Full research paper

EVALUATION OF FINAL EXAMINATION PERFORMANCE AT CZECH UNIVERSITY OF LIFE SCIENCES DURING THE COVID-19 OUTBREAK

Lukáš Moravec[1]
Jakub Ječmínek[1]✉
Gabriela Kukalová[1]

[1]Czech University of Life Sciences Prague, Czech Republic

✉ jecminek@pef.czu.cz

ABSTRACT

The COVID-19 pandemic outbreak has upended the educational system worldwide, possibly with severe long-term consequences as most training institutions were forced to move to an online environment. Given the sudden transition to remote education, the main objective of this contribution is to evaluate the impact of distance education on examination results. We investigated the examination results of tax related subjects collected at the Czech University of Life Sciences in Prague during the period from 2014 to 2020. The sample consists of examination results of 120 different classes within 6 years with a total amount of 7268 observations. Firstly, we pivoted the data into the long format and performed binary logistic regression. Our findings suggest that the odds that student successfully passes the exam increases if the student was examined online compared to in-person. Additionally, we used KNN regression which enables us to predict success rate for an upcoming semester. According to our analysis, it is expected that on average 82 students out of 100 will successfully pass the exam. The model was calibrated using cross-validation to choose optimal K.

KEYWORDS

COVID-19, e-Learning, examination, results, distance education

HOW TO CITE

Moravec L., Ječmínek J., Kukalová G. (2022) 'Evaluation of final examination performance at Czech University of Life Sciences during the COVID-19 outbreak', *Journal on Efficiency and Responsibility in Education and Science*, vol. 15, no. 1, pp. 47-52. http://dx.doi.org/10.7160/eriesj.2022.150105

Article history
Received
January 14, 2021
Received in revised form
September 3, 2021
Accepted
January 10, 2022
Available on-line
March 22, 2022

Highlights

- *The odds that the student successfully pass the exam increases if the student was examined online compared to in-person.*
- *Out of 100 students enrolled in the subject, 82 is expected to successfully complete the exam.*
- *Distance exam was successfully completed on average by two percentage point higher number of students.*

INTRODUCTION

Since the pandemic outbreak, many transmission and protective measures have been adopted in order to help mitigate COVID-19 spread. Measures preventing social interactions include transition from in-person classes to virtual, affecting all levels of education. Although e-Learning only programs have already been offered in many universities prior to the pandemic, the magnitude in which distant education is used is unprecedented.

As shown in Zhang et al. (2004), effective e-Learning environment may significantly outperform traditional classroom groups. According to Sun et al. (2008: 1196), there are seven decisive factors influencing overall learners' satisfaction with e-Learning, such as learners' computer anxiety, instructor attitude toward e-Learning, e-Learning course flexibility, e-Learning course quality, perceived usefulness, perceived ease of use, and diversity in assessment. However, as pointed by Lu, Le and Vu (2020) and Ho et al. (2021), not all training institutions were prepared for effective e-Learning implementation during the pandemic outbreak. Mudrák, Turčáni and Reichel (2020) created methodology for personalised e-course. Statistical analysis revealed that the use of personalized e-course has a positive impact on students' activity, motivation, and their level of output knowledge. As a result, Eltayeb et al. (2020) conclude that nearly 70% of Prince Sattam University students were dissatisfied with the remote education and only one fifth of students agreed that e-Learning method

helped them understand the scientific materials smoothly and clearly. On the other hand, Aristovnik et al. (2020) performed a comprehensive analysis of the pandemic perception by higher education students on a sample of 30,383 students from 62 countries and the authors mention that the students from Europe have 16.1% higher chances of attaining better overall satisfaction with their university compared to students from other continents.

Although most of the students moved to remote learning, since the COVID-19 patients strained entire healthcare systems worldwide (Weible et al., 2020) and because healthcare workers experienced high rates of infection (Ranney, Griffeth and Jha, 2020), many of the medical students volunteered to the front-line, putting their education on hold. Czech government, for example, imposed obligation of medical students to provide health and social services during the pandemic climax in October 2020. Furthermore, Resnick et al. (2021) discussed the role of public health students in research and practice activities across the US as they have been engaged in contact tracing, monitoring statistics on cases, staffing COVID-19 testing sites and help lines, etc. Given all the disruptions in the current medical educations, the majority of medical students in the UK feel less prepared for beginning work as a doctor (Choi et al., 2020).

It is generally acknowledged that the pandemic outbreak has upended the educational system worldwide, possibly with severe long-term consequences. Education has been one of the most affected due to the administrative imposition of the total closure of educational centres in most of the countries of the world (García Aretio, 2021). The closure of educational institutions has significantly disrupted the day-to-day lives of millions of students, teachers, and researchers. Moreover, with the sudden transition to online learning platforms, the limitations on research projects, as well as lack of standardised policies and procedures, the researchers are concerned about unequal impacts of the crisis (Galloway et al., 2020). Several authors investigated the overall perception of distance learning by the students, e.g., Lu, Le and Vu (2020), Ho et al. (2021), or Eltayeb et al. (2020). Malkawi, Bawaneh and Bawa'aneh (2021) investigated the satisfaction level and attitudes of undergraduate students at United Arab Emirates University towards e-Learning and virtual classes in exceptional circumstances of COVID-19 crisis. The work of Tlili et al. (2020) dealt with the impacts of the applied remote teaching methods of students with disabilities, as well as the faced challenges. Agasisti and Soncin (2020) focus on the impact in the educational sector, by describing an overview of the university's activities and reporting the actions undertaken by university in Milan, Italy. The perception and evaluation of the distance learning model by the students is also related to their ability to use the digital technologies (Peréz-López, Vázquez Atochero and Cambero Rivero, 2021). Noskova, Pavlova and Yakovleva (2021) state that students insufficiently use the digital environment potential of collaboration, knowledge exchange, and knowledge extraction from authentic sources.

Equally important is the perception of distance learning by the teachers. As several researchers point out, there are many problems that teachers face during the remote education. Kruszewska, Nazaruk and Szewczyk (2020) state that the main problems during the distance learning in Poland are insufficient equipment of students with information technologies and little or no communications with students or parents. Scherer et al. (2021) analysed readiness of higher education teachers to online teaching and learning in 58 countries. According to their results, three readiness profiles exist, such as high, low, and inconsistent readiness.

It is expected that sudden transition to remote education may be reflected in the results of university students' exams. Several authors analysed examination results before the pandemic outbreak. Otavová and Sýkorová (2017) evaluated if the way in which students were admitted could predict results in mathematics or students´ performance in general at University of Economics Prague. Klůfa (2015, 2016) studied dependence of the results of entrance examinations in mathematics on test variants at University of Economics Prague. Šánová et al. (2014) evaluated the success rate of students in the Food Goods Knowledge Subject at Faculty of Economics and Management at Czech University of Life Sciences (hereafter denoted as CZU FEM) in relation to the reduction in the amount of teaching hours. The results of the exams in the subject Accounting Theory in 2014-2017 analysed Kuchařová, Pfeiferová and Prášilová (2018). According to research results of Ječmínek et al. (2018), there is no statistically significant difference in the exam results in tax courses between students of various disciplines and forms of study at CZU FEM.

Literature review suggests that the impact of COVID-19 pandemic on university students' exam results has not yet been investigated and hence, the main objective of this contribution is to evaluate the undergraduate performance of final examination throughout the COVID-19 pandemic. We pose following research questions:

1. Is the format of the exam significant factor determining the outcome of the exam?
2. What is expected exam success rate for upcoming semester?

This article is structured as follows. Introduction briefly summarizes literature review as well as the motivation for this paper along with proposed research questions. Section Materials and Methods describes the data we used for the research and our empirical strategy. Our findings are shown in the Results section. Subsequently, we will evaluate the results and show how it relates to other scientific works in the discussion section. Finally, conclusion section is dedicated to summary as well as proposed future continuation of the research.

MATERIALS AND METHODS

The data for this study come from CZU FEM information system and cover time period from 2014 to 2020. We focus solely on tax subjects[1] because the overall difficulty and format of the exam has been steady throughout the years. Our sample

1 Tax System, Tax Theory and Policy, Local Finance and Municipality Management, Tax Administration, Tax System and Administration.

consists of the examination results of 120 different classes, from which 108 were taught in-person. The division of the sample across the years is as follows:

- 2014/2015 – 15 classes – 1185 students,
- 2015/2016 – 22 classes – 1465 students,
- 2016/2017 – 21 classes – 1301 students,
- 2017/2018 – 21 classes – 1154 students,
- 2018/2019 – 20 classes – 1169 students,
- 2019/2020 – 21 classes – 994 students.

In order to answer the first research question defined in previous section, we pivoted the data into the long format, so each observation represents one particular student and respective examination outcome (success/failure). The data now consists of 7268 observations which enables us to perform binary logistic regression. Our model is formally defined as

$$logit(p) = a + b_1 x_1 + b_2 x_2 \quad (1)$$

where p denotes probability that student pass the exam, x_1 is binary explanatory variable that represents the course (either tax course or municipal finance) and x_2 is also binary variable indicating whether it was distance or in-person exam. The method used in fitting the model is iteratively reweighted least squares (IRLS).

Expected exam success rate is estimated with a simple yet powerful machine learning algorithm KNN (*K-Nearest Neighbour*). KNN algorithm is non-parametric method used for both classification and regression. For detailed description of the algorithm see for example Altman (1992). We split the data into training and testing set which enables us to use cross-validation to choose optimal K (number of neighbours considered). We use such K that minimizes RMSPE (Root Mean Square Prediction Error) of the predicted values.

We used R statistical environment for all the calculations along with some additional third-party packages, such as *kknn*, *ResourceSelection* (Hosmer-Lemeshow test), *caret* (model training) and *tidyverse (*data manipulation and visualisation).

RESULTS

As described in previous section, we performed binary logistic regression, which enables us to estimate the relationship between the exam outcome and format of the exam. Figure 1 shows students' performance in respective academic periods. As shown in figure 1, the number of students who successfully completed the exam has remained relatively equal throughout the years. The highest success rate decrease occurred in 2015/2016 which is probably related to the total number of students. Interestingly, the proportion of students who completed the exam on their second attempt has increased in recent years.

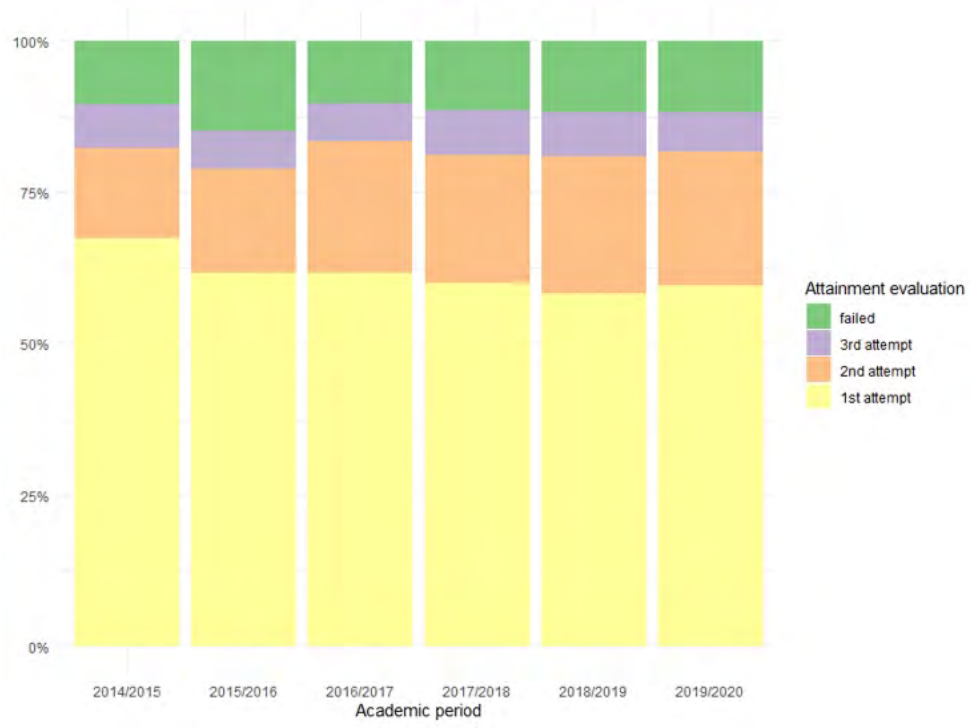

Figure 1: Course evaluation (source: own calculation)

The results of the regression are summarized in Table 1.

Coeff.	Estimate	Std. Error	*z*-value	*p*-value
(Intercept)	1.717	0.041	41.499	<0.001 ***
b_1	0.170	0.072	2.346	0.019 **
b_2	0.232	0.130	1.790	0.074*

Table 1: Model summary (source: own calculation)

As shown in Table 1, *p*-value indicates that both intercept and b_1 parameter are statistically significant at 5% level. The parameters are also all non-negative which shows positive relationship between the dependent variable (exam outcome) and explanatory variables. The model was diagnosed for multicollinearity and for goodness of fit with Hosmer-Lemeshow test[2]. The model shows that the odds that student successfully passes the exam increases by 1.185 times (exponential of the b_1 parameter) if the student studies municipal finances compared to tax course. Similarly, the odds that student passes the exam increases by 1.261 times if the exam was held online compared to in-person.

Second part of our contribution deal with predictions of examination results for upcoming semester. Firstly, we used cross-validation to choose optimal *K*. Our analysis indicates that minimal RMSPE occurs when $K = 7$ with estimated prediction error 7.62 students.

Figure 2 illustrates scatter plot along with regression curve. According to our calculations out of 100 students enrolled in the class 82 students is expected to successfully pass the exam. These calculations are somewhat unexpected as it implies relatively large number of unsuccessful students. However, since the students at CZU are allowed to take the course once again, better data are needed to determine the exact failure rate.

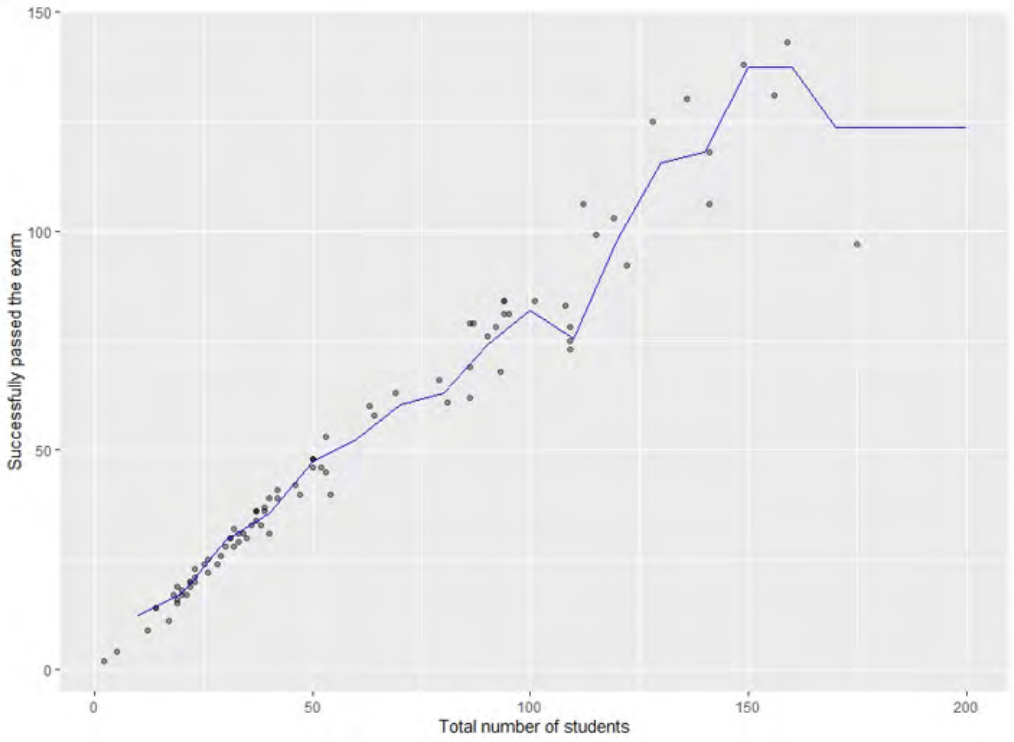

Figure 2: KNN regression plot (source: own calculation)

Although the accuracy of the KNN model decreases around the edges, setting low value of *k* often provides biased predictions as it might lead to the model overfitting. In this case, the model returns most accurate predictions for classes with less than 100 students.

DISCUSSION

Our findings suggest that the odds that student successfully pass the exam increases if the student was examined online compared to in-person. This result is on par with previous studies which found strong evidence that remote classes are more effective than traditional in-person classes (i.e., Zhang et al., 2004; Elfaki, Abdulraheem and Abdulrahim, 2019; Ilgaz and Adanir, 2020).

There are several distinctive features that may enhance effectiveness of remote education. Firstly, E-Learning materials (such as pre-recorded lectures) enable students to study the courses at their own pace (Ruiz, Mintzer and Leipzig, 2006) and if needed, watch the lectures multiple times. Additionally, online classes eliminate the need for commuting, which results in better time flexibility (Lee, Wang and Yu, 2019). On the other hand, administering the exams and ensuring fair conditions without cheating is considerably more difficult in an online environment (Harmon and Lambrinos, 2008) and hence the exam results data be subject to bias. According to Clark et al. (2020), using the same exam in an unproctored online setting as one would for a traditional in-class test does not maintain the same level of academic integrity. Training institutions should, therefore, develop alternative approach, that is more suitable for online environment. The design of such alternative approach depends on overall student assessment process, instructor's capacity, available technology, and various other factors. The design of our online tests was focused more on cheating prevention, rather than on cheating control; we have implemented several protective measures, such as calibrated time setting, multiple-choice format with different variations of the answers, inability to go back to previous questions etc. However, along with suggestions made by Clark et al. (2020),

2 Diagnostics for influential values and linearity is for this specification redundant.

we propose (i) implementing more oral exams which reduces the risk of academic dishonesty but are more demanding on time consumption and are not universally applicable for all classes and (ii) incorporate creative assignments to encourage students to think critically, develop necessary writing skills and possibly teach students to work cooperatively. Such creative assignments could be anything from a simple presentation to a coding project, case study or some real-world tasks. These practical assignments are especially useful for tax subjects, because students can fill out various tax returns, explore corporate and municipal finances and potentially solve international tax problems. Additionally, during the pandemic times examiners can use some of the available communication platforms to schedule oral exams and leverage the built-in tools such as screen sharing, document collaboration, and further discuss the assignment. Nonetheless, given the sudden transition to remote education, it is expected that training institutions will continuously improve its e-Learning system and achieve more effective online environment.

The second part of our research dealt with examination results analysis using KNN algorithm. According to our calculations, out of 100 students, 82 is expected to successfully complete the exam. We calibrated the model using cross-validation to choose optimal level of neighbours considered. This model is particularly useful for prediction as well as for monitoring expected examination success rate. Our study, however, does have some limitations; (i) the data we worked with does not include other important attributes such as gender or the age of the students which restricts the number of regressors we are able to include into the model, (ii) our study covers a limited number of taught subjects and, therefore, we cannot generalize the results for the whole faculty or university. Future research should, consider broader array of subjects and potentially gather more rich data.

CONCLUSION

Distance learning has been steadily increasing in popularity for the past two decades. Although many researchers argue that distance learning model does not perform all the functions that traditional in-person teaching does, remote education played major role preventing COVID-19 spread. In this paper, we emphasized the questions regarding the differences in CZU FEM examination results before and during the pandemic outbreak using binary logistic regression. Our findings suggest that the odds that student successfully pass the exam increases if the student was examined online compared to in-person.

Additionally, we performed KNN regression that enables us to predict exam success rate for the upcoming semesters. The estimated model implicates that expected exam success rate is on par with previous research papers that estimated average exam success rate at Czech University of Life Sciences Prague. In our future research we would like to focus on faculty wide examination results.

ACKNOWLEDGEMENT

This article was supported by the CZU FEM Internal Grant Agency under the grant Czech Social System Fraud Rate Estimation and System Optimization Proposals, number 2019B0010.

REFERENCES

Agasisti, T. and Soncin, M. (2020) 'Higher education in troubled times: on the impact of Covid-19 in Italy', *Studies in Higher Education*, Vol. 46, No. 1, pp. 1–10. https://doi.org/10.1080/03075079.2020.1859689

Altman, N. S. (1992) 'An Introduction to Kernel and Nearest Neighbor Nonparametric Regression', *The American Statistician*, Vol. 46, No. 3. pp. 175–185. https://doi.org/10.2307/2685209

Aristovnik, A., Keržič, D., Ravšelj, D., Tomaževič, N. and Umek, L. (2020) 'Impacts of the COVID-19 Pandemic on Life of Higher Education Students: A Global Perspective', *Sustainability*, Vol. 12, No. 20, 8438. https://doi.org/10.3390/su12208438

Choi, B., Jegatheeswaran, L., Minocha, A., Alhilani, M., Nakhoul, M. and Mutengesa, E. (2020) 'The impact of the COVID-19 pandemic on final year medical students in the United Kingdom: a national survey', *BMC Medical Education*, Vol. 20, No. 206, pp. 1–11. https://doi.org/10.1186/s12909-020-02117-1

Clark, T. M., Callam, C. S., Paul, N. M., Stoltzfus, M. W. and Turner, D. (2020) 'Testing in the Time of COVID-19: A Sudden Transition to Unproctored Online Exams', *Journal of Chemical Education*, Vol. 97, No. 9, pp. 3413–3417. https://doi.org/10.1021/acs.jchemed.0c00546

Elfaki, N. K., Abdulraheem, I., Abdulrahim, R. (2019) 'Impact of E-Learning vs Traditional Learning on Student's Performance and Attitude', *International Journal of Medical Research & Health Sciences*, Vol. 8, No. 10, pp. 76–82.

Eltayeb, L. B., Alharthi, N. S., Elmosaad, Y. M. and Waggiallah, H. A. (2020) 'Students' perception on E-Learning and Remote Exams during COVID 19 Outbreak 2020', *International Journal of Pharmaceutical Research and Phytopharmacological Research*, Vol. 10, No. 5, pp. 142–148.

Galloway, T., Bowra, A., Butsang, T. and Mashford-Pringle, A. (2020) 'Education in uncertainty: Academic life as Indigenous health scholars during COVID-19', *International Review of Education*, Vol. 66, No. 5–6, pp. 817–832. https://doi.org/10.1007/s11159-020-09876-5

García Aretio, L. (2021) 'COVID-19 and digital distance education: pre-confinement, confinement and post-confinement', *Ried-revista Iberoamericana de Educacion a Distancia*, Vol. 24, No. 1. pp. 9–32. https://doi.org/10.5944/ried.24.1.28080

Harmon, O. R. and Lambrinos, J. (2008) 'Are online exams an invitation to cheat?', *Journal of Economic Education*, Vol. 39, No. 2, pp. 116–125. https://doi.org/10.3200/JECE.39.2.116-125

Ho, N. T. T., Sivapalan, S., Pham, H. H., Nguyen, L. T. M., Pham, A. T. V. and Dinh, H. V. (2021) 'Students' adoption of e-learning in emergency situation: the case of a Vietnamese university during COVID-19', *Interactive Technology and Smart Education*, Vol. 18, No. 3, pp. 246–269. https://doi.org/10.1108/ITSE-08-2020-0164

Ilgaz, H. and Adanir, G. A. (2020) 'Providing online exams for online learners: Does it really matter for them?', *Education and Information Technologies*, Vol. 25, No. 2, pp. 1255–1269. https://doi.org/10.1007/s10639-019-10020-6

Ječmínek, J., Kukalová, G., Moravec, L. and Bína Filipová, D. (2018) 'Tax Courses Exams Results at FEM CULS PRAGUE Evaluation', *Proceedings of the 15th International Conference Efficiency and Responsibility in Education (ERIE 2018)*, Prague, pp. 132–139.

Klůfa, J. (2015) 'Analysis of Entrance Examinations', *Proceedings of the 12th International Conference Efficiency and Responsibility in Education*, Prague, pp. 250–256.

Klůfa, J. (2016) 'Analysis of the Differences between Results of Test Variants', *Proceedings of the 13th International Conference Efficiency and Responsibility in Education*, Prague, pp. 279–285.

Kruszewska, A., Nazaruk, S. and Szewczyk, K. (2020) 'Polish teachers of early education in the face of distance learning during the COVID-19 pandemic - the difficulties experienced and suggestions for the future', *Education 3-13*, Vol. 50, No. 3, pp. 304–315. https://doi.org/10.1080/03004279.2020.1849346

Kuchařová, I., Pfeiferová, D. and Prášilová, M. (2018) 'Results Analysis of the Exam in Accounting Theory', *Proceedings of the 15th International Conference Efficiency and Responsibility in Education (ERIE 2018)*, Prague, pp. 171–179.

Lee, T.-S., Wang, C.-H., Yu, C.-M. (2019) 'Fuzzy Evaluation Model for Enhancing E-Learning Systems', *Mathematics*, Vol. 7, No. 10, pp. 918. https://doi.org/10.3390/math7100918

Lu, D.-N., Le, H.-Q. and Vu, T.-H. (2020) 'The Factors Affecting Acceptance of E-Learning: A Machine Learning Algorithm Approach', *Education Sciences*, Vol. 10, No. 10, 270. https://doi.org/10.3390/educsci10100270

Malkawi, E., Bawaneh, A. K. and Bawaaneh, M. S. (2021) 'Campus off, education on: UAEU students' satisfaction and attitudes towards e-learning and virtual classes during covid-19 pandemic', *Contemporary Educational Technology*, Vol. 13, No. 1, pp. 1–14. https://doi.org/10.30935/cedtech/8708

Mudrák, M., Turčáni, M. and Reichel, J. (2020) 'Impact of Using Personalized E-Course in Computer Science Education', *Journal on Efficiency and Responsibility in Education and Science*, Vol. 13, No. 4, pp. 174–188. http://dx.doi.org/10.7160/eriesj.2020.130402

Noskova, T., Pavlova, T. and Yakovleva, O. (2021) 'A Study of Students' Preferences in the Information Resources of the Digital Learning Environment', *Journal on Efficiency and Responsibility in Education and Science*, Vol. 14, No. 1, pp. 53–65. http://dx.doi.org/10.7160/eriesj.2021.140105

Otavová, M. and Sýkorová, I. (2017) 'The Differences in Results among Students Admitted in Different Ways', *Proceedings of the 14th International Conference Efficiency and Responsibility in Education (ERIE 2017)*, Prague, pp. 295–302.

Peréz-López, E., Vázquez Atochero, A. and Cambero Rivero, S. (2021) 'Distance Education in COVID-19's period: An Analysis from the perspective of university students', *Ried-revista Iberoamericana de Educacion a Distancia*, Vol. 24, No. 1, pp. 331–350. https://doi.org/10.5944/ried.24.1.27855

Ranney, M. L., Griffeth, V. and Jha, A. K. (2020) 'Critical Supply Shortages - The Need for Ventilators and Personal Protective Equipment during the Covid-19 Pandemic', *New England Journal of Medicine*, Vol. 382, No. 18, pp. e41(1)–e41(3). https://doi.org/10.1056/NEJMp2006141

Resnick, B. A., Mui, P. C., Bowie, J., Kanchanaraksa, S., Golub, E. and Sharfstein, J. M. (2021) 'The COVID-19 Pandemic: An Opportunity to Transform Higher Education in Public Health', *Public Health Reports*, Vol. 136, No. 1, pp. 23–26. https://doi.org/10.1177/0033354920966024

Ruiz, J. G., Mintzer, M. J. and Leipzig, R. M. (2006) 'The impact of e-learning in medical education', *Academic Medicine*, Vol. 81, No. 3, pp. 207–212. https://doi.org/10.1097/00001888-200603000-00002

Šánová, P., Kučera, P., Vostrá Vydrová, H. and Regnerová, O. (2014) 'The Impact of Teaching Form on Study Results in Subject Food Goods', *Proceedings of the 11th International Conference Efficiency and Responsibility in Education (ERIE 2014)*, Prague, pp. 687–693.

Scherer, R., Howard, S. K., Tondeur, J. and Siddiq, F. (2021) 'Profiling teachers' readiness for online teaching and learning in higher education: Who's ready? *Computers in Human Behavior*, Vol. 118, pp. 106675. https://doi.org/10.1016/j.chb.2020.106675

Sun, P.-C., Tsai, R. J., Finger, G., Chen, Y.-Y. and Yeh, D. (2008) 'What drives a successful e-Learning? An empirical investigation of the critical factors influencing learner satisfaction', *Computers & Education*, Vol. 50, No. 4, pp. 1183–1202. https://doi.org/10.1016/j.compedu.2006.11.007

Tlili, A., Amelina, N., Burgos, D., Othman, A., Huang, R., Jemni, M., Lazor, M., Zhang, X. and Chang, T. W. (2021) 'Remote Special Education During Crisis: COVID-19 as a Case Study', in Burgos D., Tlili A. and Tabacco A. (ed.) *Radical Solutions for Education in a Crisis Context. Lecture Notes in Educational Technology*. Singapore: Springer. https://doi.org/10.1007/978-981-15-7869-4_5

Weible, C. M., Nohrstedt, D., Cairney, P., Carter, D. P., Crow, D. A., Durnová, A. P., Heikkila, T., Ingold, K., McConnell, A. and Stone, D. (2020) 'COVID-19 and the policy sciences: initial reactions and perspectives', *Policy Sciences*, Vol. 53, pp. 225–241. https://doi.org/10.1007/s11077-020-09381-4

Zhang, D. S., Zhao, J. L., Zhou, L. and Nunamaker, J. F. (2004) 'Can e-learning replace classroom learning?', *Communications of the ACM*, Vol. 47, No. 5, pp. 75–79. https://doi.org/10.1145/986213.986216