

R&D and innovation efforts during the COVID-19 pandemic: The role of universities



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ABSTRACT

Universities, as research institutions, played a significant role in the fight against the COVID-19 pandemic. This study examines how the pandemic and its related necessities affected the scope and type of research, development, and innovation (RDI) at universities in eight Central-Eastern European (CEE) countries. All Facebook posts from March 2020 until June 2021 were collected and using pandemic-related keywords, relevant posts were further extracted, coded and analyzed. Our findings elucidated significant differences among the universities in their RDI efforts during the pandemic. Austrian universities exhibited higher levels of inter-institutional research and business collaborations, whereas the RDI efforts in the rest of the CEE sample universities were geared to solve more immediate needs the pandemic brought on. One of the main contributions of this study is the understanding of the RDI potential of the region and the relevance of establishing inter-institutional and business cooperation networks at national and international levels. The study shows that during the pandemic universities demonstrated high RDI potential to quickly react to critical needs, offered open innovations, open licensing, showed collaborative abilities and effective use of their academic and student resources.

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Introduction

The current pandemic with 249 million people infected and more than 5 million deaths as of mid-November 2021 (JohnsHopkinsUniversity, 2021) is the turning point of our time in terms of drastically changing our lifestyles and the global economy. The initial waves of the pandemic brought new daily-life changes such as requirements to wear masks, social distancing, self-tracking via mobile applications and self-isolation. Although political leaders play a key role in deciding which measures the population has to follow to mitigate the effects of a pandemic (Guest, Del Rio & Sanchez, 2020; Yamey & Gonssalves, 2020), universities and research institutions also play a critical role in addressing the very nature of the pandemic (Erickson et al., 2020; Fernandez & Shaw, 2020). This crisis, like previous ones, will create new opportunities for innovation and growth for certain industries, even though these opportunities may not always be amenable to immediate commercialization. Thanks to the knowledge, experience and background of academics, corporations, governments

and non-profits, RDI activities are burgeoning during the pandemic (Fernandez & Shaw, 2020; Wigginton et al., 2020). Despite the many negative effects of this current emergency, there are several positive aspects about society's ability to tackle the crisis. In this respect, civil society has shown its strength through countless volunteers at hospitals, people sewing masks at home and many other innovations that are being developed, prototyped and produced.

Innovations and technological solutions all over the world have helped first line workers and various secondary areas affected by the pandemic. Examples of frugal innovations are ventilator multipliers produced through 3D printing, portable and open-source ventilators, and face mask production based on recycled material (Harris, Bhatti, Buckley & Sharma, 2020). Given that innovations will play a critical role in recovering from the aftermath of the coronavirus (Chesbrough, 2020), and universities are one of the vital drivers of innovation efforts it is relevant to identify and document the scope of RDI efforts at Central-Eastern European (CEE) universities and elucidate their role.

Social media is now a constant of social life. Higher education institutions engage people using platforms like Facebook to

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disseminate news and information. Hence, information, key concepts and themes can be extracted from social media content. This in turn generates knowledge that can help formulate strategies (Backman & Kyngäs, 1999; Heath & Cowley, 2004). In this study, a grounded theory approach is used to analyze social media content related to COVID 19 to identify RDI efforts spurred by the pandemic (Charmaz, 2006; Glaser & Strauss, 2017).

Specifically, this study aims to identify the scope and types of RDI in CEE universities during the pandemic in order to elucidate their role in the RDIs that emerged during this period, and to determine the RDI potential in this region in relation to the commercialization of such research and innovations. Inter-country differences of the sampled universities are also identified. Moreover, by comparing post-communist countries within the relevant geographical, political and economic context, this study reflects on the efforts of collaborating actors such as governments, R&D donors, technology and other companies in identifying universities as innovation leaders. This is relevant because in general, there is a gap in extant literature about the CEE region as a unit. Furthermore, RDI potential of the post-communist CEE countries has so far been seldom examined. Therefore, this study contributes to the existing literature in several ways. Lastly, the findings may have the potential to impact policies, initiatives, improve RDI capabilities and efficiency in the higher education institutions of the CEE region, which in turn can directly benefit the citizens of those countries in a more direct way.

The next section provides a brief description of related and relevant scholarly literature. The Methodology and Data section describes the data collected and the empirical methodology used. The Results and Discussion sections provide a brief analysis of our findings. Finally, the Conclusion provides additional insights and future research recommendations.

Theoretical background

Opportunity, necessity and crisis innovation

The current COVID-19 pandemic crisis is very different from an economic crisis such as the global financial crisis of 2008, which represented an external shock that mainly affected market dynamics. Industry and economic disruptions occurred as a consequence of the recession that ensued rather than as a consequence of the crisis itself (Mandel & Veetil, 2020). In contrast, the COVID-19 pandemic has had immediate effects on people's physical health and the entire socio-economic system (Dahlke et al., 2021; De Vito & Gomez, 2020; Zhang, Hu & Ji, 2020). Crises pose enormous pressure on technology, user practices, application, infrastructure, industry structure, policy and techno-scientific knowledge (Geels, 2002).

Clinical care and education are areas that have been relatively unaffected by the disruptive changes that have previously transformed other sectors such as banking, retail and manufacturing. The COVID-19 pandemic seems to be the catalyst for disruption in clinical care and educational systems at an unprecedented pace (Dzau, Yoe-diono, ElLaissi & Cho, 2013; Woolliscroft, 2020). The health crisis generated the need to develop new therapies and vaccines (Verma & Gustafsson, 2020); hence, investors are prioritizing investment in biopharmaceutical companies that have innovated during the COVID-19 crisis (Piñeiro-Chousa, López-Cabarcos, Quiñoá-Piñeiro & Pérez-Pico, 2022). Preliminary COVID-19-related research already indicates that innovative start-ups pivot and aim to exploit emerging entrepreneurial opportunities (Kuckertz et al., 2020; Manolova, Brush, Edelman & Elam, 2020).

Other recent changes include transitions to innovations related to information technologies e.g. cloud, Internet of Things, social media communication and open innovations. The concept of open innovation as a distributed process based on managed knowledge flows across organizational boundaries has been extended not only to

businesses, but also to the entire online environment (Chesbrough & Bogers, 2014; Secundo, Toma, Schiuma & Passiante, 2018). Thus, we are talking about innovation communities (Shaikh & Levina, 2019; West & Lakhani, 2008), user innovation activities (Ogink & Dong, 2019; Piller & West, 2014), open source software development (Nagle, 2019; Von Krogh, Haefliger, Spaeth & Wallin, 2012), and open licensing (Gorbatyuk, Van Overwalle & van Zimmeren, 2016; Wu, Little & Low, 2016).

Role of universities in RDIs

At the World Economic Forum Annual Meeting in 2018, universities were exhorted to embrace their role to drive innovation and catalyze economic development through four main paths: (1) foster entrepreneurship and create a culture of innovative thinking; (2) encourage collaboration with private companies, foundations and other research-intensive institutions; (3) promote diversity and inclusion to ensure that economic gains are shared across the economy; and (4) ensure that there is an ethical nexus between technology and society to make sure that technology will benefit humanity (Jahanian, 2018).

Along these lines, Boh, De-Haan and Strom (2016) identified six stages for bringing to market early technology at universities: (1) idea generation; (2) commercialization decision; (3) prototype generation and establishment of commercial and technical viability; (4) founding team formation; (5) strategy and commercialization process determination, and (6) fundraising to sustain activities, with the aim of convincing investors that the new technology has commercial and technical viability. In addition, they identified university programs and practices that enhance entrepreneurial efforts to commercialize university technologies such as mentoring, accelerators and incubators, and developing competitive business plans (Boh et al., 2016).

Researchers have pointed out that universities have increasingly become ambidextrous organizations reconciling research and business missions. In order to manage this ambidexterity, technology transfer offices (TTOs) or similar entities have been established in many universities (Huyghe, Knockaert, Wright & Piva, 2014). Indeed, academic spin-offs can represent an opportunity to commercialize knowledge developed within the university as well as provide compensatory self-employment opportunities by allowing skilled individuals to exploit their advanced knowledge in a given field (Czarnitzki, Doherr, Hus-singer, Schliessler & Toole, 2016; Roach & Saueremann, 2010).

Internal entities such as TTOs or their equivalents can foster academic innovation and entrepreneurship using different strategies for spinning-out companies (Clarysse, Wright, Lockett, Van de Velde & Vohora, 2005). In general, academics who are familiar with technology transfer initiatives are more likely to get involved in entrepreneurial activities as they learn the business norms and skills required to be successful in commercializing research. Generally, TTOs also organize pre-seed capital to be invested in potential spin-offs. In addition, they offer incubation services, which make it possible for academics to set up new businesses while staying on campus (Berco-vitz & Feldman, 2008; Civera, Meoli & Vismara, 2020; Clarysse & Bru-neel, 2007).

Innovation typology

Typically, an innovation has been defined as the initial introduction of a new product or process whose design departs radically from past practice. Innovation is becoming even more important to organizational growth and a way to improve competitive advantages for nations. The variety of products keeps growing, and the organizational settings as well as the external conditions keep changing. Therefore, not surprisingly, there are various frameworks to categorize innovations based on different aspects such as diffusion, impact, usage, type, etc. (Bogers et al., 2017; Coccia, 2006; Shenhar, Dvir & Shulman, 1995). The typology proposed by Dahlke et al. (2021) that

distinguishes between the needs of the users of the innovation and the needs of the innovators can be used to categorize RDI efforts at universities. (Dahlke et al., 2021; Max-Neef, Elizalde & Hopenhayn, 1989).

In order to identify the scope of the RDI efforts at universities that occurred as a result of the pandemic and to elucidate the patterns of collaboration and RDI capabilities of CEE universities we posited the following research questions: What is the scope of RDI topics in the overall university communications during the pandemic?; What are specific RDI activities that took place at selected universities during the pandemic?; and how can these pandemic related RDI activities be classified or categorized?

Methodology and data

This study is based on the analysis of communications posted on the official Facebook pages of 30 universities located in CEE countries. Facebook was chosen because it is a popular social media platform, and higher education institutions are increasingly using it for official communications with the student body (Bachmann, 2020; Fähnrich, Vogelgesang & Scharkow, 2020; Metag & Schäfer, 2019). In addition, the frequency, timeliness and completeness of communication on this platform is higher than on other communication university platforms (Zachos, Paraskevopoulou-Kollia & Anagnostopoulos, 2018). Furthermore, there is evidence that Facebook can be used to disseminate information about technology and innovations as part of a cross- or multimedia- communication strategy (Wirtz-Brückner, Jakobs, Kowalewski, Kluge & Ziefle, 2015).

Based on the analysis of Facebook communications, which were extracted in their original language. Content analysis allows us to make inferences by objectively and systematically identifying specified characteristics of messages. Our process consisted of the following steps: sample selection, definition of terms to be extracted in the languages spoken at the selected universities, category construction, creation of codes, data collection, coding, inter-coder reliability determination, and data analysis (Krippendorff, 2018).

The first research step focused on identifying the overall scope of RDI topics in university communications during the pandemic. Once the RDI items were identified, an in-depth analysis was conducted to get a more accurate qualitative picture of the RDI activities. The second step focused on identifying the type of R&D efforts, and the third step focused on identifying the innovation efforts. The level of

involvement of cooperating actors in RDI activities was also assessed. The research design including the research scope are provided in Fig. 1.

Research sample

The research sample consists of 30 top universities based in eight CEE countries: Austria, Croatia, Czech Republic, Hungary, Poland, Serbia, Slovakia and Slovenia. These countries are not only part of a geographic cluster, but they also share a common past history as part of the Austro-Hungarian Empire before its dissolution. Furthermore, all countries except Austria continued a shared socioeconomic and political path as satellite countries of the former Soviet Union. In 1991, the Czech Republic, Hungary, Poland and Slovakia created the Visegrád Group as a cultural and political alliance, which allowed for similar business conditions and socioeconomic development of the group (Bednáriková & Stehlíková, 2012; Mura, Ključnik, Tvaronavičienė & Androniceanu, 2017). Therefore, Austria serves as a benchmark country in terms of assessing RDI efforts and scope.

Besides the regional and historical consistency of the sample countries, the selection of higher education institutions is based on the Times Higher Education (“THE”) ranking and the *knowledge transfer* score. The Academic Ranking of World Universities (ARWU) and the QS World University Rankings are also well known. The selected sample universities have similar rankings across these surveys (Altbach & Hazelkorn, 2018; Baty, 2013; Lim, 2021). Since the “THE” rankings are solely based on research or research-related indicators we decided to base our selection on their metrics. The *knowledge transfer* score reflects the level of university innovation activities in terms of their ability to help industry with innovations, inventions and consultancy. The indicator also tries to capture how much research income universities earn from industry by scaling it against the number of employed academics (TimesHigherEducation, 2021). The *knowledge transfer* score of the sample ranges between 33.5 to 51.7 for CEE post-communist countries, while for Austria it ranges from 57.8 to 86.9. The sample is comprised of thirteen technical universities, twelve universities with a general focus (which include engineering, technical sciences, physical sciences, social sciences, business and economics), and five medical schools. Clearly, Austrian universities are ranked higher and have higher *knowledge transfer* scores than the rest of the universities in the sample. Table 1 provides a list of the selected universities, the number of pandemic oriented

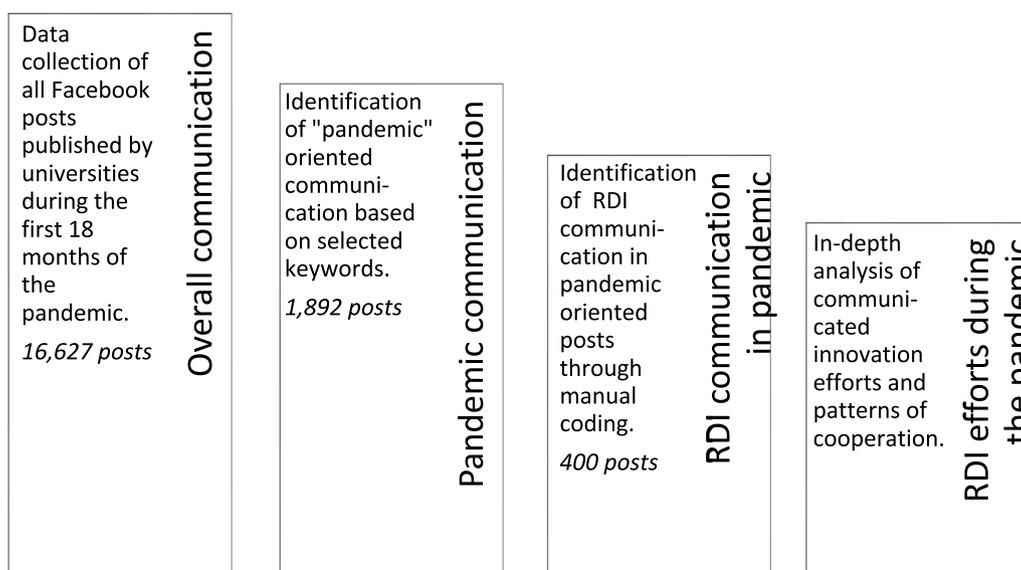


Fig. 1. Research scope and design.

Table 1
Sample universities showing the number of posts and “THE” metrics.

Country University/Acronym	N	“THE” World Ranking	
		Overall Rank	Knowledge transfer score
<i>Austria</i>	2073		
Medical University of Innsbruck ¹ / MUIIn	289	201–250	86.9
Graz University of Technology ² / GrUT	404	501–600	68.8
Technical University Wien ³ / TUWi	728	401–500	65.6
Medical University of Graz ⁴ / MUGr	181	201–250	62.6
Medical University of Vienna ⁵ / MUWi	471	201–250	57.8
<i>Czech Republic</i>	2953		
Czech Technical University ⁶ / CTU	1330	1001+	51.7
Czech University of Life Sciences ⁷ / CULS	360	1001+	51.6
VŠB – Technical University Ostrava ⁸ / VSB-TUO	403	1001+	43.1
Brno University of Technology ⁹ / BUTe	635	1001+	41.4
Technical University in Liberec ¹⁰ / TUL	286	1001+	41.2
<i>Hungary</i>	3789		
Budapest University of Technology and Economics ¹¹ / BUTE	476	1001+	43.0
University of Debrecen ¹² / UDeb	965	1001+	37.7
University of Szeged ¹³ / USze	732	801–1000	36.3
University of Pécs ¹⁴ / UPéc	971	601–800	35.2
Semmelweis University ¹⁵ / SMW	645	401–500	35.1
<i>Poland</i>	2951		
Wroclaw University of Science and Technology ¹⁶ / WUST	940	1001+	43.0
AGH University of Science and Technology ¹⁷ / AGH	472	1001+	41.4
Medical University of Warsaw ¹⁸ / MeUW	696	801–1000	39.0
Gdańsk University of Technology ¹⁹ / GdUT	352	1001+	38.6
Warsaw University of Technology ²⁰ / WaUT	491	1001+	38.4
<i>Slovakia</i>	2259		
Technical University of Košice ²¹ / TUKE	505	1001+	44.5
University of Žilina ²² / UŽil	259	1001+	42.9
Slovak University of Technology in Bratislava ²³ / SUTE	393	1001+	36.6
Slovak University of Agriculture in Nitra ²⁴ / SUA	358	1001+	35.4
Comenius University in Bratislava ²⁵ / CoU	744	1001+	33.5
<i>Croatia, Serbia, Slovenia</i>	2593		
University of Maribor (Slovenia) ²⁶ / UMA	582	1001+	40.7
University of Zagreb (Croatia) ²⁷ / UZa	805	1001+	40.3
University of Belgrade (Serbia) ²⁸ / UBe	389	601–800	39.3
University of Ljubljana (Slovenia) ²⁹ / ULju	764	801–1000	38.8
University of Novi Sad (Serbia) ³⁰ / UNS	53	1001+	35.6
Total	16,627		

University names in original language:

- ¹ Medizinische Universität Innsbruck.
- ² Technische Universität Graz.
- ³ Technische Universität Wien.
- ⁴ Medizinische Universität Graz.
- ⁵ Medizinische Universität Wien.
- ⁶ České vysoké učení technické v Praze.
- ⁷ Česká zemědělská univerzita v Praze.
- ⁸ VŠB – Technická univerzita v Ostravě.
- ⁹ Vysoké učení technické v Brně.
- ¹⁰ Technická univerzita v Liberci.
- ¹¹ Budapesti Műszaki és Gazdaságtudományi Egyetem.
- ¹² Debreceni Egyetem.
- ¹³ Szegedi Tudományegyetem.
- ¹⁴ Pécsi Tudományegyetem.
- ¹⁵ Semmelweis Egyetem.
- ¹⁶ Politechnika Wroclawska.
- ¹⁷ Akademia Górniczo-Hutnicza w Krakowie.
- ¹⁸ Warszawski Uniwersytet Medyczny.
- ¹⁹ Gdansk University of Technology.
- ²⁰ Warsaw University of Technology.
- ²¹ Technická univerzita v Košiciach.
- ²² Žilinská univerzita.
- ²³ Slovenská technická univerzita v Bratislave.
- ²⁴ Slovenská poľnohospodárska univerzita v Nitre.
- ²⁵ Univerzita Komenského v Bratislave.
- ²⁶ Univerza v Mariboru.
- ²⁷ Sveučilište u Zagrebu.
- ²⁸ Univerzitet u Beogradu.
- ²⁹ Univerza v Ljubljani.
- ³⁰ Univerzitet u Novom Sadu.

Table 2
Keywords used in the search for the relevant Facebook posts.

Keywords	Abs.	Rel. (%)
"COVID"	1049	6.31
+"korona" OR "corona"	167	1.00
+"vírus" OR "virus" OR "wirus"	247	1.49
+"korona"OR"corona" + "vírus" OR "virus" OR "wirus"	196	1.18
"korona" OR "corona"	630	3.79
+"vírus" OR "virus" OR "wirus"	479	2.88
"vírus", "virus", "wirus"	902	5.42
Posts containing at least one keyword	1892	9.79

communications, the "THE" overall ranking, and the *knowledge transfer* score.

Data collection and processing

All the posts published from January 1, 2020 to June 30, 2021 on the official Facebook pages of the selected universities were collected in their original language. Initially, 16,693 posts were obtained, however, after eliminating the non-communicative posts (e.g. changes of status, university logos or timelines) 16,627 posts remained. From this pool, 1892 posts included the keywords "COVID", "korona", "corona", "vírus", "virus", and "wirus". The number of posts comprising the relevant keywords are shown in Table 2.

The 1892 posts that included the keywords were analyzed to identify RDI and non-RDI efforts related to COVID-19 at each university. These RDI efforts were categorized and specific efforts that included business cooperation were further studied as examples of cases of RDI-business collaborative efforts.

Interrater reliability

The assessment of inter-rater reliability (IRR), also called inter-rater agreement provides a way of quantifying the degree of agreement between two or more coders who make independent ratings about the features of a set of subjects. IRR analysis aims to determine how much of the variance in the observed scores is due to variance in the true scores after the variance due to measurement error between coders has been removed (Hallgren, 2012). Several coding-related considerations were decided *a priori*. Then, a subset of 200 randomly selected posts was used for the IRR analysis (e.g. fully crossed design). Then the IRR for the subset of subjects was used to generalize to the full sample (Hayes & Krippendorff, 2007; Krippendorff, 2018; Putka, Le, McCloy & Diaz, 2008). The overall IRR was 82%, which indicates strong reliability. The scores related to individual categories are displayed in Table 3.

Topic modeling is one of the most powerful techniques for text and data mining, latent data discovery, and for finding relationships among data and text documents. Latent Dirichlet Allocation (LDA) is one of the most popular topic modeling methods (Jelodar et al., 2019). For robustness purposes we used LDA to see any relevant

information from the analysis. The topics identified by LDA matched the topics found through coding.

Results

Pandemic-oriented communications of non-RDI efforts focused primarily on protocols and guidelines for students and staff, especially during the transition to distance learning during the lockdowns. Also, a lot of communications were about socially responsible activities, expert opinions or volunteer opportunities for students and academics. Moreover, a significant portion of the communications in all countries, except Austria described low-cost or do-it-yourself (DIY) production of protective devices and aids. In the first few months of the pandemic, when these aids and resources were insufficient for the public, most universities were involved in the production of masks, protective shields, and disinfectants for health professionals and front-line workers in hospitals. These universities provided knowledge, technology and human resources for the implementation of RDI activities directly related to COVID-19 treatment, prevention or protection.

The scope of RDI topics

One fourth (21%) of the pandemic oriented posts were about RDI activities. As can be seen in Table 4, the share of RDI communications varied significantly among universities and countries. Austria had the highest share (7.2%) of RDI communication followed by the Czech Republic (4.2%). For the rest of the countries the percentage share of RDI communications varied from 1.9% for Poland to 1.2% for Slovakia. In terms of RDI communications at the university level, the Medical University of Innsbruck and the Czech Technical University in Prague had much higher levels than the rest.

University research and development areas

As expected, medical research efforts were focused on the development of treatments and epidemiology. Logically, medical universities such as the Medical University of Vienna, Semmelweis University, and universities with a medical school (CoUn, USze, UPéc, MeUW) were more active in this respect. This type of research tends to have longer lead-times because potential new treatments or medications need to go through the clinical trial process which can take a long time. The time-frame of this study was relatively short; therefore, it did not always capture the end products of these research efforts.

In most countries, the research efforts were usually carried out independently within the university, although Austrian universities exhibited higher levels of inter-institutional and industry collaboration than the rest. Only the Polish WUST reported that an anti-virus drug development research was conducted in collaboration with U.S. research groups. Data from this study was published without a patent application for easier availability. This is evidence of the solidarity that emerged among researchers during the pandemic. Besides medical oriented research, these institutions also conducted research in

Table 3
Inter-Rater Reliability (IRR) results.

Category	N	% Agreement	Scott's Pi	Cohen's Kappa	Krippendorff's
Research Topic	200	87	0.384	0.386	0.386
Research Development	200	94	0.302	0.302	0.304
Innovation: Technical	200	95	0.679	0.679	0.679
Innovation: Non-Technical	200	99	0.745	0.745	0.746
Non RDI	200	87	0.670	0.671	0.671

Table 4
The scope of universities' pandemic and RDI oriented communication.

Country University	Pandemic oriented communication		RDI oriented communication	
	Abs.	% ¹	Abs.	% ¹
<i>Austria</i>	417	20.1	84	7.2
Medical University of Innsbruck / MUIIn	81	28.0	27	9.3
Graz University of Technology / GrUT	58	14.4	5	1.2
Technical University Wien / TUWi	105	14.4	24	3.3
Medical University of Graz / MUGr	38	21.0	11	6.1
Medical University of Vienna / MUWi	135	28.7	17	3.6
<i>Czech Republic</i>	258	8.7	125	4.2
Czech Technical University/ CTU	137	20.8	93	7.0
Czech University of Life Sciences/ CULS	28	13.0	7	1.9
VŠB–Technical University Ostrava/ VSB-TUO	36	15.1	9	2.2
Brno University of Technology/ BUTe	46	7.3	10	1.6
Technical University in Liberec/ TUL	11	5.5	5	1.7
<i>Hungary</i>	421	11.1	58	1.5
Budapest Un. of Techn. and Economics/ BUTE	29	11.2	6	1.3
University of Debrecen/ UDeb	48	7.7	9	0.9
University of Szeged/ USze	103	20.4	14	1.9
University of Pécs/ UPéc	133	16.2	12	1.2
Semmelweis University/ SMW	108	21.9	17	2.6
<i>Poland</i>	263	8.9	56	1.9
Wroclaw U. of Science and Technology/ WUST	53	9.8	33	3.5
AGH U. of Science and Technology/ AGH	22	5.7	4	0.8
Medical University of Warsaw/ MeUW	140	24.5	16	2.3
Gdańsk University of Technology/ GdUT	17	7.8	2	0.6
Warsaw University of Technology/ WaUT	31	6.5	1	0.2
<i>Slovakia</i>	199	8.8	28	1.2
Technical University of Košice/ TUKE	40	9.5	6	1.2
University of Žilina/ UŽil	14	7.4	5	1.9
Slovak U. of Technology in Bratislava/ SUTe	45	16.2	8	2.0
Slovak University of Agriculture in Nitra/ SUA	22	10.0	1	0.3
Comenius University in Bratislava/ CoU	78	16.4	9	1.2
<i>Croatia, Serbia, Slovenia</i>	334	12.9	49	1.9
University of Maribor (Slovenia)/ UMA	51	8.8	10	1.7
University of Zagreb (Croatia)/ UZa	96	11.9	13	1.6
University of Belgrade (Serbia)/ UBe	32	8.2	12	3.1
University of Ljubljana (Slovenia)/ ULju	155	20.1	14	1.8
University of Novi Sad (Serbia)/ UNS	0	0.0	0	–
Totals	1892	10.1	400	2.2

¹ Out of posts published by country/university between January 1st, 2020 and June 30, 2021.

sociology, economics and environmental fields. All identified research and development topics are summarized in Table 5.

University innovations

Table 6 provides a list with a brief description of the innovations identified. Most of the innovations were focused on designing medical equipment and protective gear for healthcare professionals. Prototypes were often shared with open access platforms, e.g. freely accessible files for 3D printing.

At the beginning of the pandemic, in all countries except Austria, technological innovations focused on patenting and certifying protective medical devices, due to shortages of such devices in those countries. As the pandemic progressed, efforts in all the countries shifted to develop testing capabilities and on preventive processes in hospitals such as measuring the body temperature of newcomers and decontamination of the environment. Later the focus shifted to information systems to monitor various activities of citizens, such as data capture for contact tracing, infection risk assessment and compliance with state-imposed measures. For these innovations, universities often worked with regional and state administration entities (e.g. Hygiene Station in the Czech Republic), or already established cooperation with businesses such as the collaboration between VSB-TUO and T-Mobile in the Czech Republic.

Regarding instruction and knowledge dissemination, communications included a wide range of measures to combat the pandemic such as how to behave in public transportation systems, emergency sterilization of respirators or e-learning courses for doctors and

specialists. Many virtual conferences, seminars and lectures were also organized. Several innovation hackathons took place at the different institutions.

Finally, many universities hosted events where they provided free services or supplies, donation drives and crowdsourcing events. Several competitions and campaigns were also set up to combat the pandemic. For example, as part of a student online hackathon “Hack the Crisis”, the Smart Triage web application was created. In a similar event, WUST students created a “StopFakeNews” campaign against misinformation about COVID-19, and MeUW joined the international organization “Fight the Fakes” to raise awareness of drugs, as information emerged about counterfeit COVID-19 therapies, vaccines and drugs. Universities also participated in anti-COVID-19 programs at national (Slovak National Technology Transfer Competition) or European levels (EUvsVirus hackathon).

Discussion

Our results indicated that one fourth of the pandemic oriented communications were about RDI activities. The findings that answer our research questions are discussed below.

Clusters in RDI

Based on the data analysis, we modified the innovation typology proposed by Dahlke et al. (2021) in order to incorporate research and development efforts as well. For the R&D efforts we identified three clusters as shown in Fig. 2. In the medicine

Table 5
Research topics and projects identified in university communication.

Research Area	Research description
Medicine – Pharmaceutical research	<ul style="list-style-type: none"> • Research on therapeutic agents to fight COVID-19 (MUGr, BUTE, UPéc). • Technology for the development of recombinant antigens of the new coronavirus (UBel). • Investigation of Nano scaffolding approach for rapid design of highly immunogenic SARS-CoV-2 vaccines (ULju). • Development of new protein structures (BUTE). • The use of phages in the fight with COVID19 (MeUW). • The creation of the protease inhibitor Mpro (WUST). • Non-invasive diagnosis of arrhythmias (TeleCheck AF at MeUW). • COVID-19 genomics on mutations in genes (MeUW). • Research on the identification of genetic information of the new coronavirus (MUWi in collaboration with CeMM, CoUn). • Methods for virus preparation and sequencing (UPéc). <p>Cooperation/Collaboration</p> <ul style="list-style-type: none"> • Cardiovascular receptor blockers for COVID-19 patients (MUIn and the Klinikum Ludwig-Maximilians-Universität Munich). • ACE inhibitor therapy in the treatment of COVID-19 (MUIn, MUGr, MUWi financed by the FWF Science Fund). • Identification of a key molecule in the RNA polymerase complex (Cooperation of MUIn and the Institute for Genomics and RNomics). • Research for a vaccine against Covid-19 (MUWi in collaboration with the Institute of Pathophysiology and Allergy Research). • Drug oriented research to detect an organic compound that inhibits the activity of a key enzyme in the virus development. The data from the study was not patented to make it available for free (WUST in collaboration with U.S. research groups). • Research on a unique protein to develop a Nano-vaccine (WUTE and the Center for Advanced Materials and Technologies). • Lab tests for a vaccine developed by the Austrian biotechnology company CEBINA (UPéc).
Medicine –Treatment	<ul style="list-style-type: none"> • New COVID-19 treatments (MUGr, MUWi, MeUW, UDeb and CTU). • Endogenous antiseptic treatments for elderly COVID-19 patients (MUIn). • Research on the process of treating COVID-19 and the role of Sigma-1 receptor; BCG vaccination, primarily used against tuberculosis (SMW). • New patent for the treatment of COVID-19 complications in the treatment of pulmonary fibrosis, and development of targeted anti-cytokine treatment for post-COVID-19 multi-organ inflammation (SMW). • Study of complications and symptoms caused by COVID-19 in hemato-oncology patients (MeUW). • Computer modeling for potential drugs to treat COVID-19 (UMar) • A new system of patient care (UDeb). • Testing on the effectiveness of the anti-COVID-19 drugs Favipiravir and Remdesivir (UDeb). • Clinical trials of antiviral drugs (USze). • Testing the effectiveness of using plasma therapy (SMW).
Medicine – Epidemiology	<ul style="list-style-type: none"> • Screening studies to test the population on coronavirus related issues (MUGr, MUIn, MUWi, SMW, UPéc, USze, UDeb). • A human 3D model to understand excessive immune response to COVID-19 (MUIn). • COVID-19 forecasting models (UMWi in collaboration with Complexity Science Hub Vienna, TUWi). • 3D cell culture model to simulate the interactions of the new corona virus with human tissue layers (MUIn). • Virus diffusion modeling studies (UDeb, WUM). • Analysis of the virus in stool (UPéc) • The effect of weather on the spread of the virus (UDeb). • Transmission of the virus from animals (UPéc, CULS). • The risk of mother-to-child transmission via breast milk (MeUW). • The transmission of the virus through aerosol transport and deposition in the human respiratory tract (UMar). • Viral pathogenesis of SARS-CoV-2 infection and male reproductive health (SUAg). • Two models, logistic and classical SIR model to forecast for the course of COVID-19 infections (ULju). • Vaccination adoption study based on the analysis of opinions on social media (MUIn, MeUW). • Analysis of recommendations for measures and risks associated with them (WUST). • Attitudes towards vaccination (UMar) • Epidemiology studies (MUGr, MUIn, CoUn).
Social Sciences - Sociology	<ul style="list-style-type: none"> • Effect of pandemic on friendships, work and relationships (MUIn, BUTE). • Thoughts and feelings of people around the world, specific effects on medical students (MeUW). • The psychological impact of a pandemic (MUIn, MUWi, CoUn). • Willingness of citizens to take action or share their personal data on social networks (WUST, USz). • The ability to search for health information on the Internet (GUTE). • The effect of the measures on the elderly (MUGr, UDeb). • Incidence of new coronavirus among the population (ULju). • Health literacy research related to COVID-19 (UBel).
Social Sciences - Economics	<ul style="list-style-type: none"> • Impacts of the pandemic (UPéc, CoUn). • Pandemic effect on the labor market (UDeb) and business (CoUn).
Environmental Sciences	<ul style="list-style-type: none"> • The positive impact of lockdown on the environment and the atmosphere (WUST).

Table 6
Innovations identified in university communications.

Domains	Innovations
Medical Equipment	<ul style="list-style-type: none"> • New type of oxygen device is intended to help COVID-19 patients breathe (GrUT). • Respirator for 3D printing (AGH). Drapes and respirators (BUte). • Respirators freeSPI and BREATHU 2020 universal lung ventilator. (TUKE). • Belt with a water container for nurse's wearing masks (MeUW). • Air filter for COVID-19 (CTU) • COVID-19 Q-vent lung ventilator (CoUn), The CoroVent lung ventilator (CTU), lung ventilators (STU, MUGr).
Protectives	<ul style="list-style-type: none"> • Electrical prototype of a medical respirator FEspirator (ULju). • A helmet for non-invasive ventilation supporting breathing of patients with COVID-19 (MeUW). • Self-disinfecting coatings based on nanotechnology (USze). • Disinfectants for hands and surfaces (TUWi). • Prototypes for 3D printing of drapes or protective shields (CTU, TUL, WUST, GUTe, BUte). • Functional prototype of a reusable face mask with a replaceable filter (UBel). • DIY Face visor (TUWi), UBel). • Face protection models and door handle attachments to avoid touching them (TUWi). • Special airlock that helps effectively isolate COVID-19 patients in wards that are not properly adapted to it (WUST). • Protective shields (TUKE). • Functional prototype of a reusable face mask with a replaceable filter, (UBel) • Respiratory protection RESPIRATOR with a replaceable filter (UŽil). • RP95-M mask (CTU). • CovMask with a P3R replaceable filter (CTU, University of Hradec Králové and partner companies). • Sterilizable filters by electric current (CTU), Highly efficient cleanable filters and special nanofiber masks for doctors (TUL and partner companies).
Diagnostics & Monitoring	<ul style="list-style-type: none"> • Diagnostics pipeline (MUWi in collaboration with Max Perutz Labs and the Research Institute of Molecular Pathology). • Gargle tests to determine the frequency of active corona infections among schoolchildren (MUIn). • Rapid COVID-19 tests (TUWi). • Creation of ImGen -coronavirus diagnostics, patent filed in the United States (WUTE). • Design of PCR tests and their production (SUTE). • Analysis and diagnosis of cell samples for COVID-19 (WUST). • Development of a new one-time PCR test (MUIn, SMW, WUST). • Detection of coronavirus in saliva (SMW). • Development of "Elisa", a test for SARS-CoV-2 virus (UBel). • Creation of a mobile lab for COVID-19 diagnostics (CULS). • Testing of wastewater to signal an oncoming wave of coronavirus (MUIn, SUTE). • Creating an algorithm to increase efficiency of COVID-19 sample processing in labs (i.e. diagnostics) (CTU). • Portable kit for telemonitoring patients (MeUW). • Contactless thermal camera to detect people with fever (CTU). • Remote temperature measurement of people entering buildings (GUTE) • A thermovision device (WUST).
High Technology	<ul style="list-style-type: none"> • Technology system to store donor organs outside the body for up to 40 h, may benefit COVID-19 patients (MUIn). • Creation robotic biobank sample storage system to improve diagnostics for COVID-19 control (MUGr, USze). • A pipetting robot Eppendorf (CTU, Hospital Na Bulovce, and the Institute of Nuclear Physics in ASCR). • An aid for opening sample tubes (CTU) • Project on the usability of autonomous drones in the fight against the COVID-19 pandemic (SUTE). • Operational tests for new automotive platforms for advanced driver assistance (VSB-TUO). • Methods for developing confidential data protection and information protection using digital watermarks (AGH). • The patented Beewair device is based on an electric reactor that generates free radicals that decompose viruses and bacteria (TUKE and the French company Beewair). • An autonomous robot Covibot designed to help decontaminate rooms with bacteria and viruses (WUST).
Mobile and web applications	<ul style="list-style-type: none"> • App for contact tracing (TUWi). • Computer simulation to monitor effectiveness of COVID-19 measures (TUWi and the TUWi spin-off company #dwh GmbH). • smartWorkLifeApps to monitor life-work balance during the pandemic (TUWi). • for vaccination registration www.koronavirus24.cz http://ockovani.opendatalab.cz developed by faculty and support of Profinit (CTU). • Digital assistant Andrija on WhatsApp to answer COVID-19 related questions (UZag). • "medis vs. COVID-19" platform to allow medical students volunteer (MUGr). • Interactive COVID-19 hygiene training app (MUWi). • Apps for monitoring (VirusRadar in Hungary, eRouska in the Czech Republic), • The EpiGIS information system (IS) to capture, record and analyze the behavior of all tested people (TUL and Regional Hygiene Station; funded by Technology Agency of the Czech Republic). • Atlas mobility, a transmission interface for data on the mobility of the population in the Czech Republic (VSB-TUO, T-Mobile CZ, National Supercomputer Center). • Mobility and spatial studies (TUWi). • FreME Explorer, a mobile application that collects data on the occupancy of an individuals favorite locations and predicted the occupancy in such locations (CTU, Université de technologie de Belfort Montbéliard-France, the University of Manchester-UK, Örebro University-Sweden, National University of Science and Technology (Pakistan).

(continued)

Table 6 (Continued)

Domains	Innovations
Virtual Learning	<ul style="list-style-type: none"> • Smart Triage, a web application to process incoming patients (Charles University and CTU). • Wowee, a web application that provides financial assistance to those who find themselves in a difficult situation during the pandemic (CTU). • OmniCalculator, emphasized the importance of social distancing by keeping track of how many people were not infected because of social distancing (AGH). • Development of a simulator to train the interaction in emergency situations in the delivery room with Covid-19 protective measures (MUWi). • Instructional videos about COVID-19 related topics such as how to behave in public transportation during an epidemic, instructions for emergency sterilization of respirators (CTU). • DIY tutorials for protective equipment such masks, • Instructional videos for general practitioners and medical staff about correct procedures (MeUW). • Webinars and virtual courses were developed by almost all the sample universities.
Information	<ul style="list-style-type: none"> • Innovation competitions (TUWi), MeUW, ULju, UBel, SMW, TUKE, UZag). • COVID-19 conferences and specialized lectures were offered by almost all sample universities.
Open Innovation	<ul style="list-style-type: none"> • Patents free for limited time or indefinitely. • 3D printing instructions freely accessible.
Pro-bono/Donations	<ul style="list-style-type: none"> • Crowdfunding events (CTU) • Grants received to develop strategies to counteract the effects of COVID (MeUW), joint research with UK (CoUn), new research related to vaccines (SMW, MeUW, UDeb) • Drives to collected food, clothes and solidarity events to help students cope with the pandemic were organized at almost all the sampled institutions.

cluster, the sub-themes were pharmaceutical research, treatments for COVID-19 and epidemiological studies. The two other clusters are comprised by studies in the socioeconomic and environmental fields.

Regarding innovation efforts, we identified four overarching clusters and nine distinct domains of innovations that cover a wide range of innovations from medical equipment to apps for vaccination registration, as shown in Fig. 2. Cluster one is *Adaptations* and encompasses the two domains of Medical Equipment and Protectives. Cluster two is *Digital Innovations* and comprises the domains of Mobile and Web applications, Diagnostics & Monitoring, and High Technology. Cluster three is *Online Platforms* and branches off into Virtual-Online learning, Information, and Open Innovation. Cluster four is *Solidarity* with the domains Open Innovation and Pro-bono/Donations.

the domains of Virtual Learning and Information sharing. Cluster four is *Solidarity* with the domains Open Innovation and Pro-bono/Donations.

Collaborative efforts

This study has also shown that cooperation between universities and with external entities such as government institutes and private companies is crucial for RDI. The level of commercialization of the innovated products is also highly dependent on such cooperation. While the identified research was mainly the effort of individual universities, cooperation with other universities was not the norm in

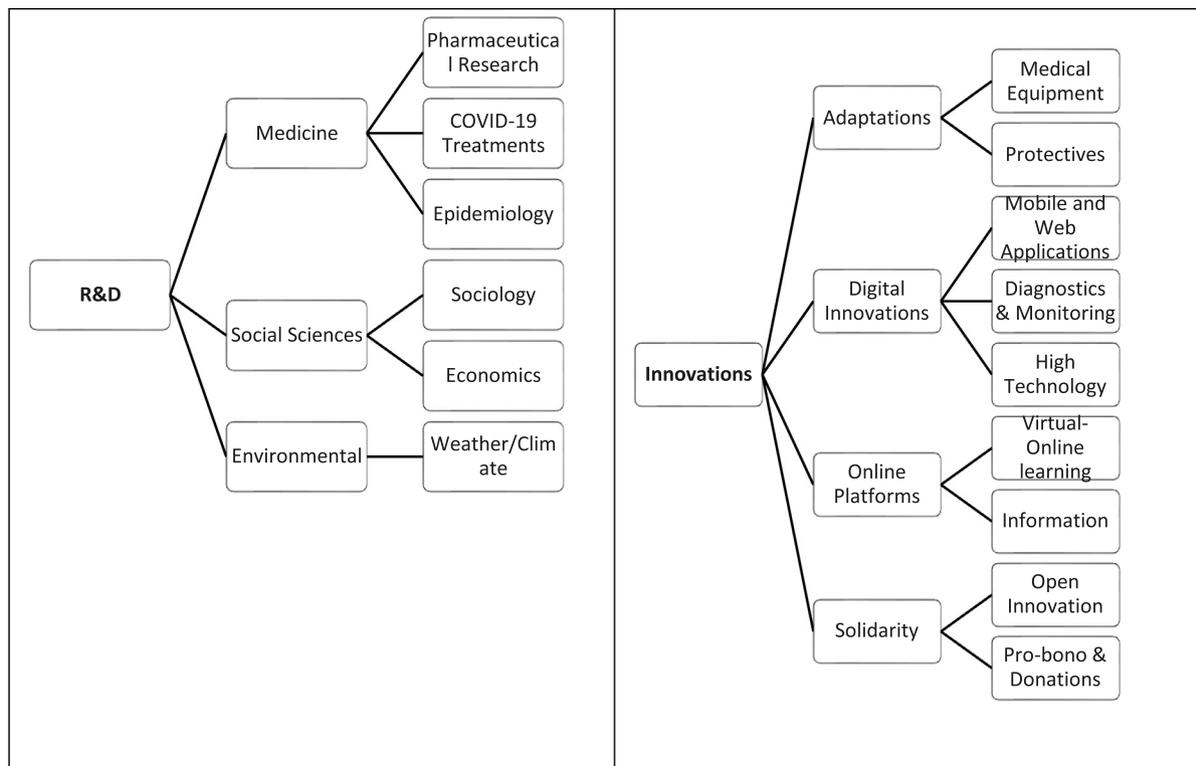


Fig. 2. RDI clusters, sub-themes and domains.

Table 7
Cases of innovations that resulted from collaborative efforts with businesses.

Name	Description	Certification	Co-operation
CoroVent - lung ventilator	The CoroVent lung ventilator was developed in 35 days. A free temporary open license was offered to any user worldwide for testing, manufacturing, distribution and modifications. The cost per ventilator is less than 10,000 USD. Detailed information is available at micomedical.cz. Potential worldwide production was possible due to an open license and easy servicing.	The product obtained the FDA EUA (Emergency Use Authorization), and a Czech emergency certification in October 2020.	CTU in Prague in co-operation with COVID19CZ (a Czech tech-companies initiative), MICO firm and hospitals.
CovMask -the full-face mask	A full-face mask CovMask with a P3R replaceable filter with a protection level higher than the FFP3 filter was created by modifying a snorkeling sports mask. The model and tuned gcodes on MK3S for 3D printing were provided to download for free. More than 20,000 masks were produced and supplied to medics in Czech hospitals. More information is available at www.covmask.cz .	Completion and efficiency of the product have been subjected to laboratory analyzes, but the complete protective mask with filter has not been certified.	A consortium of universities (CTU in Prague, Un. of Hradec Králové), business retailers (Decathlon, Sportissimo), packaging firms (Unipap, Servisbal), and other nonprofit and public organizations.
RP95–3D mask	CTU in Prague developed a new RP95-M model for mass production in the form of plastic injection. The mask meets the same or higher degree of protection as the FFP3 respirator; can be used repeatedly due to proven sterilization and disinfection procedures. Sterilization in a steam sterilizer (autoclave); disinfection by spraying with an alcohol-based disinfectant solution (85% ethanol). Print data and instructions for making own mask via 3D printing are open and available at www.RP95.cz .	Certification according to the EN 140:1999 standard for a prototype of RP95–3D mask (protective personal aid) during second half of March 2020. Full CE certification was obtained in June 2020. The procedure was verified by testing and authorized by national authorities.	CTU in Prague, Trix Connection (a university spin-off) and the CARDAM company. In addition, anthropologists from Masaryk University provided a database of 3D face images for used for the development of children masks.
Air filter	Beewair air filter device is based on an electric reactor that generates free radicals that decompose viruses and bacteria. Production of this decontamination device began in October 2020 at the university Prototype and Innovation Center. The price ranged from 1800 to 4200 euros. This is an improvement of the original French model Beewair 60.	The original device was patented earlier by Beewair company. This device was adapted and a new prototype developed by TUKE. No certification yet.	Faculty of Mechanical Engineering of TUKE and the French company Beewair.

most countries except Austria. However, research or innovations with potential commercialization increased with the number of partners involved. Research needs were usually formulated by hospitals or medical staff, then solutions to the problems were mostly formulated by the individual universities or research centers. The commercialization of a product usually occurred with the participation of a university spin-off or a cooperating external company. Examples of successful cooperation include several research projects in Austria, the connection of Slovak firms into the consortium "IT firms help to Slovakia" under the auspices of the TUKE or the connection of technologies, industry and Nano technologies in the international platform Synergy Interreg Central Europe (for researchers, Ph.D. students, students and companies) coordinated by TUL. In addition, there were more specific collaborations such as the agreement between WUST and the Japanese company Peptide for the distribution of chemical compounds. Another case of cooperation was the association of five Polish universities in the fight against COVID-19. Several examples of cooperation between universities and businesses that produced innovations are described in more detail in Table 7.

It is worth mentioning that new research organizational units were established at several universities in Hungary, Poland and Croatia. A new virology laboratory was founded at the UPéc; and the WUST in cooperation with the Croatian University of Kragujevac established a laboratory for research into the reduction of virus

penetration into the human body. MeUW has initiated the establishment of an anti-COVID-19 laboratory using molecular methods to examine medical specimens. The Center for Infectious Animal Diseases was established at the CULS with the aim of monitoring the risks associated with the spread of selected infectious diseases in animal populations.

The selected universities located in Croatia, the Czech Republic, Hungary, Poland, Serbia, Slovakia and Slovenia clearly lag behind Austrian universities in terms of the level of inter-institutional and business cooperation as reflected by their *knowledge transfer* scores. On the other hand, universities from CEE post-communist countries had a higher tendency to communicate appeals to the public about participating in donation drives (e.g. plasma, blood) as well as the development of more tools for national screening and monitoring of the pandemic. Nevertheless, the pandemic seems to have spurred a wave of new collaborations in these countries, that hopefully will be sustained beyond the pandemic. The increased inter-institutional and business collaboration is a positive trend that should be encouraged to continue.

Finally, in all countries, the pace of RDI efforts was much higher in the first three months of the pandemic (March, April and May of 2020) despite the increases in the number of COVID-19 infections and deaths. No RDI efforts were communicated during the summer time when most universities are off.

Innovation leadership

Although it is not possible to draw precise conclusions about the innovation potential based solely on the analysis of the universities' social media communication, certain differences between countries and universities are relatively obvious. The highest level of research development collaboration was observed in medical schools and universities with medical schools. Austrian medical schools exhibited the highest levels of inter-institutional research collaboration. The highest potential in terms of the quantity of emerging innovations and in terms of the degree of their completion was observed in technical universities, with Czech and Polish universities leading in this aspect. Lower innovation potentials were observed at Austrian, Croatian, Hungarian, Serbian, Slovak and Slovenian universities. At the same time, there are also visible differences among the universities. Technical universities had higher outputs and primarily became the innovative leaders in technological innovation. Similarly, medical schools and universities with well-established medical schools and science schools also scaled up their research and development projects.

The leader among the sample universities in terms of the highest number of research collaborations were the Austrian medical schools (MUWi, MUGr and MUIIn). In terms of finalized, patented, certified and commercialized innovations, the leader was the CTU in Prague.

Conclusions

This study identified the scope of RDI activities of selected CEE universities during the pandemic. The results indicate that universities have significant potential for initiating and coordinating RDI efforts. Austrian universities with already established inter-institutional networks were able to quickly refresh such connections to shift resources to pandemic related projects while maintaining existing research projects. The rest of the universities in the study had fewer established collaboration and partnerships, but they were able to relatively quickly establish new inter-institutional and business networks. These were mostly geared towards innovations of protectives, medical equipment and diagnostics. In other words, professional research background, human, knowledge and technical resources can be mobilized quickly and thus play a key role in combating the pandemic. Our findings are supported by previous research (Ebersberger & Kuckertz, 2021).

In sum, the selected Austrian universities had the highest number of RDI communications focused on joint cooperation and inter-institutional collaboration at a national level, use of spin-offs, and private research funding. The RDI communications in the Czech Republic emphasized the fast development of protective equipment (ventilators, masks) offered to the public through patents with open access and cooperation with businesses. Polish and Hungarian institutions mostly communicated published pro bono (without patenting) research therapy results. In addition, information about national screening studies, and campaigns to donate various items ranging from plasma to material things was also communicated. Finally, overall RDI communications of Croatian, Serbian, Slovak and Slovenian institutions were lower than the rest, but were also focused on research projects and innovations.

The results of the study also demonstrate that innovations in most countries, except Austria, originated in very diverse forms and often informal ways. In addition, many of these innovations were low-cost or DIY productions of protective devices and aids. In the first months of the pandemic, when these aids and resources were insufficient for the public, most universities were involved in their production.

Medical schools were very proactive and frequently collaborated with hospitals to quickly identify their needs and provide rapid and

scalable solutions. At universities, mostly faculty participated in innovation endeavors, but students also actively participated in the RDI processes. Existing partnerships with businesses were quickly re-activated and new partnerships formed relatively fast. Many innovations were also based on improvements or adaptations of existing products (e.g. the Beewair devices based on the original business model and the Wowee web application which repurposed as a fundraising application).

An important aspect of many of these pandemic related innovations is that they were made accessible and free of charge to anyone in need. In other words, most universities emphasized in their communications that one of their main motives was to help regardless of the profit potential. It is clear from the results outlined above that the framework for knowledge transfer to support open innovation in healthcare ecosystems is broad and capable of quickly adapting in the event of a pandemic. The extended network of voluntary agents and other actors such as individuals and government institutions is easily activated during a crisis. It is important to note that a significant number of donors contributing to RDI activities emerged during the pandemic in the examined countries.

Therefore, this study contributes to the existing literature in several ways. The scope and type of RDI efforts at universities in eight CEE countries was identified. Our findings elucidated the RDI potential in the region as well as significant differences between the countries and universities studied. Austrian universities exhibited higher levels of inter-institutional research and business collaborations than the rest of the CEE post-communist universities. On the other hand, RDI in these countries was geared to solve more immediate pandemic related needs.

Finally, this study also has some limitations associated with the methodology and the scope of the study. The limitations are mainly related to the use of the official Facebook posts of universities. These posts usually communicate and present successful stories of academics and students. Unsuccessful RDI activities or cooperation are generally not disclosed. At the same time, not all RDI efforts are necessarily published on Facebook. Another limitation is associated with the type of posts. Facebook posts tend to be short and may oversimplify some RDI activities, or may not describe them at all.

Future research could focus in more detail on specific aspects of RDI identified in the present study. For example, even though RDI collaborations and cooperation were examined in some detail, the specific types of collaborative agreements and the process of how universities reach out to external agents can be further elucidated. Another possible area to explore are the causes of inter-country and inter-university differences or the effect of supporting competitions and campaigns of RDI efforts. Furthermore, more insights would be gained by geographically extending the research to more countries and universities.

Declaration of Competing Interest

The authors declare no conflict of interest.

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