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MOOCS and 100 Days of COVID: Enrollment surges in massive open online astronomy classes during the coronavirus pandemic

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ABSTRACT

One side-effect of the COVID-19 pandemic has been increased enrollment in online classes. The paper explores the surge in activity from March through June 2020 in two massive open online classes (MOOCs) on Astronomy, offered by Coursera and Udemy. The increase in enrollment in both classes was an order of magnitude over the similar time span in previous years. Learners enrolling during the pandemic were more likely to be younger than thirty and less likely to have advanced degrees. A majority were full-time undergraduate students, and relatively few were professionals working in technical fields. The largest number of new students were from India and overall, the biggest surge in enrollment came from people in developing countries, particularly in Asia. Those who enrolled during the pandemic were more likely to take the course to get a certificate or to further their career goals than because they had intrinsic interest in the subject. Social motivations were important, particularly among full-time students in the course. These results, albeit limited to MOOCs in astronomy, suggest that new audiences have been turning to online classes during the pandemic for gaining credentials or advancing their professional skills.

1. Introduction

The ongoing COVID-19 pandemic has scrambled and disrupted many aspects of daily life. Not since HIV/AIDS, thirty years ago, has the world been subject to a global health crisis, and in many ways, we are in uncharted waters (Fauci et al., 2020). Education has been profoundly affected, as classes were forced to move online at very short notice and partway through the semester. This worldwide transition had massive practical implications for schools (Viner et al., 2020) and colleges (Crawford et al., 2020). Individual universities and some international organizations have responded with guides on how to implement flexible learning systems (Huang et al., 2020), since the pandemic is very likely to impact educational practices for another year or more.

Massive open online classes, or MOOCs, form an important part of the educational response to the pandemic. MOOCS burst onto the education scene in 2011, when two Stanford professors offered the course "Introduction to Artificial Intelligence" to 160,000 students from around the world, of whom 20,000 completed the course. Since then, the MOOC phenomenon has grown to 13,500 courses from 900 universities worldwide, reaching over 110 million students, a total which excludes China (Shah, 2019). The traditional audience for MOOCs is adult learners, who take free classes, or pay a modest fee for a completion certificate, and who are not seeking college credit. There is active debate on their role and value in higher education (McClure et al., 2019), and persistence rates are much lower than for typical college classes (Evans et al., 2016). Many MOOC providers have responded to the crisis by reducing or waiving fees on thousands of offerings, and they have seen enrollments surge since the pandemic took hold in March (McCluskey, 2020).

We offer three MOOCs, offered through Coursera and Udemy, the first of which began early in 2013. The classes enroll adult, free-choice learners who are typically studying for personal rather than professional reasons (Impey et al., 2016). In this research, we have investigated attributes of the courses that increase engagement and completion (Formanek et al., 2017), and the varied motivations of the adult learners, most of whom already have degrees (Formanek et al., 2019). This paper will focus on two astronomy courses (Coursera, 2020a; Udemy, 2020a) which together have enrolled over 250,000 learners. The first author of this paper is the primary instructor of both courses. First, we summarize the enrollment surge during the second quarter of 2020 and its tight connection to the timing of the pandemic. Then, we look at systematic differences between learners pre-COVID and during COVID. Finally, we

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discuss whether the recent growth in MOOC enrollments has long-term implications for online learning and the future of higher education.

2. Research questions

This project was triggered by the circumstance of a global pandemic, the first to occur since online education has spread to almost every part of the world. Given this unique situation, the reliability of the analysis is rooted in the fact that we have almost five years of stable data that precede the pandemic. Our research questions are centered on any changes that are seen starting in March of 2020.

The research questions are motivated by the widespread changes forced on informal and formal education by the pandemic, where campuses were closed and instruction could only occur online. A survey of the major MOOC providers showed that their enrollments surged by a factor of 2–3 in the spring of 2020, and we will see that the astronomy MOOCs discussed in this paper saw even larger growths in enrollment in 2020 (Shah, 2020a). There are concerns that online learning can disadvantage members of underserved communities (Kizilcec et al., 2021), so we were interested in whether the democratizing potential of MOOCs was being realized.

- What were the demographics and characteristics of the learners driving the surge in enrollment, and how do adult learners use MOOCs to respond to isolation and upheaval during a pandemic?
- What were the changes in motivation of the new learners as compared to the learners before the COVID-19 pandemic, and how are online modes of learning use to adapt to a global health crisis?

3. Methods and research design

The two MOOCs that are the subject of this paper are survey courses covering all aspects of modern astronomy. They are intended for the general public, so assume no prior knowledge of astronomy and they do not contain mathematics. The class on Coursera is called “Astronomy: Exploring Time and Space” and it has 19 h of videos and takes approximately 42 h to complete. Other components of the course are readings, quizzes, projects, and peer-reviewed short writing assignments. The class on Udemy is called “Astronomy: state of the Art” and it has 24 h of videos and takes approximately 36 h to complete. Other components of the course are readings and quizzes. Both courses offer completion certificates.

This study draws from the following data sources:

- Course data provided by Coursera and Udemy,
- Responses for the motivational survey administered to participants of our Coursera MOOC.

For our Udemy course only cursory data on learner’s enrollment and progress (gradebook) were available which did not allow us to conduct in-depth analysis. Therefore, we only report the overall enrollment spike for Udemy and limited additional engagement data. On the contrary, thanks to the detailed Coursera data exports, we were able to obtain geographical information about our users.

The main source of quantitative data in our study was the motivational survey which was distributed to our Coursera learners as a first course assignment, verified by the survey verification quiz. Participation was voluntary. Applications for Human Subjects Research for both the Coursera and the Udemy surveys were submitted in late November 2016, and approved by the University of Arizona Institutional Review Board less than a month later. The project was judged to be exempt and so does not have a continuing review requirement. All MOOC participants could opt out of the survey at any time. If they participated in the survey, no personally identifying information was collected. No reward was offered or given for participation in the survey.

The total sample size was about 23 thousand learners as of June 22nd, 2020, when the dataset was exported. The instrument contained various demographic questions regarding learners age, gender, science background, and occupation. In addition, we asked about their reasons for signing up for the course, and finally we administered the modified Science Motivation Questionnaire II (Glynn et al., 2011). The full instrument contains 36 questions with answers on a Likert frequency scale: never, rarely, sometimes, usually, always. The full questionnaire can be found in the appendix of (Formanek et al., 2019).

For the purposes of our analysis we count active MOOC participants, or users, rather than those who enroll, since the majority of those who enroll never actively participate. For Udemy, an active user is defined as anyone who has made measurable progress through the course material. For Coursera, an active user is defined as someone who completed the survey verification quiz, the first assignment of the course.

This work is a multiple case study adopting a descriptive research design (Yin, 1994). We seek any statistically significant results between groups of learners. These can be either participants of the two MOOCs, those who enrolled at different times (before and during pandemic) or those distinguished by different demographical characteristics (country of origin, occupation). Since the distributions of demographic indicators and responses to the motivation questionnaire are non-parametric, we use the two sample Kolmogorov-Smirnov test (Goodman, 1954) to identify statistically significantly different outcomes. The significance level is indicated for each test.

4. Results before and during the pandemic

This paper investigates course enrollment, learner demographics and learner behavior, before and after the onset of the COVID-19 pandemic. Although we present data for Coursera and Udemy, we focus on Coursera since we only have enrollment data, and limited data on progress and completion, from Udemy. We use a worldwide lens for this study. While a majority of the learners live in the United States, over 180 countries are represented. As for a boundary between pre-COVID time and a time when daily life was altered, a natural demarcation is March 11, 2020, when the World Health Organization declared COVID-19 to be a pandemic. Educational institutions around the world closed rapidly in March as the pandemic took hold (UNESCO, 2020). The China lockdown ran from 24 January to 25 March, but most countries started their lockdowns in a three-week period from mid-March to early-April (Aura Vision, 2020). Lockdowns have eased in most countries at different times through April and May, although they have recurred as parts of the world experienced additional COVID-19 surges in late 2020 and early 2021. For the purposes of the paper, we set the period starting the data after the WHO declaration, March 12, 2020 as the time during the pandemic. The cutoff for data collection is somewhat arbitrary since the pandemic continues. We choose June 19, 2020, which encompassed the enrollment peak and a subsequent decline for both Udemy and Coursera. Therefore, this study is about participation in MOOCs during the first 100 days of COVID-19.

4.1. Enrollments

Most of the people who enroll in any MOOC do not complete the course. Reasons most often given are that they are too busy or that the course takes too much time (McLeod et al., 2015; Reich & Ruiperez-Valiente, 2019). For the Udemy course, over the three years from January 2017 to the end of December 2019, an average of 840 enrolled in the course per month. In 2020, the approximate numbers that enrolled in the first five months of the year were 860, 720, 1590, 10820, and 2600. On Udemy, the enrollment surge was concentrated in April, the first full month of layoffs and the lockdown in most countries. Adopting the normal spring enrollment baseline of 840, the extra enrollment from March to May was 12,490. During those three months, 83% of all those enrolled were associated with the pandemic. Enrollments in Coursera also showed a surge by more than a factor of ten

relative to the previous few years, but the timing was slightly different. An average of 1100 people enrolled per month from January 2017 to the end of December 2019. In the first five months of 2020, approximate numbers that enrolled were 1310, 1040, 4360, 16740, and 13980. Coursera's enrollment surge continued for longer than Udemy's. Adopting the normal spring enrollment baseline of 1100, the extra enrollment from March to May was 31,780. During those three months, 91% of all those enrolled were associated with the pandemic. This means that the 100 days under study can be assumed to be composed of learners whose participation was triggered by the unique circumstance of COVID-19. Fig. 1 shows the daily new active users during the first 100 days of the pandemic.

New active users since the inception of the Udemy course are plotted in Fig. 2. New active users since the Coursera cohort version of the course started are plotted in Fig. 3. In both MOOCs, a dramatic surge in active users is seen as the pandemic started.

4.2. Demographics

To learn about the demographics of people enrolled in the Coursera MOOC, we have been administering an optional survey as they start the class. After the start of the pandemic approximately 28.1% of enrolled learners completed the survey, and this number was significantly lower before the start of the pandemic at 18.7%. The first results from this survey have been published by Formanek et al., (2019). We see a substantial increase in the college-age population, ages 18 to 30, relative to the situation before the pandemic (Fig. 4). There is also an increase in the fraction of learners who have a high school education, some college education, or a bachelor's degree, relative to those who have more advanced degrees (Fig. 5). A third of the MOOC learners hold bachelor's degrees, another quarter are in high school, and less than one in six have an advanced degree. Both differences are highly significant, at $p = 0.001$ significance level measured with a Kolmogorov-Smirnov two sample test.

Gender balance did not change significantly through the first half of 2020. Learners are split 55% male and 45% female throughout the long history of this MOOC. There is a small, but highly significant at the $p = 0.001$ significance level difference in the number of previous science classes, with the mean number slightly lower during the pandemic. Overall, this astronomy MOOC was the first for a third of those enrolled, another third had taken one to four previous classes, and about one in five had taken ten or more previous classes. Table 1 gives the breakdown of self-reported occupations. The data show a substantial change as the pandemic started, with a higher than average increase in full-time students and unemployed learners and a lower than average increase of professionals in any fields (science, engineering, computers or software, law, business, and medicine). Full time students constitute the majority of those who enrolled in the COVID-19 surge.

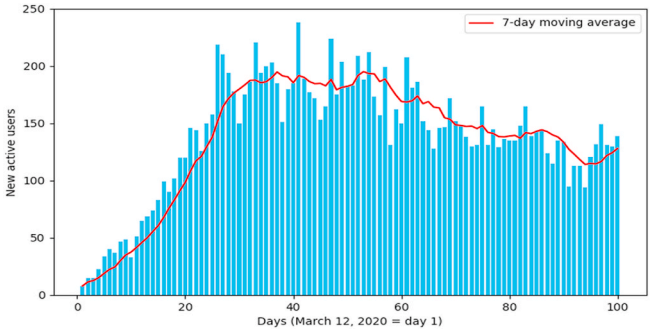

Fig. 1. New daily active users in the Coursera MOOC "Astronomy: Exploring time and space".

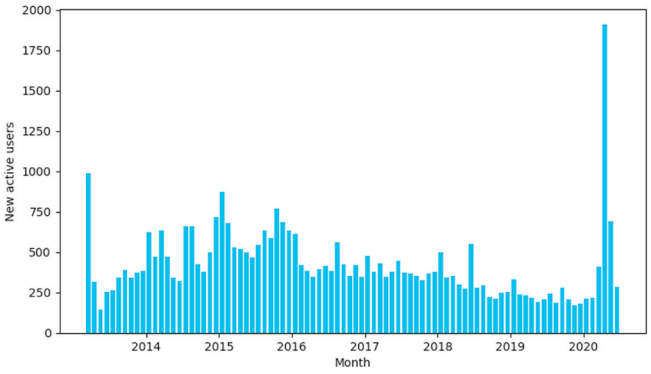

Fig. 2. Monthly new active users in the Udemy "Astronomy: State of the art" MOOC.

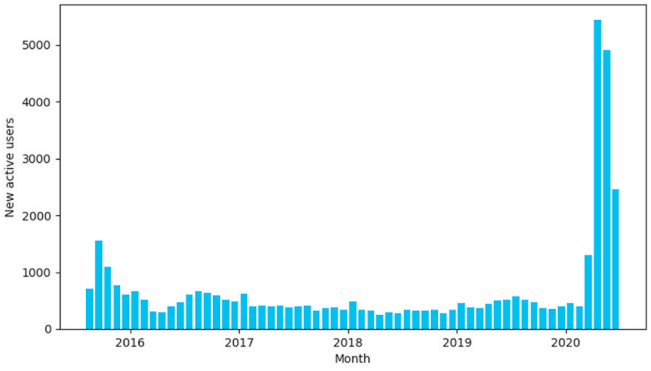

Fig. 3. Monthly new active users in the Coursera "Astronomy: Exploring time and space" MOOC.

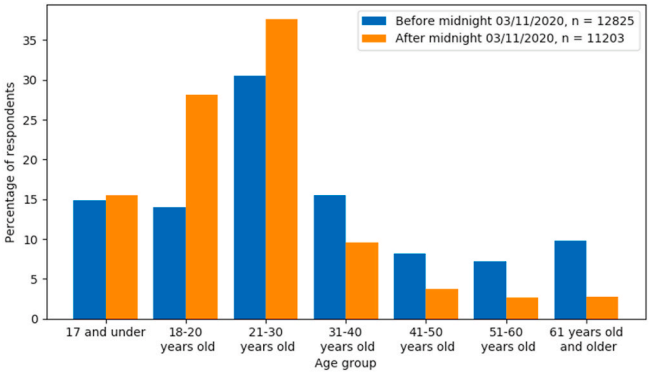

Fig. 4. The age distribution of survey respondents in the "Astronomy: Exploring time and space" MOOC.

4.3. Geographics

Massive open online classes have had an international reach from their inception. The two MOOCs described in this paper are very international. The Udemy course has learners from 182 countries, representing 81 languages. The top ten countries represented over the history of the course are: U.S. (35%), India (12%), U.K. (6%), Australia (4.7%), Canada (4.1%), Egypt (2.8%), Brazil (2.3%), Germany (2.1%), Turkey (2.1%), and Mexico (1.3%). The Coursera course has learners from 170 countries; the top ten over the history of the course are: U.S. (23%), India (20%), U.K. (3.9%), Brazil (3.6%), Canada (3.4%), Mexico (2.5%), Russia (2%), Egypt (2%), Germany (2%), and Spain (1.9%). In Table 2, we show the countries of MOOC participants ordered by the ratio of

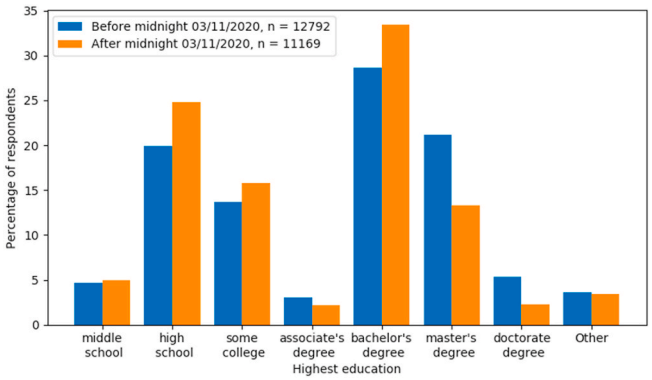

Fig. 5. The education level of survey respondents in the "Astronomy: Exploring time and space" MOOC.

Table 1
Occupations of survey respondents in the "Astronomy: Exploring Time and Space" MOOC.

Occupation	Before midnight March 11, 2020	Rate per month	After midnight March 11, 2020	Rate per month	Rate ratio
Full time student	3940	71.18	5894	1797.77	25.26
Unemployed	916	16.55	946	288.55	17.44
All	**12783**	**230.93**	**11162**	**3404.61**	**14.74**
Educator (school/ college)	945	17.07	648	197.65	11.58
Service/retail	426	7.70	258	78.69	10.23
Work at home	367	6.63	222	67.71	10.21
Other (please specify)	1507	27.22	861	262.62	9.65
Professional (science/ engineering)	1375	24.84	775	236.39	9.52
Managerial/ business	951	17.18	534	162.88	9.48
Social services	154	2.78	76	23.18	8.33
Professional (law/ medicine)	621	11.22	305	93.03	8.29
Manual (agriculture/ construction)	111	2.01	54	16.47	8.21
Clerical/ administrative	327	5.91	140	42.70	7.23
Technical (software, computers, etc.)	1143	20.65	449	136.95	6.63

their active participants in the months before the pandemic to the months after the pandemic started. Only those countries with more than 50 active learners are counted.

The overall increase in is a factor of nine, but there is wide variation in the level of increase. Notably, the increase in the top-ranked country for enrollment, the U.S., was a factor of 4.2, while the increase in the second-ranked country, India, was almost seven times higher, a factor of 27.8. This surge vaulted India to the most heavily represented country during the pandemic. It is noticeable that the countries with the biggest increase in enrollment are developing countries, particularly in Asia, while the countries below the average level of increase are Western or industrialized countries. To explore this phenomenon in more detail, for each country we considered measures of mean wealth per capita (Credit Suisse, 2019), and the percentage of individuals having Internet access (World Bank, 2020). The variables that dictate enrollment in a MOOC are undoubtedly complex, and they may depend on culture and location, so this is just an exploratory analysis.

Figs. 6 and 7 show the relationships between surge in active users (the ratios listed in Table 2) and mean wealth, and the surge in active users and Internet connectivity. They both illustrate statistically significant correlations. In Fig. 6, higher enrollment surges are associated with countries having low mean wealth, at $p = 0.001$ confidence level. The associated correlation coefficient, Pearson's r, is -0.40. All but one of the two dozen wealthiest countries show a lower than average rise in participants, whereas all but two of the dozen poorest countries show a higher than average rise in participants. Also, in Fig. 7, higher enrollment surges are associated with countries having lower percentages of the population with Internet connection, at $p = 0.001$ confidence level. The associated correlation coefficient, Pearson's r, is -0.62. The countries with the eight lowest levels of Internet connectivity all show higher than average increases in participants. Internet connectivity and wealth also are weakly correlated, but that relationship is not shown here. The data imply that people in poorer countries were seizing the opportunity to learn using the Internet, despite their connectivity challenges.

4.4. Motivations

In earlier work, we explored the motivations of those enrolling in an astronomy MOOC (Formanek et al., 2019). We revisit this analysis in the context of the pandemic-related surge in enrollment. In response to the question "Why did you sign up for this course?" participants could choose among seven answers, plus "other." Pre-COVID, the top two answers given were "interest in astronomy" and "it was free." The response "to earn a certificate" came a distant fourth, over ten times less frequently cited than "interest in astronomy." During the pandemic, "to earn a certificate" saw a large boost, two times larger than any other response. Participants could also choose, from a list of 26, the top five reasons they took the class. Pre-COVID, the top two answers both reflect non-vocational approach to learning: "because it satisfies my curiosity" and "I'm not an expert but I like to learn about things." During the pandemic, those were still numerically the two most popular reasons, but vocational reasons got biggest boosts: "this will help me get ahead on my career," "this course will help me achieve my career goals," and "I'm hoping to work someday in this area."

A more nuanced exploration of learner motivations comes from the survey that asked them to rate the applicability of 36 statements, on a scale of never, rarely, sometimes, usually, and always. The survey instrument was a modified form of one that has been validated in a research setting (Barak et al., 2016; Glynn et al., 2011). In our previous work (Formanek et al., 2019) we showed that based on factor analysis of the responses, we can distinguish the following motivational categories with a high degree of internal consistency:

- Astronomy Hobby motivation,
- Career motivation,
- Grade motivation,
- Intrinsic motivation,
- Self-determination,
- Self-efficacy,
- Social motivation.

During the pandemic, the top four most significant increases were for career motivations, and 11 out the 13 most significant increases were for either career or social motivations (see Table 3). In this table the change is denoted by D = decrease, I = increase, and N = no change. By contrast, all of the self-efficacy motivations saw a decrease or were unchanged, and a majority of the astronomy hobby and intrinsic motivations also saw a decrease or were unchanged. When looking at the students alone, the only motivation that increased was social. These patterns show that the "surge learners" are quite different from normal learners in an astronomy MOOC, who are driven by curiosity and a prior interest in the subject.

Table 2
Ratio of enrollment rate increase in the "astronomy: Exploring time and space" by country.

Country	Total Enrolled	Before midnight March 11, 2020	Rate per month	After midnight March 11, 2020	Rate per month	Rate ratio
Bangladesh	501	104	1.88	397	121.09	64.45
Thailand	332	72	1.3	260	79.3	60.97
Tunisia	65	20	0.36	45	13.73	37.99
Philippines	475	168	3.03	307	93.64	30.85
India	8416	3180	57.45	5236	1597.07	27.8
Nepal	121	49	0.89	72	21.96	24.81
Sri Lanka	109	48	0.87	61	18.61	21.46
Pakistan	395	180	3.25	215	65.58	20.17
Kazakhstan	74	34	0.61	40	12.2	19.86
Ecuador	83	40	0.72	43	13.12	18.15
Nigeria	80	39	0.7	41	12.51	17.75
Indonesia	226	114	2.06	112	34.16	16.59
Morocco	91	50	0.9	41	12.51	13.85
Malaysia	163	91	1.64	72	21.96	13.36
Turkey	452	260	4.7	192	58.56	12.47
Colombia	582	336	6.07	246	75.03	12.36
Saudi Arabia	135	80	1.45	55	16.78	11.61
Singapore	380	226	4.08	154	46.97	11.51
Egypt	483	296	5.35	187	57.04	10.67
Lebanon	61	38	0.69	23	7.02	10.22
Viet Nam	82	52	0.94	30	9.15	9.74
Peru	104	66	1.19	38	11.59	9.72
UAE	268	174	3.14	94	28.67	9.12
All countries	**40092**	**26115**	**471.77**	**13977**	**4263.23**	**9.04**
Mexico	943	623	11.25	320	97.61	8.67
Romania	210	141	2.55	69	21.05	8.26
Argentina	245	165	2.98	80	24.4	8.19
Serbia	60	41	0.74	19	5.8	7.82
Italy	412	284	5.13	128	39.04	7.61
Bulgaria	53	37	0.67	16	4.88	7.3
Ukraine	235	165	2.98	70	21.35	7.16
Germany	747	535	9.66	212	64.66	6.69
Costa Rica	78	56	1.01	22	6.71	6.63
Chile	226	165	2.98	61	18.61	6.24
Portugal	150	110	1.99	40	12.2	6.14
Canada	1560	1160	20.96	400	122.01	5.82
Brazil	1111	839	15.16	272	82.96	5.47
United Kingdom	1857	1403	25.35	454	138.48	5.46
Ireland	180	136	2.46	44	13.42	5.46
Norway	60	46	0.83	14	4.27	5.14
Russia	627	482	8.71	145	44.23	5.08
Hungary	111	86	1.55	25	7.63	4.91
Switzerland	143	111	2.01	32	9.76	4.87
France	520	405	7.32	115	35.08	4.79
Israel	262	205	3.7	57	17.39	4.69
South Africa	213	167	3.02	46	14.03	4.65
Hong Kong	194	153	2.76	41	12.51	4.52
Poland	235	186	3.36	49	14.95	4.45
Austria	83	66	1.19	17	5.19	4.35
New Zealand	157	125	2.26	32	9.76	4.32
USA	10329	8261	149.24	2068	630.78	4.23
Australia	794	637	11.51	157	47.89	4.16
Spain	865	695	12.56	170	51.85	4.13
Croatia	83	67	1.21	16	4.88	4.03
Japan	166	134	2.42	32	9.76	4.03
Netherlands	500	404	7.3	96	29.28	4.01
Czechia	102	83	1.5	19	5.8	3.87
Greece	306	251	4.53	55	16.78	3.7
Finland	67	55	0.99	12	3.66	3.68
Denmark	87	73	1.32	14	4.27	3.24
Belgium	168	142	2.57	26	7.93	3.09
South Korea	103	89	1.61	14	4.27	2.66
Sweden	130	114	2.06	16	4.88	2.37
Puerto Rico	54	48	0.87	6	1.83	2.11
Taiwan	108	96	1.73	12	3.66	2.11
Belarus	64	57	1.03	7	2.14	2.07
China	323	302	5.46	21	6.41	1.17

4.5. Demography and geography

To refine the analysis, we revisit the demographic and motivation data but looking for differences between the countries with above average enrollment surges (a ratio above 9 in Table 2) and those with below average surges (a ratio below 9 in Table 2). As can be seen in Table 2, almost all of the former group are developing countries, while the latter group includes all the major European and English-speaking countries. All the following differences are significant at a $p = 0.001$ level by a Kolmogorov-Smirnov two sample test. Learners from the

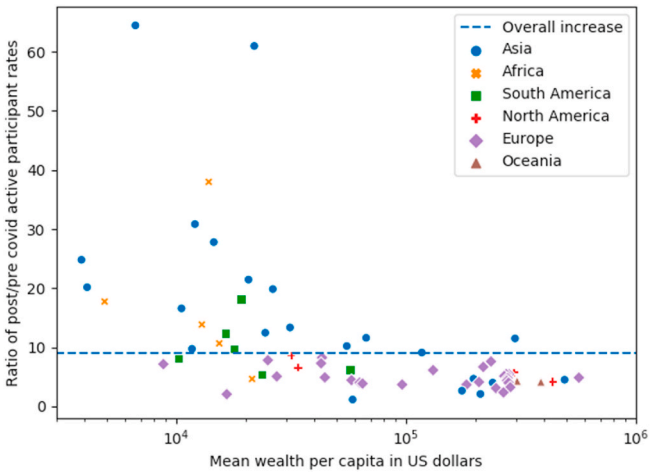

Fig. 6. Active User Enrollment Rate Increase Ratio in "Astronomy: Exploring Time and Space" MOOC vs Mean Wealth per Capita.

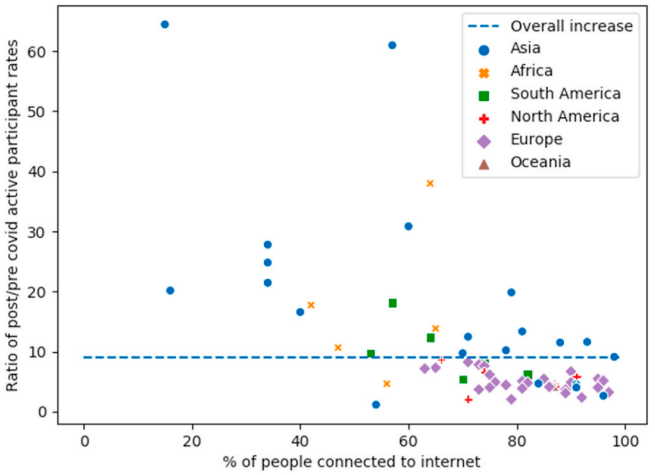

Fig. 7. Active User Enrollment Rate Increase Ratio in "Astronomy: Exploring Time and Space" MOOC vs Internet Connectivity.

countries that surged the most are younger, more likely to be male, and less likely to have advanced degrees or be retired. In countries surging above average, 68% of the learners are full-time students, compared to just 33% in countries with a below average surge. In terms of their reasons for taking the course, learners in the countries that surged the most were more than twice as likely to want to earn a certificate, and less motivated by the fact that the course is free. Similarly, they were more than twice as likely to have career motivations and were less motivated by fun or entertainment. Overall, career and social factors were dominant for people in the countries where the surge was the greatest.

Another way to look at the data is to separate the "high surge" countries (mostly in Asia and/or developing) from the "low surge" countries (mostly Western and/or industrialized) and look for changes in demographics or motivation before and during the pandemic. A clean division between these groups of counties is membership in the Organization for Economic Cooperation and Development (OECD, 2020), a forum of countries committed to democracy and the market economy. Only 2 out of 37 OECD members (Turkey and Colombia, where the latter joined the OECD in April 2020) are in the high surge category; all the rest are in the low surge category. The following changes are all significant at above the $p = 0.001$ confidence level. Learners in both sets of countries were younger and included fewer people with advanced degrees after the pandemic started. High surge countries had

Table 3
Motivation changes during the pandemic.

Question	Motivation category	Change	Statistics	pvalue
Knowing science will give me a career advantage	Career	I	0.124	<0.001
Understanding science will benefit me in my career	Career	I	0.123	<0.001
My career will involve science	Career	I	0.122	<0.001
Learning science will help me get a good job	Career	I	0.117	<0.001
I like to take science classes with my friends/family/club	Social	I	0.110	<0.001
I learn better when I learn science with other people	Social	I	0.086	<0.001
I will use science problem-solving skills in my career	Career	I	0.084	<0.001
I think about the grade I will get in science classes	Grade	I	0.081	<0.001
I want to be able to say that I've taken this astronomy class	Social	I	0.081	<0.001
I want to be able to say that I've taken a science class	Social	I	0.075	<0.001
I like to take science classes to interact with other people	Social	I	0.072	<0.001
I like to do better than other students on science assignments	Grade	I	0.069	<0.001
I like to learn science from a well-known scientist/ professor	Social	I	0.063	<0.001
I have strategies I use to learn science well	Self-det.	I	0.056	<0.001
Getting a good science grade is important to me	Grade	I	0.052	<0.001
I wanted to learn about a particular Astronomy topic	Astr.-hobby	I	0.043	<0.001
I spend a lot of time learning science	Self-det.	I	0.041	<0.001
The science I learn is relevant to my life	Intrinsic	I	0.041	<0.001
I usually put enough effort into learning science	Self-det.	I	0.035	<0.001
I like to learn about science because it interests my friends/family	Social	I	0.030	<0.001
I usually prepare well for science assignments	Self-det.	I	0.026	0.001
I wanted to learn about Astronomy in general	Astr.-hobby	D	0.023	0.003
Astronomy is my hobby	Astr.-hobby	I	0.022	0.006
I believe I can master science knowledge and skills	Self-efficacy	D	0.022	0.006
I am curious about discoveries in science	Intrinsic	D	0.020	0.02
I enjoy learning science	Intrinsic	D	0.020	0.02
I believe I can earn a high score in a science course	Self-efficacy	N	0.017	0.08
I usually study hard to learn science	Self-det.	N	0.017	0.07
It is fun to learn about science	Intrinsic	N	0.016	0.11
Learning science is interesting	Intrinsic	N	0.013	0.31
I enjoy learning Astronomy	Astr.-hobby	N	0.011	0.51
I am sure I can understand science	Self-efficacy	N	0.009	0.71
I am confident I will do well on science assignments	Self-efficacy	N	0.008	0.83
It is fun to learn about Astronomy	Astr.-hobby	N	0.008	0.87
Learning Astronomy is interesting	Astr.-hobby	N	0.007	0.91
Learning science makes my life more meaningful	Intrinsic	N	0.006	0.98

approximately 60% male learners both before and during the pandemic, while for low surge countries the gender balance shifted from 55% male before the pandemic to 45% male after it started. Both groups of countries added learners who were students or unemployed through the pandemic, but the high surge countries also added educators. The fraction of learners motivated by a certificate increased by more than a factor of two all countries as the pandemic started, but at all times it was more important for learners in the high surge countries.

4.6. The special case of China

A comment should be made about one country that is anomalous in the data: China. Over the entire history of the course, China ranks 13th among 180 countries, just behind Turkey, a developing country with 17 times fewer people. During the pandemic, Table 2 shows that China had the smallest increase in enrollment among 62 countries with enrollments over 50. Its enrollment during the pandemic ranks 54th. The comparison with India is striking. They are developing countries with almost identical populations. India added 58 learners per month pre-COVID and 1576 per month during the pandemic. China added 5 learners per month pre-COVID and 6 per month during the pandemic. While it's true that China did its lockdown for two months before the rest of the world, the absolute numbers are very low. The probable explanation is that China has been rapidly developing MOOCs using its own providers (Zheng et al., 2018). According to press reports from the Chinese Ministry of Education, the country has 20 MOOC providers offering 15,000 courses and reaching 270 million learners (Bowden & Shah, 2019). India, by contrast, has a relatively under-developed online education sector, with about 10 million learners. Only 25% of its population is enrolled in higher education, and there is a large, unsatisfied demand from lower income groups and those outside urban areas (Lau et al., 2020). The demographics of the learners from India was predominantly "full-time student" so it is possible that our course supplemented online offerings of the Indian higher education institutions after the lockdown started.

5. Online education during a global health crisis

Many lives have been lost, and many more greatly disrupted, by COVID-19 as it swept across the world during 2020. A rare shaft of light in this gloomy landscape has resulted from the fact that enforced isolation has given people more time for recreation of various kinds. Schools and colleges were scrambling to take their classes online, but the MOOC providers have been offering online classes for nearly a decade and their infrastructure was scalable enough to handle the extra demand. The capability to learn any subject without constraints of time or space is an unquestionable benefit of living in the continuing age of the Internet (nternet Live Stats, 2020).

Udemy issued a report documenting a surge in global online learning as the pandemic hit (Udemy, 2020b). In a month, they saw 425% enrollment growth from individuals, an 80% increase in use by businesses and governments, and 55% growth in new course creation. Surges in India, Italy, and Spain were coincident with orders to shelter in place. The biggest enrollment growth was seen in courses for technical skills like neural networks, courses for soft skills such as communication, and courses for hobbies and recreation. Coursera had 10 million enrollments in a 30-day period starting in mid-March, up 640% from last year. They responded to the pandemic by providing free access to their university partners for 3800 courses and 500 specializations and giving free certificates for certain courses, including the one reported here (Coursera, 2020b). All the major providers of MOOCs saw an increase in traffic of over 50% (Shah, 2020b).

Even before the global pandemic hit in early 2020, online education was growing rapidly and it was delivering high quality instructional content to audiences worldwide. In less than a decade, MOOCs have reached 380 million people worldwide. There is a steady trend towards credentials, for-credit classes, and even full degree programs. If MOOCs can offer more tertiary education, they could make a big impact on economic development. Higher levels of education correlate with higher earnings all across the OECD (Card, 1999). In the United States, with education beyond a Bachelor's degree, the gain in earnings is 90% (Autor, 2014). Presently, the global participation rate is low. The number of people continuing to post-secondary education has grown from 100 million in 1970 (or 3% of the world population) to 725 million in 2015 (or 10% of the world population). That leaves 700 million children without access to higher education, mostly in developing countries (Wittgenstein Center, 2015). Projections suggest a worldwide demand for higher education of two billion people by 2060 (Roser & Ortiz-Ospina, 2018).

Research on MOOCs from Coursera illuminates the reasons people take these classes, and how they perceive the benefits. Half have a primary goal of improving their current job or finding a new job (Zhenghao et al., 2015). They are classified as "career builders." Nearly 90% of the career builders reported benefits from taking a MOOC. The surge in our astronomy MOOC is disproportionately composed of these career builders. MOOC enrollees are well-educated adults in developed countries, who are expected to derive the most benefits from MOOCs. However, these data suggest a different, and more interesting, conclusion. In rich countries, career builders with low socioeconomic status and lower levels of education report tangible career benefits at the same rate as those with high status and a high level of education. But in developing countries, people with lower socioeconomic status and lower levels of education are *more* likely to report career benefits.

Another study of a different set of Coursera MOOCs compared learners who were unable to afford a formal education to a larger comparison sample. Although less well-educated, the financially challenged students earned certificates of distinction at a higher rate than students in the comparison sample (Dillahunt et al., 2014). Another study was the first to include multiple MOOC providers in the developing world (Garrido et al., 2016). Low- and middle-income populations make up 80% of these MOOC learners, in contrast to users in the U.S. and Western Europe. Despite lower levels of education, half the participants in developing countries received a MOOC certification, and another third completed the course, far higher than the single digits reported in the United States. Women are more likely than men to get a certification or complete the course. This is generally true for MOOCs in STEM subjects (Jiang et al., 2018). These results suggest that as MOOC credentials become more formalized and widespread, these online courses can play an important role in advancing the status of women and more generally advancing in developing countries.

Turning to the implications of our study, the answer to our research questions are that adults, particularly in developing countries, seized on an existing opportunity to learn about the subject of astronomy, and they were disproportionately motivated by professional advancement. This study has limitations in that it is only based on two MOOCs, and the subject is astronomy, which is a pure science with no immediate practical benefit. Astronomy MOOCs will not illuminate the motivations of the many people who might be using online learning to advance economically. Future research would benefit from interviews with course completers, to learn what they got from the course and whether astronomy is a particular interest or part of a general interest in online learning.

More broadly, MOOCs have received particular attention as an educational vehicle in developing countries (Dewar et al., 2014; Kanwar & Daniel, 2020). However, delivering access to the least educated citizens has been difficult, due to challenges of infrastructure and sustainability (Castillo et al., 2015). The use of MOOCs to learn a new skill is well-known, but they are also being used to train teachers (Misra, 2018) and researchers (Murugesan et al., 2017). The pandemic has given MOOCs a boost, and in doing so, has highlighted their strength of flexible, scalable online delivery. But it has also revealed their weaknesses, such as a continuing digital divide (Hill & Lawton, 2018), inadequate

digital skills of many adult learners, and the struggle of teachers and learners to adapt to an online environment (Scarpetta and Qunitini, 2020). Even before COVID-19, attention was being given to ways that online learning could help adults worldwide to be more resilient in the face of social upheaval and economic crisis (Gaulee et al., 2020). With the catalyst of the pandemic, the democratizing potential of MOOCs might yet be realized.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Chris Impey: Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Martin Formanek:** Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization, corresponding author.

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