класифікація доступних та найбільш поширених в українському освітньому та дослідницькому середовищі: Coursera, edX, Prometheus, Udemy. Ще одним цікавим напрямком є так зване мікронавчання. Водночас використання вищезазначених типів освітніх онлайн-ресурсів для цілей організації та проведення наукових досліджень, а також відбору та впровадження нових інструментів обробки інформації про об'єкти наукових досліджень є ускладненим або неможливим.

Результати. Однією з найбільш вдалих реалізацій в цьому напрямку вважається ідеологія Software Carpentry. Автори на волонтерських засадах беруть участь у проєкті, який реалізує Університет Сент-Ендрюс (Шотландія) з перекладу курсу «Мова програмування Python» з англійської мови на українську.

Висновки. Запропоновано узагальнену теоретико-множинну модель такого інформаційного середовища взаємодії освітньої та наукової спільноти.

Ключові слова: *моделювання, онлайн-навчання, відкрита наука, ефективність освіти, ресурсне забезпечення.*

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1 Introduction

The level and speed of development of modern information technologies, the aspiration of modern society to informational unification necessitate the creation and implementation of a new model of the educational and scientific community interaction to ensure free, operational and effective access to the information resources being required for the purpose of implementing innovative means of studying and utilizing information processing tools. That applies not only to non-formal education, or the implementation of the lifelong learning – LLL concept [1], so-called continuous education. In the last three years, when the whole world was fighting the Coronavirus Disease 2019 (COVID-19) [2], and the war in Ukraine has started – the way of life of Ukrainians, the way of communication, thinking, and vision of the future have changed. Pandemic and war present drastic challenges to the education system including technical, cognitive, managerial, and behavioral ones. Under such external conditions, classical methods of teaching and scientific research cannot be fully implemented, thus the educational and scientific community is looking for new approaches that can ensure the necessary level of education efficiency under the condition of severe limitations of resources, where time is the first of them.

2 Statement of the problem

Taking into account constantly increasing attention to such field of human activities as an on-line learning, namely online IT education in recent years there have been a number of scientific publications devoted to modeling and optimization issues. The following studies can be highlighted.

In paper [10] a thorough empirical comparative analysis of the quality of online learning and a comparison between face-to-face and online learning on a statistical sample of Polish medical school students is provided. It has been discovered that there is no statistical difference between face-to-face and online learning in terms of opinions on the ability of the learning method to increase knowledge (P = .46). E-learning was rated as enjoyable by 73% of respondents.

In the study [11] the set of 729 Massive Open Online Courses (MOOCs) on Coursera has been examined by using such a modelling algorithm as Latent Dirichlet allocation (LDA). This research proposes some useful conclusions concerning two major themes such as MOOC delivery and subject matter.

The research [12] proposes comprehensive review of the 29 to analyze and describe the adaptation process from face-to-face to online education and the perceptions of faculty and students during the pandemic. The study has been developed following the methodology supported by the PRISMA statement and the PICoS strategy, retrieving scientific literature from Web of Science, Scopus, ERIC and PsycINFO.

Study [13] is devoted to studying the impact of online degree programs on students' educational investment decisions and career goals. Based on a human capital theory, and using data from a 2017 survey of students enrolled in an online master's degree program in computer science at a highly ranked US university, this study explores how motivation for seeking an online graduate degree in computer science varies by student demographics and professional background/preparation.

The problem of designing relational coordination system for coordination and integration of processes of online education into classic university education system by using structural equation modelling (SEM) technique has been considered in [14].

The study [15] examines phenomena of digitalization of education how it drives teachers to adjust their teaching methods. The latent profile and qualitative analyses have revealed different clusters of teacher responses, from strong resistance to online teaching to transformation of teaching practices.

The main result of the study [16] is that it is statistically proven on the basis of a large number of personal characteristics, that additional e-learning practice leads to better grades in university exams.

An analysis of these and other publications shows that the vast majority of studies consider the conceptual and applied issues of supporting formal school and university education by means of online learning, while for the field of Computer Sciences and Information Technologies it is no less important to study the issues of optimizing the process of retraining and obtaining additional knowledge for research and practical activities in different areas.

2 Objectives

Therefore, today an urgent problem is formulating principles of construction, modelling, and systematization of the properties of the information non-formal learning environment as an interactive educational and scientific platform that allows decision makers to use their extremely limited resources effectively and to acquire the necessary amount of knowledge suitable for direct practical usage.

In this work we consider the problem using the Software Carpentry as an example [3].

3 Results

To solve the formulated problem, we have conducted system analysis of the paradigms of the following informational educational environments, which are the most widespread and available in the Ukrainian educational and research community: Coursera [4], edX [5], Prometheus [6], Udemy [7].

Coursera was launched in 2012 with a mission to provide universal access to world-class learning. It is now one of the largest online learning platforms in the world, with 113 million registered learners as of September 30, 2022. Coursera partners with over 275 leading university and industry associates to offer a broad range of content and credentials, including guided projects, courses, specializations, certificates, as well as bachelor's and master's degrees. Institutions around the world use Coursera to upskill and reskill their employees, citizens, and students in many high-demand areas, including data science, technology, and business.

edX is an American massive open online course provider created by Harvard and Massachusetts Institute of Technology. It hosts online university-level courses in a wide range of disciplines to a worldwide student body, including some courses at no charge. It also conducts research into learning based on how people use its platform. edX runs on the free Open edX open-source software platform. 2U is the parent company, with edX operating as its global online learning platform and primary brand for products and services. edX has 3600+ courses, 42 million users and 160+ partners.

Prometheus is the leading online education platform in Ukraine with over 700 000 online registered students and over 90 online courses. The company is working in close cooperation with top Ukrainian universities, prominent professors, international organization, and government.

Prometheus obtained a license for Ukrainian translation and dubbing of massive open online courses for the teachers by the Massachusetts Institute of Technology, Columbia Teachers College, and Queensland Universities. The certificate of completion is officially recognized by the Ministry of Education as an official teachers' training.

Udemy Inc. is a global destination for teaching and learning online. It was founded in May 2010 by Eren Bali, Gagan Biyani, and Oktay Caglar. As of July 2022, the platform has more than 54 million students, 204,000 courses, and 71,000 instructors teaching courses in over 75 languages. There have been over 741 million course enrolments.

Students take courses primarily to improve job-related skills. Some courses generate credits toward technical certification. Udemy has made a special effort to attract corporate trainers seeking to create coursework for employees of their company.

These are large repositories of well-prepared popular training courses that have a meaningful content, are designed for several weeks and even months of training, support the classic distance learning paradigm and generally require significant resources from the user in order to master them.

Another interesting direction is the so-called microlearning [8]. Today, the traditional distance learning format, according to the multiple scientists' estimates, is losing its effectiveness. The development of a learning paradigm, which allows dynamically updating various, short-term training courses, is attracting considerable attention.

At the same time, using the listed types of educational online resources for the purposes of organizing and conducting scientific research, as well as selecting and implementing new tools for processing information about objects of scientific research is difficult or impossible.

The ideology of Software Carpentry can be considered as one of the most successful implementations in this direction. Software Carpentry is a platform that teaches «basic laboratory skills for research computing» [3]. The mission of this project is to unite specialists in nature protection, geographers, ecologists, zoologists and other scientists. The courses of Software Carpentry are master classes that teach how to manipulate data and information and analyze it in an effective, reproducible and collaborative way. Software Carpentry teaches how to use complex modern information technologies (R, RStudio and GitHub), analyze scenarios, create convincing visualizations and learn joint work processes, without requiring previous experience.

Software Carpentry Foundation is a volunteer non-profit organization dedicated to teaching researchers basic computing skills.

Since 1998, Software Carpentry teaches researchers to create purpose-built tools, whether it be a Unix shell script to automate repetitive tasks or software code in programming languages such as Python, R, or MATLAB. These enable researchers to build programs that can be read, re-used and validated, greatly enhancing the sharing and reproducibility of their research.

All Carpentry workshops are hands-on two-day training events during which the attendees gain practical skills and understanding how particular software development tools and methodologies can benefit their own work. The core curriculum taught at Software Carpentry workshops typically includes:

1. automating tasks using the Unix shell;
2. structured programming in Python or R;
3. version control using Git or Mercurial.

The list is not exhaustive – all training materials are freely available under the Creative Commons – Attribution License from the Software Carpentry's lesson repository. Materials can be reused in any way you wish, without asking for special permission, provided that the original source is cited.

It should be noted that the authors have their own successful experience of learning and cooperating with this platform. The authors are participating in the project implemented by University of St. Andrews (Scotland) on translation the «Python programming language» course from English to Ukrainian as volunteers. At the time this work being published, 80% of the course has already been translated (Fig.1). After its completion, all stakeholders will have access to educational materials.

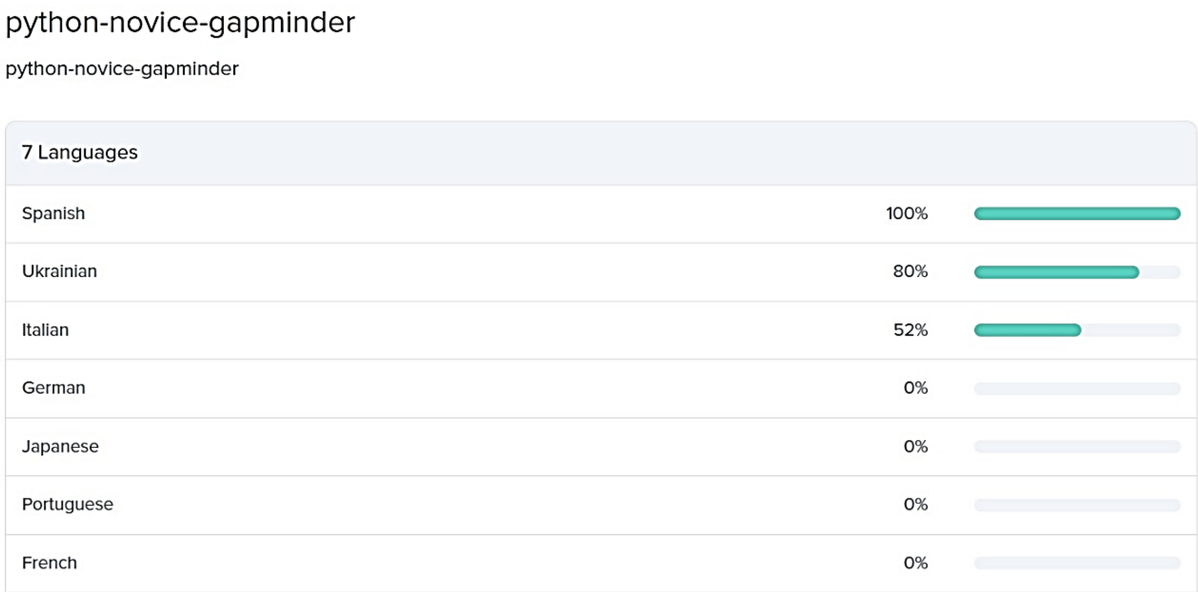

Fig. 1 General course translation statistics

As a generalized model of such an information environment for such a non-formal educational and research community interaction we can consider a system (1):

$$S = (< M, R>, P) = (C, P), \tag{1}$$

where M – is a set of elements of the information environment, R – is a set of interlinks between elements from M, P – is a set of system S efficiency criteria, C – is a structure of the system S, so R – may be considered as tools of ordering elements of the set M into the structure C.

Each of the components of the system S has a hierarchical nature. Thus, a discrete set M of elements is a set of known online learning platforms $\{M_1, ..., M_N\}$, from leading universities and companies, each i-th of them contains the set of various courses $\{M_{n_1}, ..., M_{n_{Kn}}\}$, each one M_{n_k} of which, in turn, has a modular structure

$$M_{n_k} = \{M_{n_k}^1, ..., M_{n_k}^{L_{n_k}}\}, n = 1,... , N, n_k = 1, 2, ..., K_n, \tag{2}$$

For every online learning platform M_n, the discrete set P_n of its properties may be presented as some type of a tuple:

$$P_n = \{T_n, V_n, F_n, \{L_{n1}, L_{n2}\}, \{I_{n1}, I_{n2}\}, D_n, Re_n, OS_n\}, n = 1, 2,..., N, \tag{3}$$

where:
- T_n – is a training time;
- V_n – is an amount of acquired knowledge;
- F_n – is a possibility of further self-study;
- L_n – is a level of presentation:
  - L_{n1} – is an adequacy in terms of important concepts;
  - L_{n2} – is a possibility of direct application for the purposes of scientific research;
  - L_{n3} – is a viability of practical tasks.
- I_n – is an appearance of course:
  - I_{n1} – is a factor of interactivity;
  - I_{n2} – is an ease of perception;
- D_n – is a degree of openness (open source) of resources;
- Re_n – is a possibility of refactoring;
- OS_n – feature of supporting open science paradigm [9].

Note that the system has a hierarchical structure, and at the upper level of the hierarchy for n=1, 2, …, N, the elements of the system S are weakly connected, that is, we can assume that the system S at that level is disconnected, while at the lower levels of the hierarchy for each set S_n, the set R_n of interlinks forms a rigid structure C_n.

Some of properties (3) are inherent in the entire system S (S_n) as a whole, some are characteristics of the elements $\{M_{n_k}, R_{n_k}\}$.

Obviously, the system S (1) is an essentially dynamic one, that is, the states of all elements of the system S are functions of time t. However, in this study, we assume that the time interval Δt where the system state stays unchanging satisfies the condition $\Delta t > \mathrm{T}$, so we will assume that all elements M, R, P of the system S during training time T are constant.

The quantitative definition of properties P_n allows forming a set of partial efficiency criteria of the kind:

$$\{Q_{1n}, Q_{2n},...,Q_{10n}\}, \tag{4}$$

a scale of measurement of which in the general case must be established on the basis of expert knowledge processing. These partial criteria form a general criterion – the quality of education Q – in the world that is constantly changing.

The concept of quality of education has been considered in many scientific publications. Moreover, 17 Sustainable Development Goals (commonly known as the Global Goals) were formulated in 2015, where the fourth goal is to improve the quality of education.

According to [17] quality education specifically entails issues such as development of appropriate skills, gender parity, provision of relevant school infrastructure, equipment, educational materials and resources, scholarships, or teaching force.

Considering this generally accepted definition, the quality of education is primarily a characteristic of the equipment and accessibility of an education process and education system.

However, in this paper we consider another aspect of the quality of education, namely the degree of compliance of the goals and results of education with the requirements Q_{real} of practical activity in the IT sphere.

Thus, the problem of defining appropriate information learning environment is a multicriteria and multidimensional one:

$$(n^*, k^*) = \underset{S_{n_k}}{\operatorname{argmin}}\, \mu(Q_{real}, Q_{S_n}), \qquad (5)$$

where $\mu(Q_{real}, Q_{S_n})$ – defines some kind of metrics as proximity measure for this pair of vector criteria (Q_{real}, Q_{S_n}).

Thus, the quality of education Q is a generalized property of the system of non-formal education S to offer a set of skills and competencies that allow decision makers to find themselves in the labor market in IT field for an acceptable time τ, $\tau \ll T$.

For a formal representation of such a property, it is necessary to define the vector Q_{real}, which defines the definite point (usually such a point is called a pole) in multidimensional space of knowledge, skills and competencies required in practice.

That vector can be designed on the basis of an analysis of labor market requirements and measured by analyzing a number of widely known Internet resources such as Robota.UA (https://rabota.ua/ua), UA.Jooble.org (https://ua.jooble.org/) Novarobota.UA (https://novarobota.ua/), Freelance.ua (https://freelance.ua/), LinkedIn (https://gb.linkedin.com/), Indeed (https://indeed.com/), Glassdoor (https://glassdoor.com/) etc. Generally, to consider those resources we need to determine the weighting factors, which characterize their importance and reliability.

4 Conclusions

The tuple of criteria (4) considered above, can be applied in three different ways.

First, the criteria (4) can be classified as those that is important to evaluate the amount of necessary knowledge to solve a specific practical problem in the short term, for example, under estimating what amount of knowledge is necessary to perform data analysis in MS Excel.

Second, the subject of the assessment can be a certain volume of knowledge, which is the base for further growth. For example, a course on paradigms of object-oriented programming.

Currently, courses that have a dual nature are being rapidly developed. The main idea of such education and scientific direction lies in studying certain set of tools, for example, a programming language or tools to perform data analysis in order to solve practical problems from a definite subject area, so that criterion L_{n3} , viability of practical tasks, is implemented and generates an immediate synergistic effect. The design of the Carpentry information environment is based on this principle.

Moreover, another important Carpentry principle is «Docendo discimus» (by teaching, we learn) that is formulated by Lucius Annaeus Seneca. Following this principle, Carpentry supports and brings together wide community of practitioners and scientists, for example, proposing to translate education courses on different languages.

As directions for the further research, we are planning to build a description of the set of criteria in an explicit form and develop a decision support system for choosing an information learning environment.

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