Nanoscribe Publication Analysis 2019-2022

An Interactive Qualifying Project
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WORCESTER POLYTECHNIC INSTITUTE
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Abstract

Worcester Polytechnic Institute has a lab called the Lab for Education & Application Prototypes. In this lab, there is a 3D printer capable of extreme detail and precision and can be used in a wide range of fields from biology, and photonics to chemistry and more. This 3D printer is called a Nanoscribe 3D printer and is a type of nano 3D printer. The vast number of applications that this nano 3D printer can be used is the reason for wanting to explore where this technology exists and what kind of smaller and lesser-known applications this technology is being used for.

This data collection and presentation will be done by using a data mining software called “Publish or Perish 8” and the data will be presented by using a combination of Excel and some excel add-ons to create tables, graphs, and geographic heat maps. As well as using an online word cloud generator to create two word clouds. This data will then be analyzed and conclusions will be made as for the geographic heat maps the countries that are lacking publications will be noted and this can be used to see where this technology should be expanded across the world thus allowing for more discoveries and innovations to occur in this revolutionary field.

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Introduction

The state of Massachusetts started an initiative to bring revolutionary technology and further develop and bring advanced manufacturing systems to Massachusetts (MassTech, 2020). This initiative is known as the Massachusetts Manufacturing Innovation Initiative, and its purpose was to help fund labs that will directly connect with the manufacturing industry to make advancements in manufacturing technology (MassTech, 2020).

This initiative allowed for the creation of many multi-million dollar facilities in Massachusetts that were funded by multiple Manufacturing USA Centers (MassTech, 2020). Manufacturing USA Centers are a series of innovative facilities that have the purpose of enabling experimentation and product development of emerging technologies, these facilities focus on the development of programmable backpacks, developing a circuit that uses light instead of electricity to help improve data centers efficiencies, and extending the range of electric cars (Manufacturing USA, 2020). Now, this relates to Worcester Polytechnic Institute as there is a facility on campus called the “Laboratory for Education & Application Prototypes” or LEAP facility for short. This facility is not limited to Worcester Polytechnic Institute, but to other colleges and universities in Massachusetts. Examples of this include the Massachusetts Institute of Technology, Quinsigamond Community College, Bridgewater State University, and Stonehill College (Worcester Polytechnic Institute, 2022).

These LEAP facilities focus on education and hands-on training about the emerging field of photonic integrated circuit ecosystems and their related fields (Worcester Polytechnic Institute, 2022). To give some background, an integrated photonic circuit is essentially an electronic circuit that uses light and lasers and light-sensitive components. This type of circuit has several benefits such as it is more thermally efficient when used in a data center

(Manufacturing USA, 2020; Synopsys, 2018). The M2I2 initiative had a focus on education and prototyping of photonics, fabrics, robotics as well as flexible electronics, and the reason for focusing on photonics was the reason for the creation of these LEAP facilities like the one located at Worcester Polytechnic Institute (MassTech, 2020). This facility was created to allow communication between students and industry to help train these students on this equipment, which is focused on integrated photonics. These LEAP facilities were funded by the Massachusetts Manufacturing Innovation Initiative, with additional help from AIM Photonics which was funded by the Department of Defense. To create advancements in integrated photonics technology that will lead to revolutionary breakthroughs as well as educate the current and future workforces (Massachusetts Center for Advanced Manufacturing, 2019).

Massachusetts Institute of Technology has its own LEAP facility for its school. This LEAP facility focuses on educating the current and future workforce regarding integrated photonics, while also focusing on packaging the photonic system (MIT News, 2022) with the idea of also guiding the semiconductor industry in the way of integrated photonics (Massachusetts Institute of Technology, 2020). Worcester Polytechnic Institute and Quinsigamond Community College share a LEAP facility on WPI's campus. This LEAP facility compliments MIT's facility, as it aims to train the current and future workforce in integrated photonics, while acting as a place for the industry to collaborate with the two colleges to make advancements in the fields of photonics, and a focus on biomedical photonic based systems (MIT News, 2022), such as medical devices, and nanoscale and microscale prototyping development (Worcester Polytechnic Institute, 2022).

The newest LEAP facility which is located at Western New England University, this LEAP facility is similar to the other 3 facilities, except the primary focus of this facility is on the

testing of integrated photonics (Western New England University, 2022). The last LEAP facility is located at Bridgewater State University and is shared with Stonehill College (Worcester Polytechnic Institute, 2022). This LEAP facility at BSU has a similar purpose when compared to the other 3 LEAP facilities in Massachusetts, this being that this facility is focused on educating the next workforce and current workforce when it comes to working with mid-infrared lasers and quantum-device-based photonics (Bridgewater State University, 2023; MIT News, 2022). Although these three labs are separate from one another they function to help spread the importance of photonics and its future (Worcester Polytechnic Institute, 2022), and the sharing of these valuable labs allows students to have easier access to the technology they will be working with in the future. While also allowing for a closer connection between the students and potential future employers.

At WPI's LEAP facility, there is a 3D printer that is capable of extreme detail. This printer is called a two-photon polymerization (2PP) 3D printer, it is different from normal 3D printers such as an FDM (fused deposition modeling) this style of 3D printer uses a combination of motors to move 3 axes and moves a print head around that contains a heating element that can melt plastic and then dispense it through a fine nozzle this technology will print one layer at a time. The other type of standard 3D printer that a 2PP printer is different from is an SLA (stereolithography) 3D printer.

Instead of focusing on making models down to the millimeter, a 2PP printer focuses on making models that are detailed to the nanometer (Nanoscribe, 2021). This form of fabrication is known as microfabrication, and the technology that allows for the Nanoscribe 3D printer to function is revolutionary.

The Nanoscribe 3D printer is a 2PP printer that is manufactured by Nanoscribe in Germany that can create such precise models that traditional SLA and FDM 3D printers cannot achieve (Nanoscribe, 2021). This is due to the mainstream 3D printer only having a significantly lower precision than the Nanoscribe printer (Formlabs, 2023). For example, the average FDM 3D printer has a precision of 0.5 mm, while the average SLA 3D printer has a precision of 0.1mm (Formlabs, 2023). While compared to the Nanoscribe 3D printer which has a precision of 100 nm (Nanoscribe, 2021). As can be seen, the Nanoscribe 3D printer can create objects with extreme precision that no standard 3D printer is capable of.

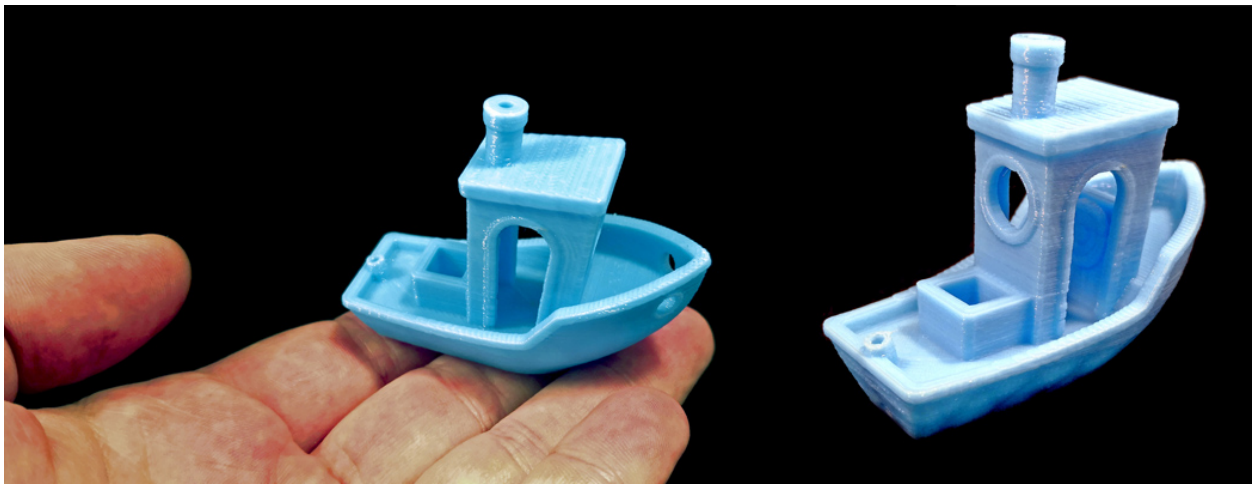

Figure 1: A sample print from a standard FDM 3D printer hand for reference (Edditive Blogs, 2018).

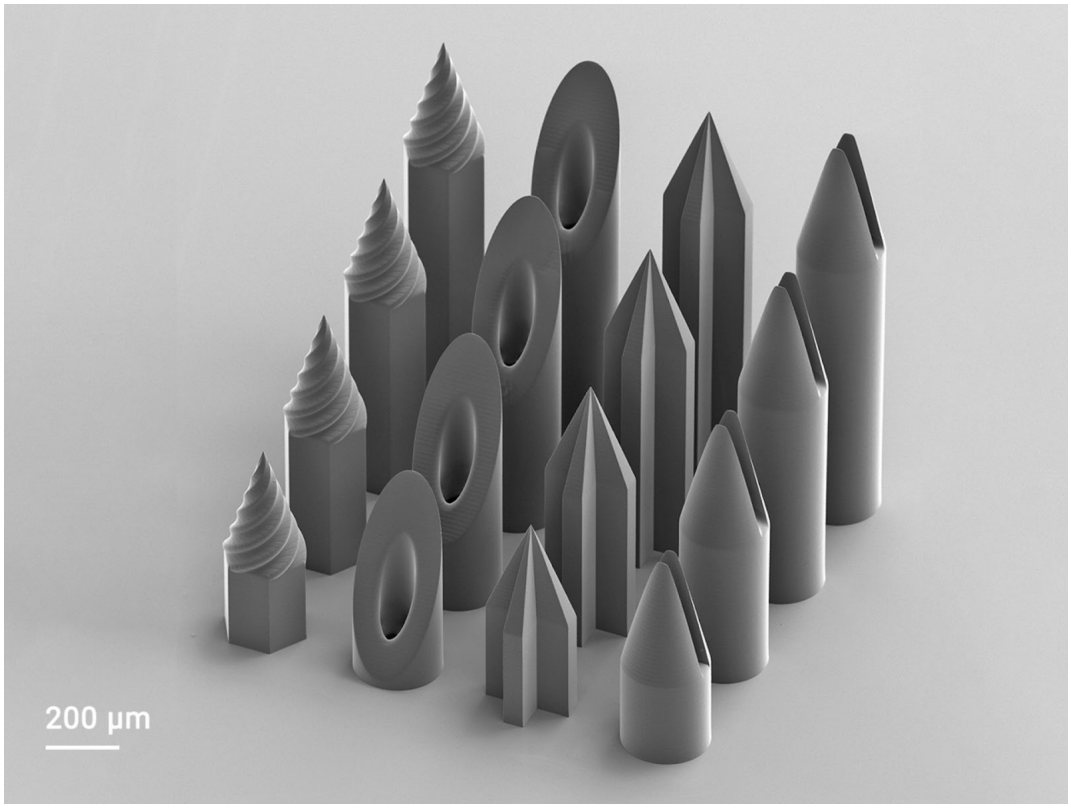

Figure 2: A sample print from a Nanoscribe 3D printer (Wide range of applications in research, 2023)

This technology of microscale 3D printing is changing the landscape of microfabrication. The more traditional styles of microfabrication include, “photolithography, soft lithography, film deposition, etching, and bonding” (Betancourt, 2006). These styles of microfabrication tend to be specialized to make each component. While a 3D printer is capable of creating many different models as compared to the commonly used subtractive manufacturing method when working with microfabrication (Betancourt, 2006). The traditional style of microfabrication was with the use of lithography and a series of chemicals that would remove uncured material, this process is similar to the process of creating a printed circuit board (Betancourt, 2006). While 3D printers at the microscale allow for the use of making complex structures that a normal manufacturing process would be unable to handle creating. WPI providing access to one of these Nanoscribe 3D

printers on campus allows students to get a handle on the potential uses of these microscale 3D printers, while also allowing them to gain experience at the same time.

These 2PP printers are unlike a normal SLA (stereolithography) 3D printer, which typically cannot achieve the same level of detail and precision, 2PP printers use a laser to cure a liquid resin and are capable of achieving a higher level of detail and precision (Kim & Lee, 2019). There are several key differences between these two types of 3D printers that make the 2PP technology more versatile and capable of creating more intricate structures, while some drawbacks such as the price of the Nanoscribe printer.

Figure 3: A picture of the Nanoscribe Photonic Professional GT+ printer at WPI's LEAP facility (WPI LEAP, 2023)

The cost of a Nanoscribe 3D printer is in the realm of $350,000+ (*Nanoscribe Photonic Professional GT2 review,* 2019). Along with the initial cost of the printer alone being very high, the Nanoscribe printer will need to be put into a cleanroom. This is due to the issues with contamination, sensitivity to stray light, and foreign objects such as dust, hair, dirt, and more that

have the potential of interfering with the printer's function. These cleanrooms are controlled environments that have air filters that can filter out dust, airborne microbes, and aerosol particles, which then leave a room that has minimal contaminants (Angstrom Technology, 2016). These cleanrooms come in all different types of classifications, for the case of the cleanroom at Worcester Polytechnic Institute's LEAP facility is a Class 10,000 (Worcester Polytechnic Institute, 2023). The cost of a cleanroom is not cheap by any means, with roughly $10,000-$15,000 for a modular 10'x10' cleanroom (Cappello, 2019). This high price tag for just getting a Nanoscribe 3D printer started is quite difficult for some schools to justify by themselves.

2 Photon Polymerization Printer Operation

2PP printers function similarly to a Stereolithography (SLA) 3D printer. Instead of using a high-resolution display, 2PP printers use a combination of mirrors and lenses to direct the narrow beam of infrared light at a wafer. The laser that the Nanoscribe 3D printer uses has a wavelength of 780 nm and pulses at a frequency of 80 MHz or once per 100 femtoseconds (University of Pittsburgh, 2018). This wafer is also placed on a 3-axis bed that can move perpendicularly to the laser allowing the laser to essentially draw out the object. This function is similar to taking a ballpoint pen and a piece of paper and holding the pen stationary while the piece of paper is moved around under it. The wafer has a layer of infrared reactive resin that will cure once it is exposed to infrared light. After the printer completes each layer, the bed has to move up and get a new layer of resin on it, this is to form the next layer of the object, then the laser will follow its next path and cure the layer. This process will continue until the object is fully created.

The issues with printing at this scale are the issues with cross-contamination of foreign materials, such as dust. This being the case the Nanoscribe printer has to be used and stored in a clean room, which a traditional SLA 3D printer does not need to do this is due to the Nanoscribe printer can print in details of less than a particle of dust, while an SLA 3D printer is unable to do this. Another downside to this technology is it is quite slow, as the hardware that controls the laser on the Nanoscribe is only able to move so fast, and since it must cure the resin 2 photons at a time this causes this process is significantly slower when compared to SLA 3D printing. While SLA 3D printing on the other hand can cure an entire layer at once because it uses a digital display that is similar to the displays found on smartphones. For Nano 3D printing this means it takes a long time for each object to be created, although this process is time-consuming it means each of the objects is created with extreme accuracy and precision.

Nanoscribe 3D printers also use a technique called Galvano scanning, which is a form of 3D printing that uses a high-precision galvanometer mirror to direct a laser beam onto a material (Olympus Life Science, 2018). This allows for a high degree of control over the laser beam, which in turn allows for the printing of highly detailed and precise structures at the nanoscale. Nanoscribe 3D printers are capable of printing structures with feature sizes as small as a few nanometers and a resolution of up to a few tens of nanometers. These printers also use a laser that fires in the terms of 1×10^{-15} of a second. This is called a femtosecond laser, these lasers can output an extreme amount of power but only for a very short period. This laser technology pairs well with the technology in a Nanoscribe printer as with these lasers, there is quite a bit of control over its power input and the time it fires. This allows for the extreme precision that is required to create the objects in these 3D printers.

2PP printer capabilities

The desire for a 3D printer that is capable of creating smaller and smaller objects has skyrocketed over the past few years. The potential uses such as integrated photonics, working with bio-resins, material engineering, microfluidics, micromechanics, refractive micro-optics, diffractive micro-optics, and many more have been increasing at an astronomical rate (Nanoscribe, 2018).

Another key difference is the materials used. Nanoscribe printers typically use a photopolymer resin that is specially formulated to work with the two-photon polymerization process (Baumann & Girgis, 2008). This resin is often designed to have very low viscosity, which allows for high resolution and fine feature size (Baumann & Girgis, 2008). In contrast, normal SLA 3D printers use a wider range of resins that may not be optimized for high resolution and small feature sizes (Formlabs, 2022).

Finally, the size of the structures that can be created is also a major difference. Because of its high resolution and small feature size, a Nanoscribe printer can create structures that are much smaller than those that can be created with a normal SLA 3D printer (Kim & Lee, 2019). This makes Nanoscribe printers ideal for applications such as microfabrication, microelectronics, and biomedicine (Nanoscribe, 2018), where small-scale structures are needed, but at the cost of additional printing times.

The draw for 3D printers that are capable of making smaller and smaller objects. Smaller and more finely printed objects open a lot of doors to parts of biology that have never been explored before such as 3D printing. An example of this would be the creation of micro stents in the medical field. Which allowed them to be used in children with obstructive uropathies (Indirect 4D printing, 2019).

These printers also have the ability to mimic the natural microenvironments of cells (Charbe, 2017). Thus this helps promote cells to grow and can also increase the success rate of tissue repair (Charbe, 2017). Another application of the Nanoscribe printer is the creation of microfluidic objects, these allow for the manipulation of small fluid samples (Mastering and 3D in-chip printing of microfluidic devices from 2D to 3D microfluidics, 2016). This is useful in areas of drug delivery, disease diagnosis, and analysis of cells (Mastering and 3D in-chip printing of microfluidic devices from 2D to 3D microfluidics, 2016).

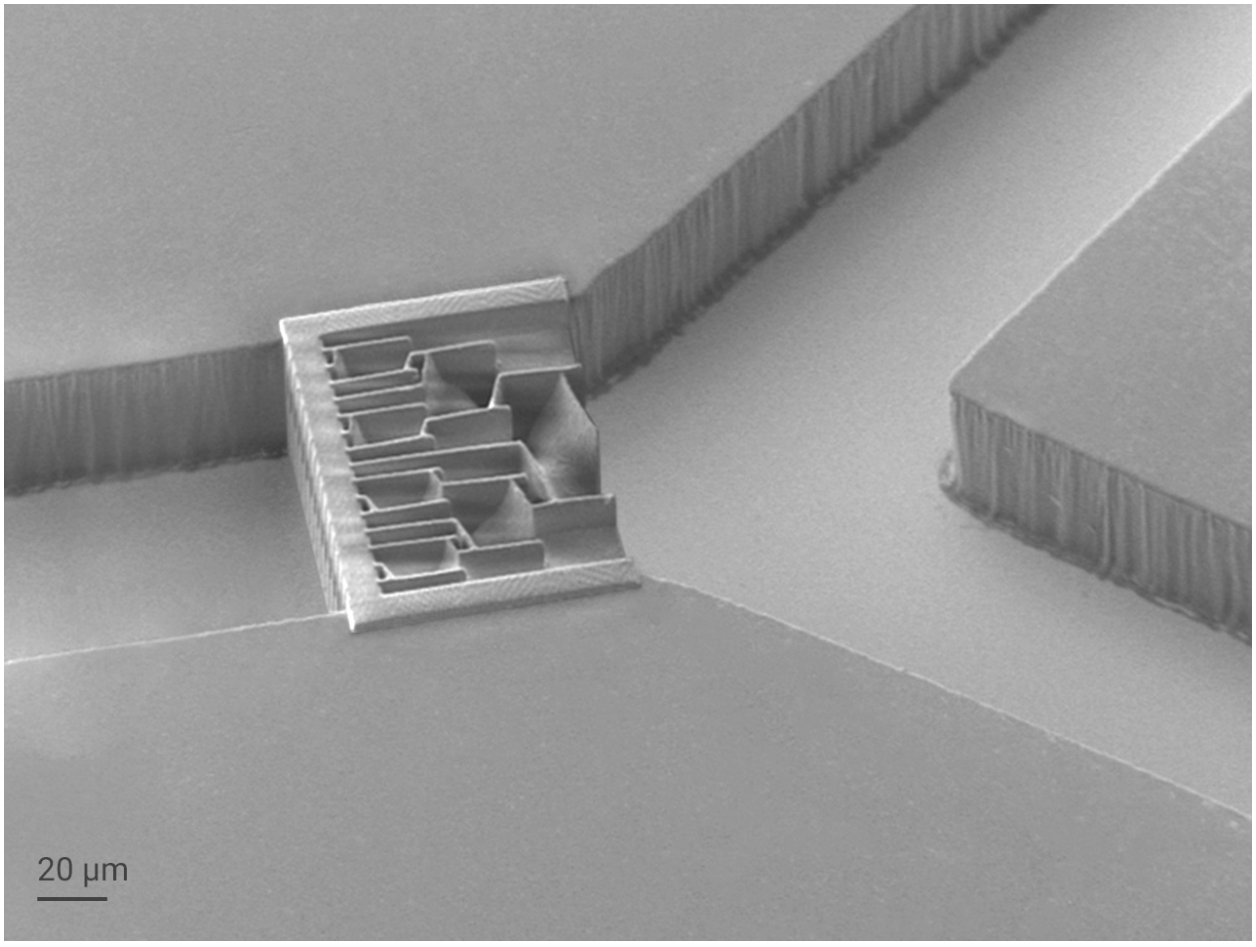

Figure 4: Image of a Microfluidic Mixer made by a Nanoscribe printer (Mastering and 3D in-chip printing of microfluidic, 2022)

The Nanoscribe 3D printer also allows for the creation of microscale optics, such as lenses and gratings (Additively manufactured 3D micro-optics with 3D design freedom, 2018).

These components are essential for the creation of new and more advanced imaging and sensing technology (Additively manufactured 3D micro-optics with 3D design freedom, 2018). Which in turn allows for the growth of cell imaging and biosensing (Charbe, 2017).

Since Nanoscribe is a leader in the field of microscale 3D printing, many publications have been made by using the technology that Nanoscribe provides with their 3D printers. To develop a better understanding of the capabilities of these 3D printers, it was determined the best way to understand some of the capabilities of the Nanoscribe 3D printer was to dive into data mining Google Scholars. There are many different subjects regarding Nanoscribe printers but after observing some of the larger subjects, it was determined that one growing field that would be the focus of this report was regarding "Nanoscribe and Biology" publications. As many of these Nanoscribe printers are used in the field of photonics research. While in reality the capability of these printers is not just limited to integrated photonics. Thus, exploring some of these other topics in this case biology is going to be important to show off some up-and-coming innovations in biology. This leads to the first main question, while these printers have the ability for these applications, how widespread are they?

Aside from the data mining and just presenting tables on the information that was gathered from the years 2019 to 2022, it was determined that making use of geographic heat map tools that are available on Microsoft's Excel to make heat maps of the publications of each of the years, two for each year, one being of the world and the other of the United States of America. There will be a total of 8 geographic heat maps, 4 of which are world heat maps, and 4 being of the USA. These geographic heat maps would allow the question of where are some areas where this innovation is being made and where are some places where these growing fields are missing.

Each one of these heat maps will use a color scale of green to red, green. Green means one publication and red is the maximum number of publications made in that country, and as the number of publications, the shade green will slowly change to red. Other than the heat maps some of the data will be conveyed using word clouds. By using online word cloud generators to show the most common words that were used in all of the titles of the publications as well as the abstracts. This will give a great visual representation of the most common subjects of each of the publications about Biology.

The word clouds show off a visually appealing way to analyze the most commonly used words in each of the subjects, in this case, the titles or abstracts. When word clouds are used for the title it will help highlight some of the primary topics from each of the publications into one easily digestible image. Though word clouds do have a downside which is that the data is very qualitative instead of quantitative, this being the case will justify a frequency table being added in addition to the word clouds to allow the data to be shown quantitatively.

The word clouds revolving around the abstracts is very similar to the word cloud about the titles except that the abstracts tend to highlight some more subsection in each of the publications. This will allow this word cloud to be more meaningful and dive deeper than the other word cloud regarding the titles.

Motivation

The goal of this report is to analyze the current trend with nano 3D printing publications to judge what some of the main fields in biology will be in the future and to analyze the locations of the publications. This will then allow for the potential area where the most valuable publications will be made, this can generally be done by comparing the countries with the

highest number of publications. While the main fields of publications can be judged by the frequency table of the titles and abstracts, which will show off some of the most popular topics in these publications. Before data mining, it was estimated that there were an increasing number of publications throughout the years, and most publications would be made in the United States due to the sheer number of Universities and Colleges this is due to the amount of funding the United States Government provides to these higher education institutions to allow the United States to set the bar for the best technology.

Method

Data mining Google Scholars was determined to be the best way to find a lot of publications regarding Nanoscribe 3D printers and biology. Although there is one issue with data mining Google Scholars. Google uses a program called reCAPTCHA which is a program that prevents bots from interacting and scraping data from the protected site (reCAPTCHA, 2023). This creates issues when it comes to data mining as one can imagine.

This is when a community of data miners on Reddit showed off some of the potential solutions for this reCAPTCHA issue (Flemon, 2018). At first, the use of a custom python script was thought of, except the script would run into issues with the reCAPTCHA blocking the script from scraping the data from Google Scholars. A few individuals claimed that this free software called “Publish or Perish” allows you to scrub through the publications on several scholarly websites (Flemon, 2018).

This software can pull the titles, abstracts, the number of times the publication has been cited, the publishers, and the article URLs this information was then transferred to an Excel Sheet where all the data would be organized. This software was able to shorten the amount of

hand scrubbing significantly, but more information was desired, such as the location of each of these publications as well as the names of Colleges and Universities that published them.

From this, each of the articles had to be visited by following the article URLs that Publish or Perish was able to scrub and then look into the main author of each publication to pin where these publications were made (Harzing, 2016). This process was time-consuming as it took around 2-5 minutes to confirm, compare all of the authors from each of the articles, and ensure the publication information was correct. Below is a list of the information that was collected by Publish or Perish.

- Number of Citations
- Title
- Abstract
- Authors
- Publisher
- Article URL
- Year Published

Although this information is vital to the data needed for this report, the location of these publications is also needed and is not provided by Publish or Perish. Thus, this process is completed by manually skimming through the authors and the location of each publication. This process could be automatically completed by a script if an individual was very familiar with python and data mining scripts. This would make scrubbing through the publications a breeze and would significantly reduce the time spent collecting the data from each of these publications.

Publish or Perish was used to scrub through each year of the publication regarding Nanoscribe and biology starting in 2019 to 2022. Then as stated above manually scrubbed each

document to find which institution and location each publication was made. If the location was anywhere except for the United States, just the country was documented. If the publication was made in the United States then the state was noted as well.

The data was further refined by hand by removing uncited publications with the threshold for each year being set to an arbitrary number, for 2019 being that anything under 10 publications will be ignored, 2020 being 4 or fewer. By 2021 the threshold was 2 or fewer and by 2022 there was no threshold as publications could not have been out for long enough to have any citations be made from them.

This data refinement was able to remove unnecessary articles that the community found less useful as compared to some other articles that drew the attention of the entire community's attention. This means that the more citations a publication had the more this article contributed to further research into the uses that Nanoscribe printers provided in the field of biology.

The thought process behind collecting all of this data was to enable the easy digestion of the locations of these publications and what colleges and universities contribute the most to Google Scholars about Nanoscribe and biology. While looking deeper into articles that are not just published on Nanoscribe's website. This data also can help people understand where Nanoscribe 3D printers might be located. Nanoscribe does not actively publish which colleges and universities currently have one of their printers, but using this data it is obvious for some of these locations.

With the use of this data, it can allow colleges and universities to communicate with one another and help more colleges and universities access one of these Nanoscribe 3D printers as well as allow companies and the government to reach out to these labs in the future make innovations and discoveries in the realm of Nanoscribe and biology. That way they will have the

opportunity to contribute to some of the publications being made and potentially make some discoveries with the printer.

The data collected regarding the locations of each publication allows for the use of a geographic heat map. These heat maps allow for the easy digestion of the location data rather than looking at a frequency table showing which countries had the most publications. These heat maps give a good visual demonstration of that and allow people to easily see which countries are lacking publications. This will then allow companies to explore a list of colleges and universities that have an active community around a Nanoscribe 3D printer and then help create an environment similar to the LEAP facilities in Massachusetts, where companies and students can collaborate to create or work on industry-leading innovations. This data will allow other colleges or universities to collaborate with others and potentially get access to a Nanoscribe 3D printer allowing their students to work with industry-leading equipment.

These heat maps will be created in Excel using a Geographic Heat Map Generator. This add-on in excel requires a frequency table to be created, with the country listed and next to that, the total number of instances that the country created a publication on Google Scholar. The frequency table was created in Excel by using the Countif function followed by the countries' names. For the heat map of the United States, the same tool was used but a new frequency table was used that would track the number of publications by state now. This could then be applied to show which states have no access to these Nanoscribe printers, and the colleges and universities could use this data to help fill in the gaps in Nanoscribe Publications.

Another form of visually showing data is with the use of word clouds as stated earlier. There will be two-word clouds for all of the years, one consisting of the keywords from the titles and the other consisting of the keywords from the abstracts. These word clouds will be generated

via an online word cloud generator called “Word It Out” (Word it Out, 2023). This online software allows the user to plug in the words they want to turn into a word cloud, in this case, it is the titles and abstracts. The software allows the user to filter out certain words that do not pertain to the subject, in the case of the titles and abstracts the words, “Nanoscribe, and Biology” were removed as they were determined to not be relevant to the word cloud. The interest was instead on some of the subjects that are grazed over in the word clouds rather than just the mentioning of Nanoscribe and biology.

These word clouds can also be studied by paying attention to some of the smaller words that were occurring in the word clouds. As some of these words could be up-and-coming revolutions in the microfabrication and biology industry.

Along with the word clouds, it was determined that creating a series of histograms based around the names of the schools that made publications during the years 2019-2022 would be beneficial to showing off some of the primary locations and schools that were making these publications. The histograms were created by using Excel and the included histogram chart tool. First, a frequency table had to be created with the names of each of the schools that were listed next to each publication.

At this point, the COUNTIF() function was used that will count how many instances there were of a school in this case. From this the duplicates of the institutions’ names had to be removed, luckily Excel has a convenient tool that is able to remove any duplicate names of the schools to the data getting skewed from having a school written down more than once.

One other way of conveying the data that was collected throughout this study is the use of a frequency table that will complement the word clouds. As the issue with word clouds is the data presented is strictly qualitative which is not easy to digest accurately. The solution to this is

by using a frequency table that will show off the words of interest and the number of instances in either the title or the abstract. These frequency tables were created the same way as the frequency tables for the countries, states, and institutions. Except, this frequency table needed the use of a different variation of the COUNTIF() function on Excel. This variation was "COUNTIF(range, "*optics*") this was done because excel has to search a series of words in each title for the word in question and this function allows it to do so.

There are a few concerns that came up when data collection was occurring, such as is there enough data points to be able to justify coming up with a reasonable conclusion or would this small data set not be representative of nano or micro 3D printing as a whole. The table below shows some of the different values for the number of publications over the 4 years for different subjects that pertain to the subject of this report, Nanoscribe, and Biology.

Subject	Number of Publications (2019-2022)
3D printing	113,000
3D printing and Biology	20,100
3D printing, Biology and Micro	16,300
3D printing, Biology and Nano	15,500
3D printing and Nanoscribe	981
Nanoscribe and Biology	528

Figure 5: Number of publications for different subjects over the years 2019 to 2022

The table above shows how this report regarding Nanoscribe and Biology publications is only a very small portion of the total number of publications regarding 3D printing, Biology, Micro and Nano 3D printing, and Nanoscribe publications. This being the case, this report focuses on a very niche group of publications in an attempt to get an estimate for the whole community of micro and nano 3D printing as a whole. Although this report focused on such a small group of publications it could be easily scaled up to get a picture for the spread of publications for more broad publications. This could be done with the use of a python script to

pull the location information from each publication and put the data into an Excel document, which would then allow for a heat map to be created. These heat maps would then give a better look as to what countries are lacking publications and how they could potentially give students in those countries access to one of these pieces of technology that is capable of micro or nano 3D printing.

These word clouds and heat maps are great for helping judge what the dataset is mainly about and where the locations of the publications were made. Thus, making the data easier to comprehend and understand. As stated previously this data allows colleges and universities to allow their students to have a chance to use a revolutionary piece of microfabrication that will play a role in everyone's life in the future. As well as giving this opportunity to companies that are looking to work with the next workforce or work on prototypes that will innovate their industry.

Results

Publication Table

Year	Raw Number of Publications	Citation Thresold	Refined Number of Citations
2019	176	10	102
2020	122	4	52
2021	125	2	73
2022	105	0	105
Totals	528		332

Figure 6: Table of Number of publications per year before and after citation threshold

The table above compares the total number of publications per year on Google Scholars along with the threshold for the total number of citations for each year. As can be seen the year 2019 saw the most number of publications at 176 total publications. Although there were a lot of

publications made during that year, some of these were not validated and helpful to the scientific community. This was judged by the total number of times the publication has been cited in other publications. This was set to be 10 as stated previously for the year 2019. This was to help remove the publications that were not as important to the scientific community.

The next year 2020 saw a total of 122 publications, the determined threshold for this year was determined to be 4 citations, this is due to the scientific community having time to validate some of these publications, of these 122 publications only 52 surpassed the set threshold. For the year 2021, a total of 125 publications were made and this led to the citation threshold being 2 citations. This is due to the scientific community not having a lot of time to reflect on and use these publications in their research. After the citation threshold, only 73 publications were determined to be validated by the scientific community.

The final year of this study 2022 saw a total of 105 publications made, but since this year just came to a close as of the time this report is being written the citation threshold had to be set at 0, because the scientific community has not had enough time to validate these publications. This meant that all 105 publications were put into the heat maps and word clouds as well as the histograms in this report. This may cause issues with some of these publications not holding up to the scientific community in the future, thus it might throw off some of the data for this report.

Heat maps

World Heat Map 2019 to 2022

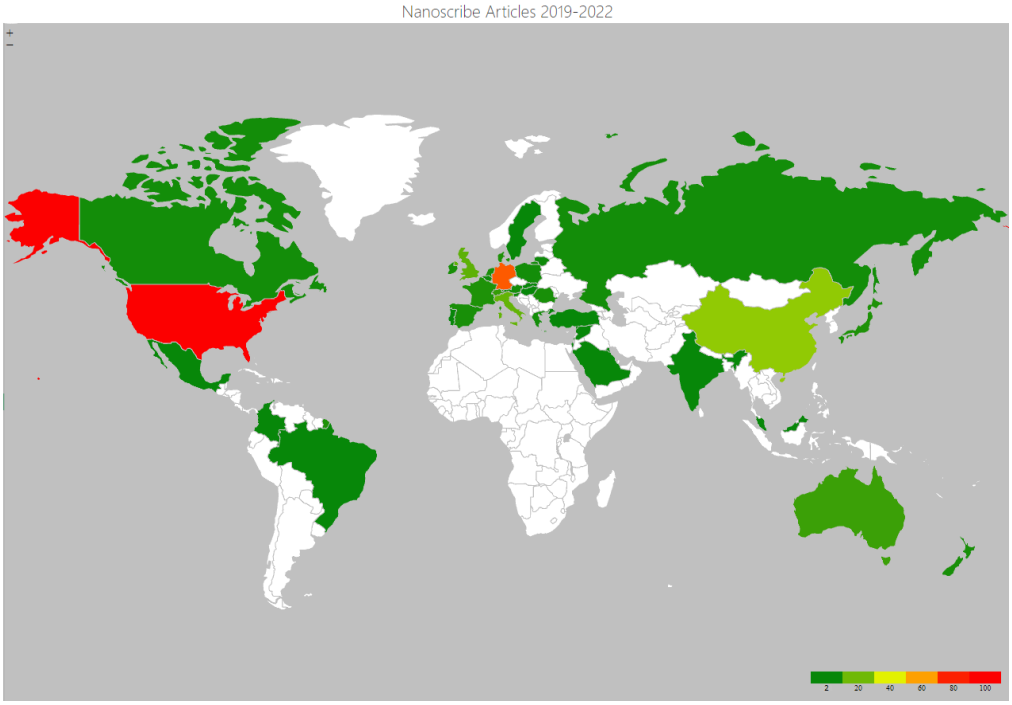

Figure 7: Heat map of the World 2019-2022

World Heat Map 2019

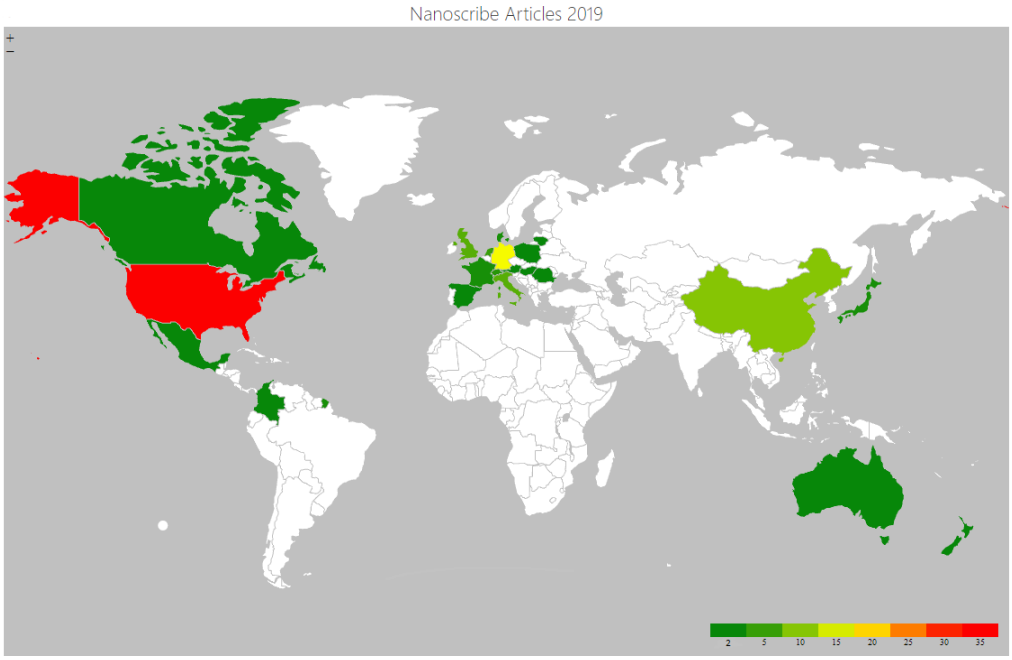

Figure 8: Heat map of the World 2019

World Heat Map 2020

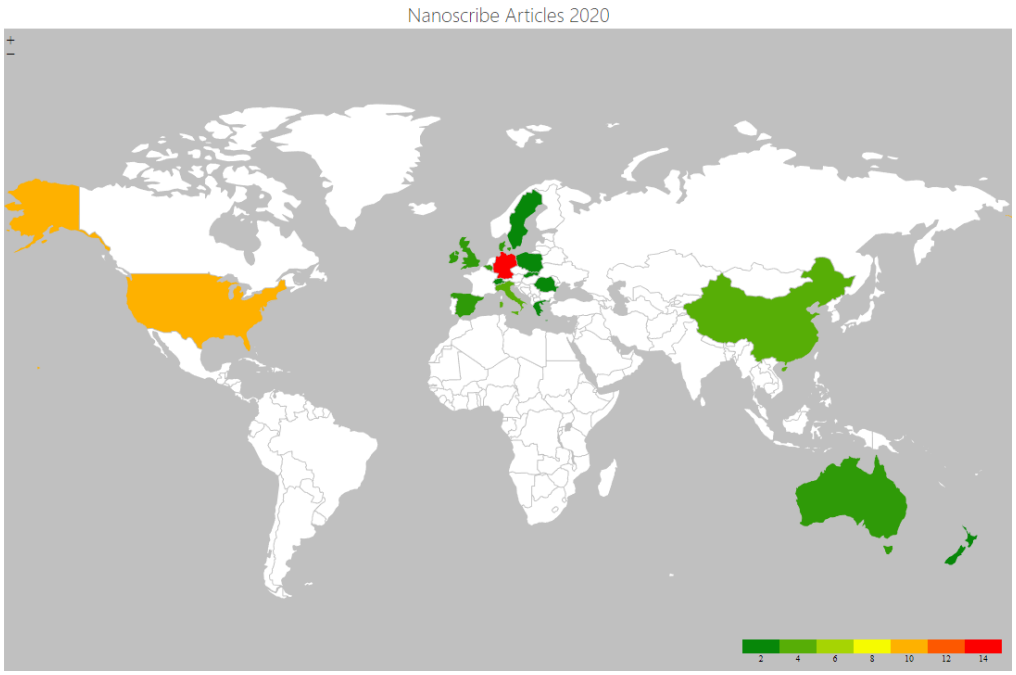

Figure 9: Heat map of the World 2020

World Heat Map 2021

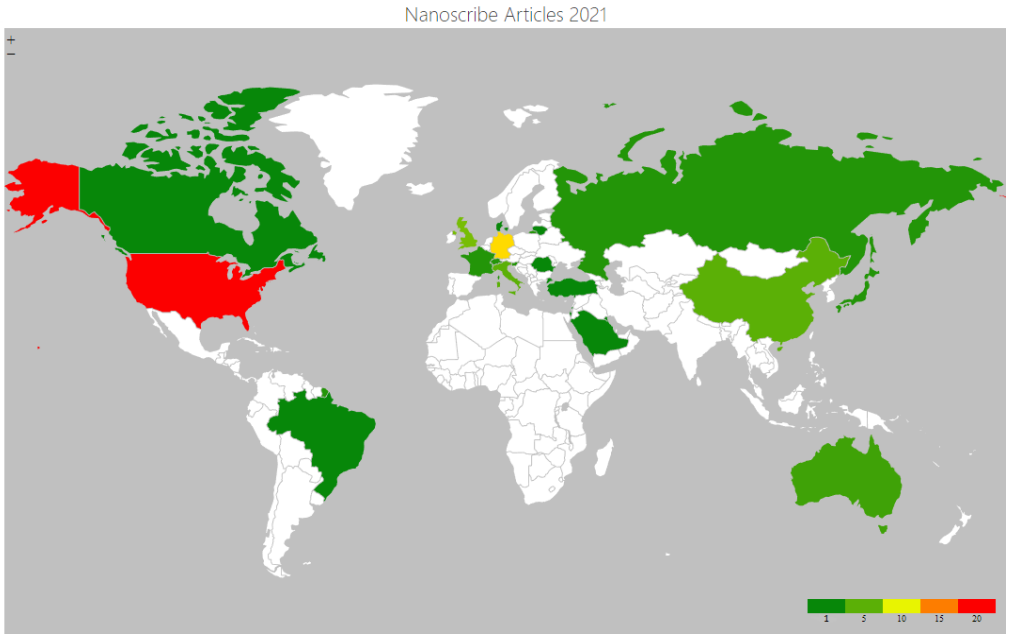

Figure 10: Heat map of the World 2021

World Heat Map 2022

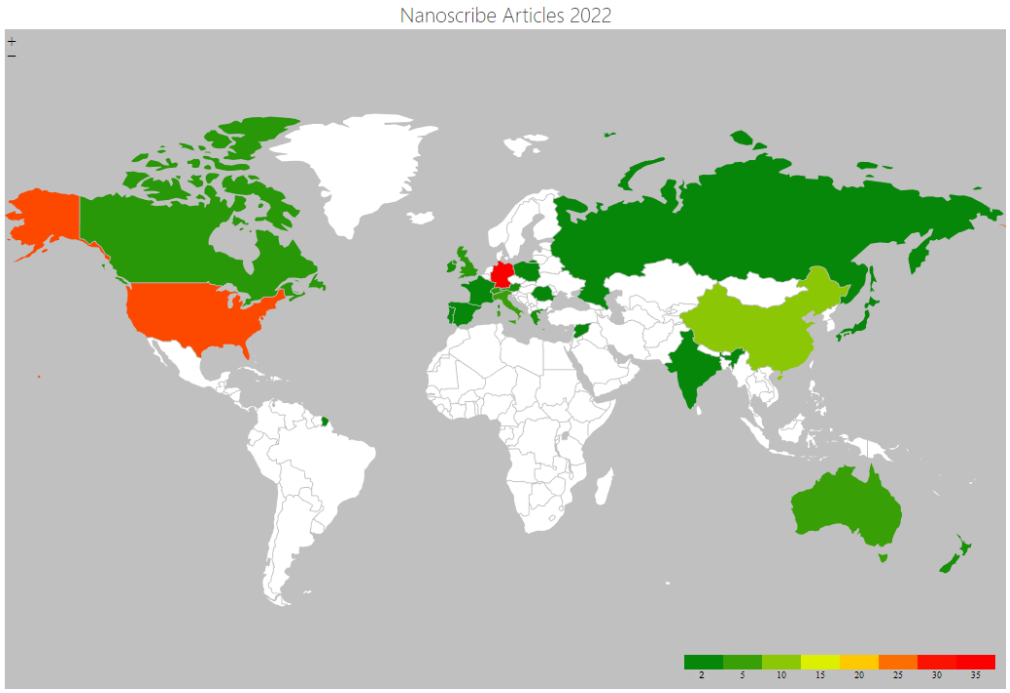

Figure 11: Heat map of the World 2022

World Heat Map 2019-2022 Continued

The heat map above is with all of the data points combined from every year in this study. As can be seen, the United States and Germany still have the most number of publications throughout the years of this study. The United States during this time had a total of 84 publications, while Germany during this time had 70 total publications. This was then followed by China with a total of 25 publications from the years 2019-2022.

Although the countries that produced the most publications are important, this heat map with all of the data throughout the years can paint a picture that shows which countries do not have access to a Nanoscribe 3D printer. Africa has zero publications from the years 2019-2022. It could then be assumed that there is a lack of access to this kind of Nano 3D printing in Africa and that companies and institutions in Africa would benefit from helping fund some of these facilities for some institutions in Africa.

This heat map also reveals that the majority of these publications came from North America, Europe, and Asia. This shows how prevalent this technology is in these regions of the world. It should be the goal of institutions in the regions where there is a lack of publications to allow their students to get access to this type of technology.

World Heat Map 2019 Continued

This heat map is regarding the year 2019 about Nanoscribe publications locations. The most common locations for publications being published are the United States as there were 31 publications during this year and Germany which had 16 publications during the year. Followed by China which had 9 publications, and then the United Kingdom as well as Italy both made 6 publications this year.

The United States is a leader when it comes to the number of publications regarding Nanoscribe 3D printers due to the number of Universities and Colleges that own and have access to a Nanoscribe 3D printer. This allows for more students and professors to explore the capabilities of the Nanoscribe printers.

Germany made the 2nd most amount of publications in the 2019 year, due to Nanoscribe being based out of Germany at the Karlsruhe Institute of Technology. Meaning a lot of the publications that were made in Germany came out of Karlsruhe Institute of Technology. As the direct connection between the school and the company Nanoscribe allowed for a lot of research and developments in these publications to be made.

The year 2019 was an important year to look at for the set of data collected for this report, as it was the last full year before the pandemic in 2020 disrupted work across the globe. This is a notable year due to the number of publications being at the highest this year compared to the other years that were studied before removing publications that had under 10 citations. This pandemic that slowed the production of articles in the field of Nanoscribe and biology was not just limited to this field of publications but slowed down all publications that were being made during this time.

During the year 2019, 102 publications regarding Nanoscribe and biology were made that had over the threshold of 10 citations. The citation threshold was to remove less useful publications that did not help the scientific community as much. If there was no minimum number of citations for each year there would be a total of 176 publications that would be taken into mind when plotting the heat map for this year. This would then only increase the spread of publications because the odds that there were no other countries that contributed to these studies would be minimal, thus meaning the spread would increase as previously stated.

As can be seen in the heat map there is a void of no publications being made in Africa, South America, and Asia other than China and Japan. This would indicate the lack of access to a Nanoscribe 3D printer in these regions of the world. To mitigate this issue, Nanoscribe could reach out to colleges and universities in these countries to see if they would be interested in purchasing a Nanoscribe 3D printer. This would allow for more publications to be made regarding this nanoscale printing technology.

World Heat Map 2020 Continued

The heat map above is about the Nanoscribe publications regarding biology during the year 2020. During this year there were only 52 publications made. This can be attributed to the Covid-19 pandemic sweeping the world, freezing supply chains as well as closing down most higher education laboratories. This year had the lowest number of publications as compared to other years during this study this is due to the pandemic.

The threshold for the minimum number of citations for this year was determined to be 4, as a lot of the publications that had contributed to the scientific community had at least 4 publications and the other publications were disregarded as they were seen as less important for the scientific community.

The majority of publications made this year were before the pandemic struck and shut down the world on March 15th, 2020 (CDC, 2022). As stated before this worldwide shutdown caused labs containing these Nanoscribe 3D printers at Colleges and Universities to not be used for most of the year.

During this year, 13 publications were made in Germany, while only 9 publications were made in the United States, while Italy and China are tied for the number of publications this year being 3.

This year did not contribute nearly as much to the total dataset for this study but it did allow us to see how the pattern of the countries still publishing Nanoscribe publications did not change much compared to 2019. With a few notable exceptions such as Japan, Canada, and a few other countries in Europe. This year can nearly be discarded when analyzing the year by itself as the amount of information that is provided by this year is minimal. Although when this year is put into the total dataset it can still be seen as useful to help understand the trends and gaps in publications geographically.

Additionally, this field of publication was not the only subject that was affected by publications, such as when comparing the year 2019 to 2020 in regards to Biology publication on Google Scholars there was a total of 721,000 publications during the year 2019 and the year 2020 there was a total of 554,000 publications. This being the case there was a decrease of roughly 23% in the total publications being made between 2019 and 2020. When compared to the decrease of 49% in Nanoscribe and biology publications between these two years, the decrease in Biology publications is far less than the decrease in Nanoscribe publications but this shows how this decrease in publications due to the pandemic was not limited to just Nanoscribe and biology publications.

World Heat Map 2021 Continued

The heat map above is about the publications during the year 2021, this year was still facing some of the issues and supply chain shutdowns that the Covid-19 pandemic caused in 2020. Although during this time, Colleges and Universities began allowing students and educators back in the labs under certain restrictions. This then allowed research to continue with the Nanoscribe 3D printers across the world.

For this year 73 publications were made that had over the determined threshold of 2 citations minimum for this year. Based on the initial number of publications it can be seen that colleges and universities were now opening their labs for students and educators. This then allowed for the number of publications to be more than in 2020. But there still were 29 fewer publications this year as compared to the year 2019 which is a 28% decrease from the year 2019.

This difference can once again be blamed on the Covid-19 pandemic slowing down economies and reducing the amount of work getting done on these publications. A lot of students and educators still did not feel comfortable returning to the lab for personal reasons. Some colleges and universities remained remote for the year 2021 (Anderson, 2021). This is what prevented the number of publications from beating or matching 2019's number of publications.

Although this year as stated above had fewer publications than initially expected, this heat map shows some of the hotspots for the newer publications being made. The heat map shows how the spread of Nanoscribe publications was being spread out and was coming from the countries that have been already putting out publications, but instead, these publications are spreading to countries that have yet to make a publication on Nanoscribe 3D printers and biology. Some notable examples of these new publication locations are Brazil, Turkey, Saudi Arabia, Israel, Russia, and Slovenia. The reason for these publications being made in these locations could be a contribution from these countries' governments thus allowing for access to these Nanoscribe 3D printers and naturally, this would lead to publications being made in these countries.

The United States during this year had the most amount of publications at 18 publications, while Germany had the 2nd most publications at 11, and The United Kingdom had the 3rd most publications at 5. This compared to the year 2020 shows how the order of which

country made the most publications flipped between Germany and the United States of America. While the United Kingdom has taken China and Italy's spot for the 3rd most amount of publications made in 2020.

This year does not vary too much for the 2019 publication heat map other than the United Kingdom having the 3rd most publications during this year, as compared to China making the 3rd most publications during 2019. During this year the association between the number of schools can be applied to the reason why the United States makes the most amount of publications can be made but Germany and the United Kingdom contest that idea. As the United Kingdom has 8% of the number of colleges and universities compared to the United States (US vs UK universities). While Germany has 15.2% of the number of colleges and universities compared to the United States (Besart, 2013). The reason why these countries have such a high number of publications is that Nanoscribe is based out of Germany and it allows for these schools that are closer to Germany to get ahold of a Nanoscribe 3D printer. Thus this means more publications will be made in these countries.

World Heat Map 2022 Continued

The heat map above is concerning the year 2022, this year saw the lifting of most Covid-19 restrictions (CDC, 2022). This meant that a lot of college and university labs were now being reopened. This being the case it is expected that more publications will be made as compared to the previous two years, 2021 and 2020.

During this year there were 105 total publications made about Nanoscribe and biology. This year had 32 more publications as compared to 2021, which is a 44% improvement. Showing how these labs were now being opened and research was no longer halted due to Covid-19 restrictions. Going back to the heat map it is evident that Germany was the leader this year with

30 publications, followed by the United States of America with 26 total publications. With the 3rd most publications being made in China this year with 9.

This year followed a very similar pattern to the year 2020 when it comes to countries leading with the most amount of publications. Once again Germany has the most amount of publications compared to other countries as Nanoscribe is based out of a college in Germany called Karlsruhe Institute of Technology, this allows for easy access to Nanoscribe's facility and the number of printers available at some of the colleges and universities in Germany is what allows for the high amount of publications. While the United States had the 2nd most amount of publications. This is likely due to the number of universities and colleges in the United States.

This year had the most variety for countries making publications about Nanoscribe and biology, with 25 different countries making publications. Some of these countries have not made a publication about Nanoscribe and biology yet in this study. Such as India, and Portugal. The spread of publications being made is far superior compared to the 2019 heat map meaning more colleges and universities are getting access to these Nanoscribe 3D printers allowing for the opportunity to perform research about them. This then makes the spread of publications increase, as 2019 only had 24 different publications made, but the majority of these publications were made in Western Europe and Eastern Asia.

While compared to 2022 the spread is broader as stated above, the spread of publications varies from most of North America, both East and West of Europe, and more areas in Asia. This spread is not perfect but it still shows how schools across the world are putting in the effort to be able to allow their students to explore the opportunities a Nanoscribe printer allows.

With the loosening of Covid-19 restrictions in 2022, it was expected that there would be more publications made during 2022 as compared to 2019, as the technology was more readily

available. This was the case in this study, as there were 3 more publications in 2022 as compared to 2019. This growth of 3% is less than what was expected for growth between 4 years of publications. But once again this is due to the Covid-19 pandemic delaying research and shutting down economies, this meant supply chains were not functioning very efficiently.

United States Heat Map 2019 to 2022

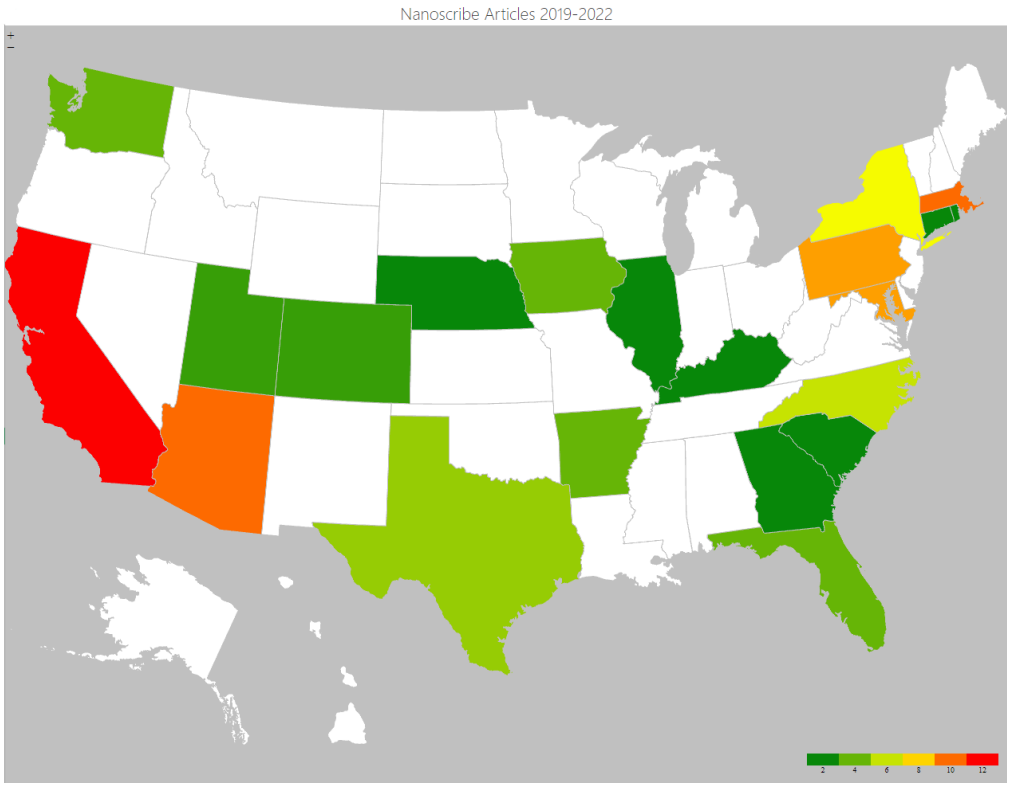

Figure 12: Heat map of USA 2019-2022

United States Heat Map 2019

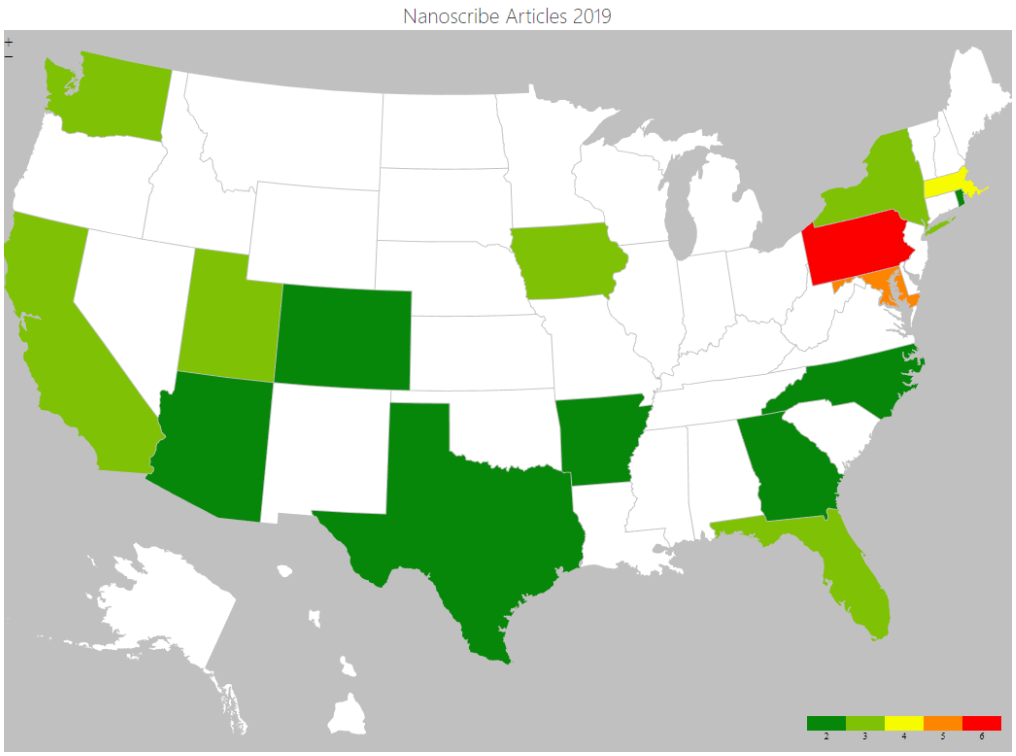

Figure 13: Heat map of USA 2019

United States Heat Map 2020

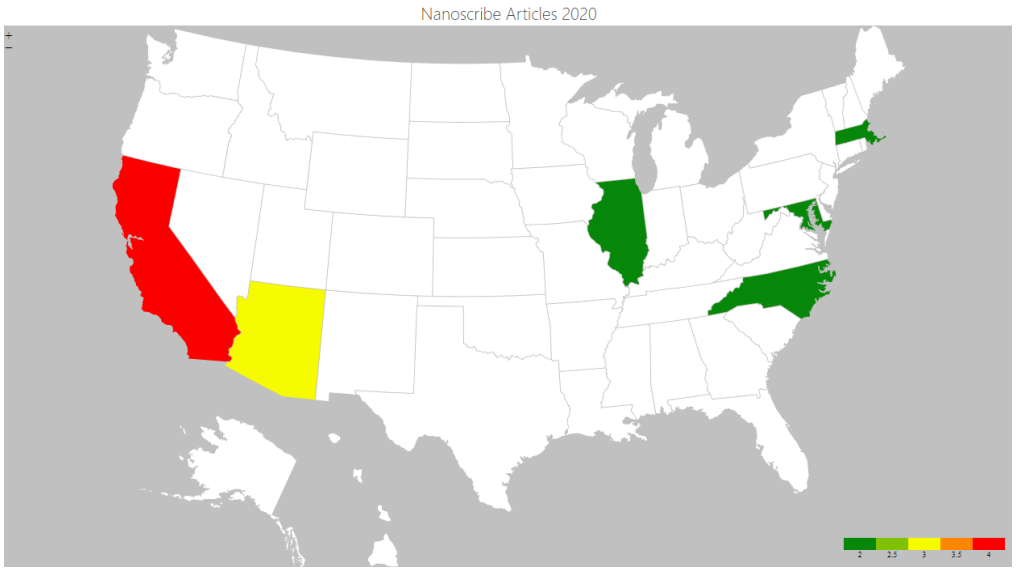

Figure 14: Heat map of USA 2020

United States Heat Map 2021

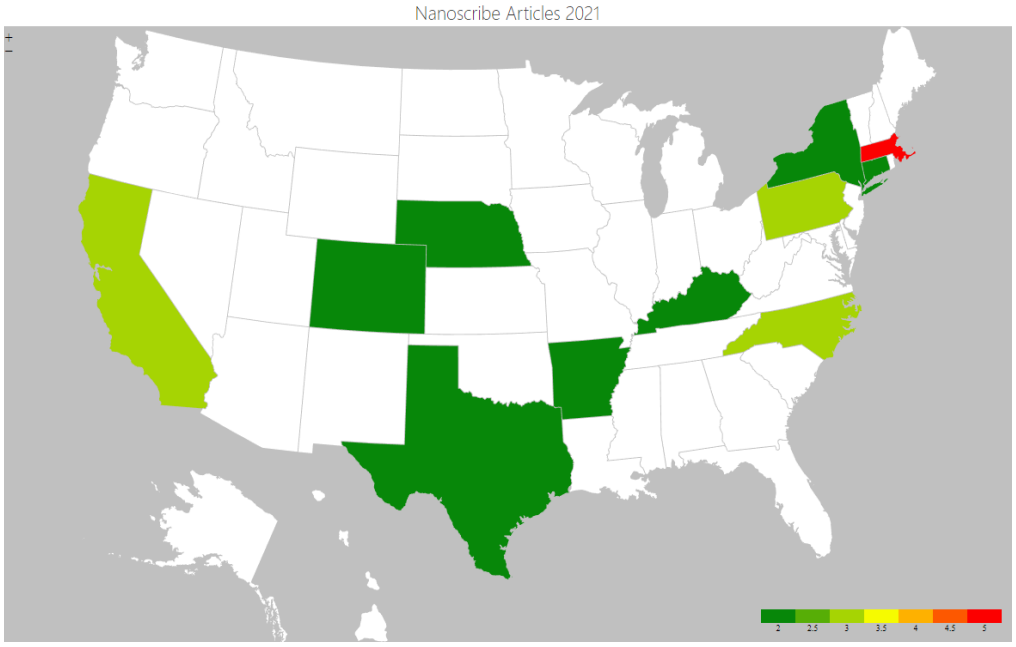

Figure 15: Heat map of USA 2021

United States Heat Map 2022

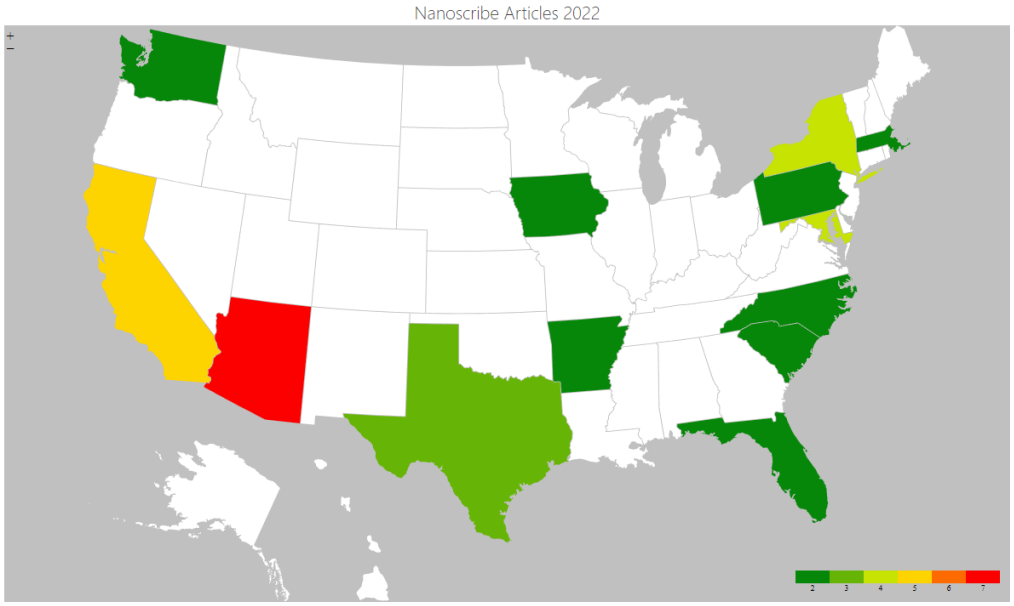

Figure 16: Heat map of USA 2022

United States Heat Map 2019-2022 Continued

The heat map above is the publications per state from years 2019 to 2022, as it can be seen California, Arizona, Massachusetts, Pennsylvania, and Maryland all have made the most amount of publications during this time. California was able to produce a total of 11 publications, and Arizona and Massachusetts both produced 9 publications. While Maryland and Pennsylvania both produced 8 publications this year.

Although it is important to observe what states were producing the most amount of publications as this would indicate multiple institutions creating publications, meaning a lot more students had access to this type of technology, it is still important to look at the spaces where these publications were missing. Looking at the heat map above it is evident that most of the Northern United States are lacking publications throughout this study. This would indicate the lack of access to one of these Nanoscribe 3D printers.

Information like this would allow institutions to observe breaks in the available technology in these regions and could then use this data to invest in this type of technology on their campus. This would then lead to a draw from companies and students at these institutions to research different fields of Nanoscribe technology and the potential that these printers have.

United States Heat Map 2019 Continued

The heat map above is about the number of publications per state for the year 2019. This year is notable because it is the year right before the Covid-19 pandemic. As stated earlier was the reason why all of the colleges and universities' labs were shut down. During this year it is very apparent that Pennsylvania was leading the country with the most publications being made in that state. Pennsylvania had a total of 5 publications made during this time while the state with

the second most amount of publications was Maryland with a total of 4 publications in 2019. Then followed by Massachusetts which had a total of 3 publications in 2019.

As can be seen on the heat map the spread of publications is quite large, as most states except for the midwest have a neighboring state that has made publications about Nanoscribe 3D printers and biology. The white areas on these heat maps can help show to schools in these areas that it would be best to get access to one of these Nanoscribe 3D printers that way they will allow their students to experiment and learn about a new technology that is shaping the future when it comes to biology and photonics.

United States Heat Map 2020 Continued

The heat map above is with the year 2020 and the number of Nanoscribe publications made in each state of the United States. This year looks more empty than 2019, which was due to the Covid-19 pandemic shutting down colleges and university research labs, halting any research that was being done and that would have a publication made in regards to the research that was being completed. The state with the most publications during this year was California with a total of 3 publications. Followed by Arizona with a total of 2 publications and the rest of the states that are colored green had only 1 publication this year.

Since the number of publications made in the United States during this year was only 9 it is safe to say that this data is nearly irrelevant to this study as the numbers are so low due to the pandemic that it could lead to invalid conclusions to be made, thus messing with the results of the study. So this year leads to a lack of conclusions to be drawn to it, due to the lack of publications made.

United States Heat Map 2021 Continued

The heat map above shows the publications that were made in the United States during 2021. There were a total of 18 publications made in the US during this year, with the most publications being made in Massachusetts during this time, with 4 publications. Followed by California, North Carolina, and Pennsylvania all these states with a total of 2 publications each. The number of publications during this year is still significantly less than in the year 2019. This can be attributed to the colleges and universities having Covid-19 restrictions and economies still recovering from the nationwide shutdown in 2020.

The spread of publications during this year was far weaker than the year 2019. Most states in the US have no neighboring states that have made any publications regarding Nanoscribe 3D printers and biology. This can show how many schools in certain states are lacking an accessible Nanoscribe printer. That could help their students get into a fast-growing field and help lead to the advancements of microfabrication and help lead to potential revolutions in the biology or photonic field.

United States Heat Map 2022 Continued

The heat map above is concerning the number of publications per state in the United States during the year 2022. This year's heat map is closest to 2019, which shows that the world is recovering from the Covid-19 pandemic. This heat map shows that the state with the most publications was Arizona with 6 publications. Followed by California with 4 publications this year and then followed by Maryland and New York with 3 total publications this year.

The United States this year made 26 publications, and the spread of these publications across the United States is nearly on par with the year 2019. When both 2019 and 2022 are compared it can be seen that only a few states are missing from the heatmaps, such as

Connecticut, Utah, and Colorado. The spread is most definitely greater than it was in 2020 and 2021 but once again that is due to the Covid-19 pandemic.

Histograms

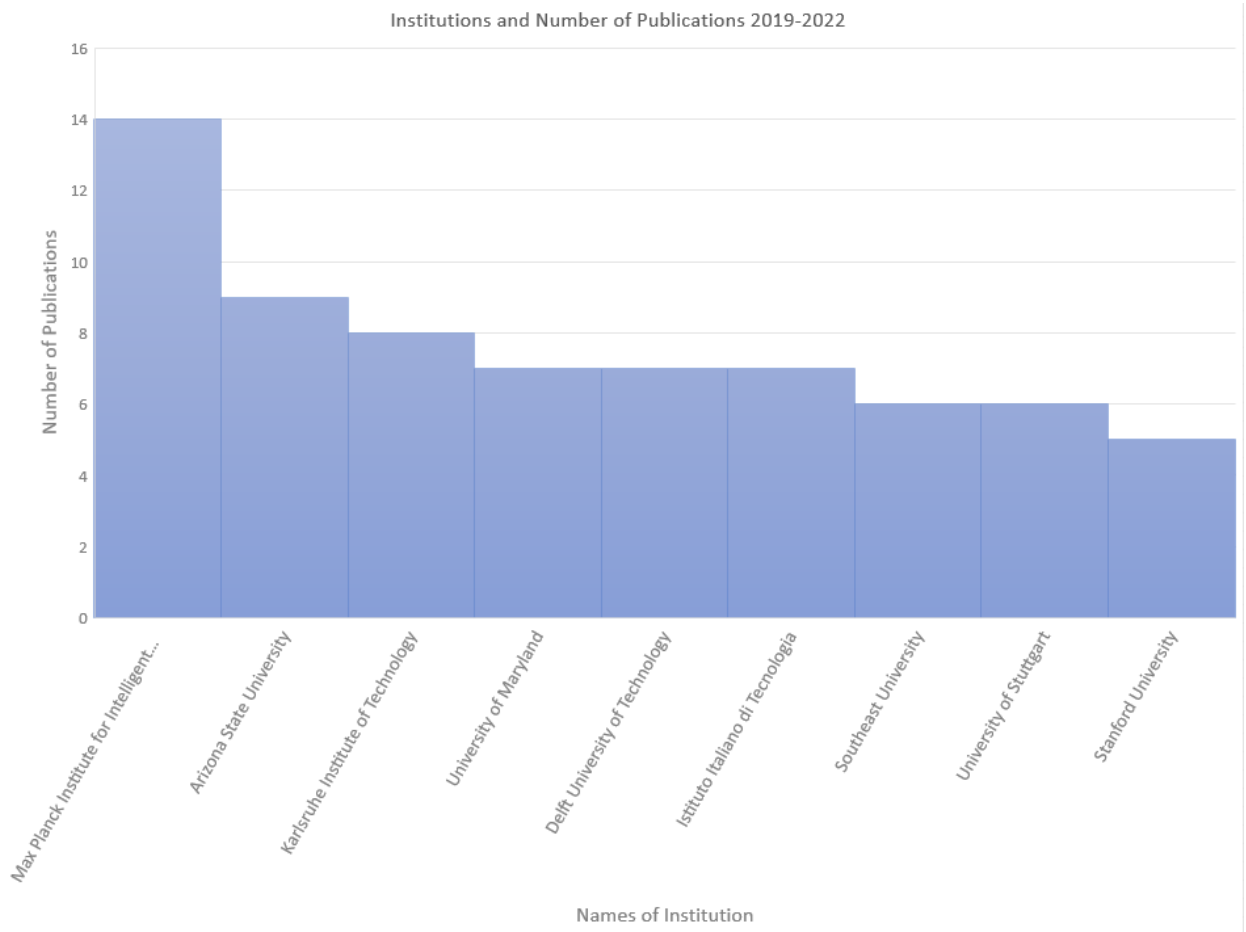

Figure 17: 2019 to 2022 Histogram of the number of publications based on Institutions

The histogram above is in regards to the institutions that produced the most amount of publications over the year of this study. This histogram does not include all 204 institutions that made publications about Nanoscribe and biology from 2019 to 2022 but rather focuses on the schools that made more than 5 publications. This is to show off some of the institutions that contributed the most over 2019-2022.

As can be seen above Max Planck Institute for Intelligent Systems was the institution that made the most amount of publications from the years 2019 to 2022 with 14 publications total. This was then followed by Arizona State University with 9 total publications, then Karlsruhe Institute of Technology with 8 publications. Then the following institutions made 7 publications total, the University of Maryland, Delft University of Technology, and Istituto Italiano di Tecnologia. This was then followed by Southeast University and the University of Stuttgart with 6 total publications, and finally Stanford University with 5 publications.

As can be seen, the majority of these top-producing institutions are based out of The United States, or Germany. This is likely due to the amount of funding the United States Government provides that way the best technology is produced there, and Germany likely has many publications due to its proximity to the Nanoscribe headquarters at Karlsruhe. This makes a lot of educators and schools very familiar with the use and operation of these Nanoscribe printers allowing the students to be able to get more guidance when it comes to completing research on these printers.

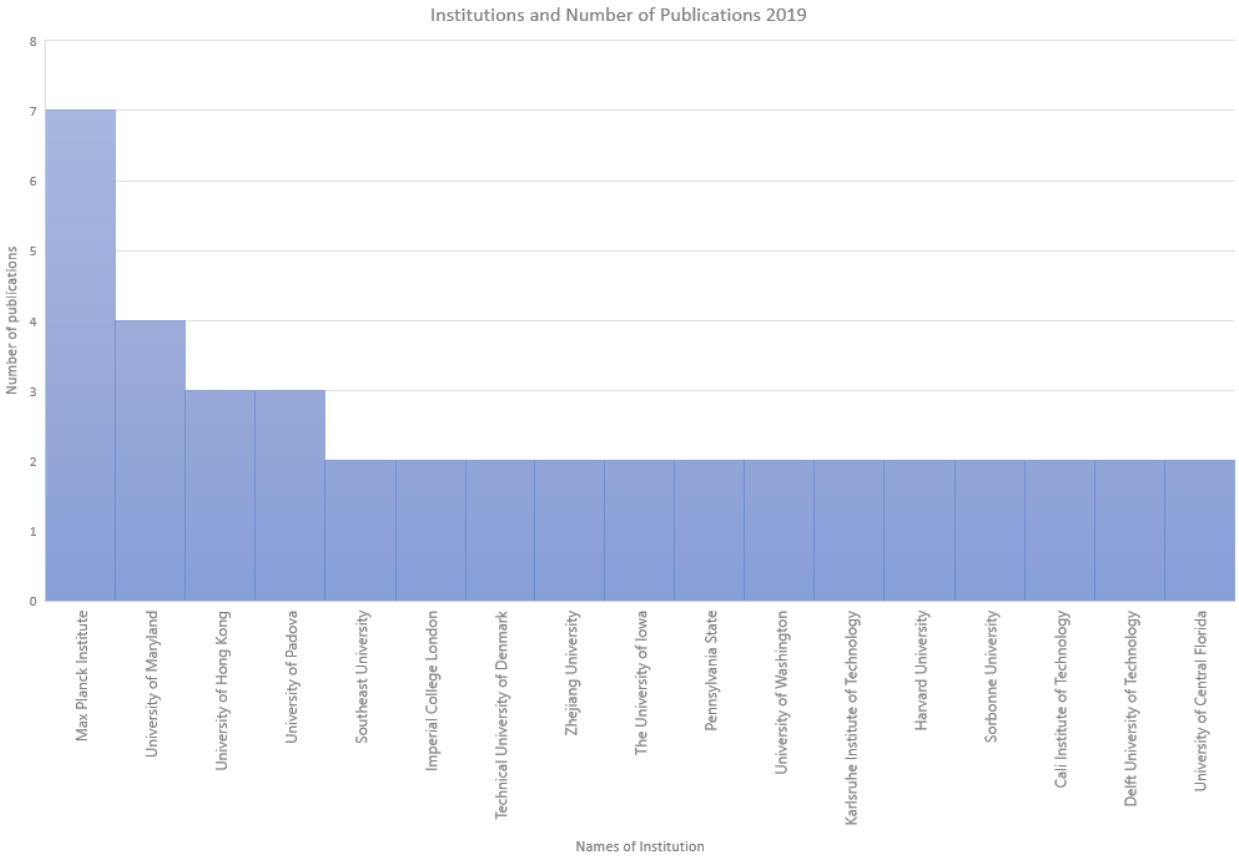

Figure 18: 2019 Histogram of the number of publications based on Institutions

The histogram above is in regards the number of publications that each school was able to produce during the year 2019. Initially looking at the histogram it can be seen that 7 publications alone were made at Max Planck Institute for Intelligent Systems. The high amount of publications at Max Planck alone is due to the schools' proximity to Nanoscribe's headquarters in Germany, and that Max Planck has a lot of educators who are familiar with the field of photonics and Nanoscribe 3D printing. Thus making mentoring students through their operation and research on the Nanoscribe printer easier.

The school that produced the second most amount of publications this year was the University of Maryland with 4 publications this year. This is most likely due to a peak in interest regarding the Nanoscribe printers due to professors and educators showing off some of the

technology to help draw interest from their students. This appears to be the work of 3 different groups during this year at the University of Maryland.

The vast number of schools that made publications during the year 2019, as there were a total of 76 different schools around the world that made publications. Although this number of different schools making these publications seems high it still is not nearly as large as the year 2022's number of publications.

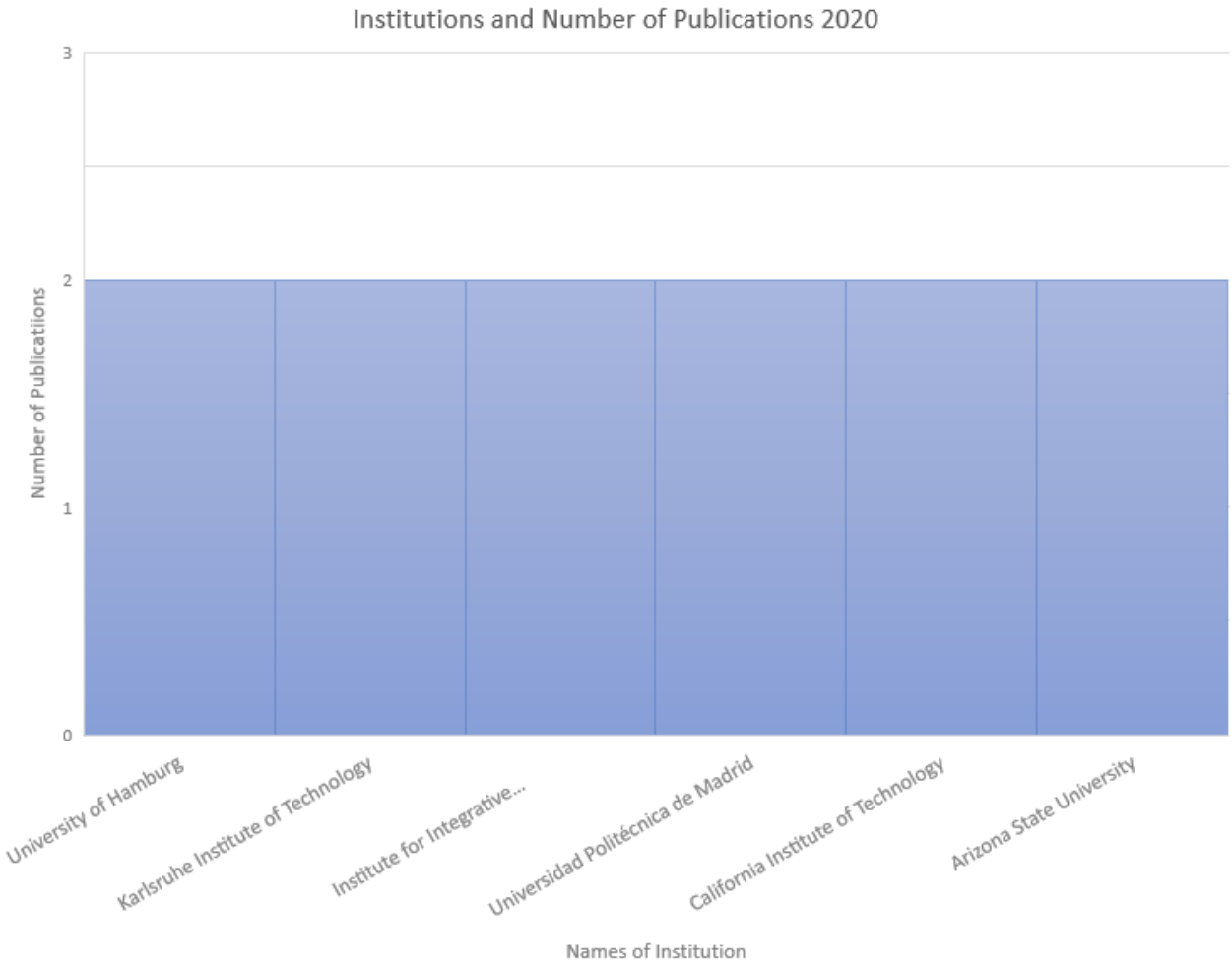

Figure 19: 2020 Histogram of the number of publications based on Institutions

The figure above is the histogram regarding the number of publications per institution for institutions that made over 2 publications this year. This minimum of 2 publications is to help reduce the clutter with the number of schools making it difficult to digest the focus of the

histogram. During this year the pandemic disrupted the institution's labs by shutting them down. This made the maximum number of publications made this year to be two, and the University of Hamburg, Karlsruhe Institute of Technology, Institute for Integrative Nanosciences, Universidad Politécnica de Madrid, California Institute of Technology, and Arizona State University.

During this year the total number of different Institutions creating these publications was 45. This total number of schools making publications is significantly less than the previous year, which is due to the Covid-19 pandemic slowing innovation and preventing work from getting done in laboratories.

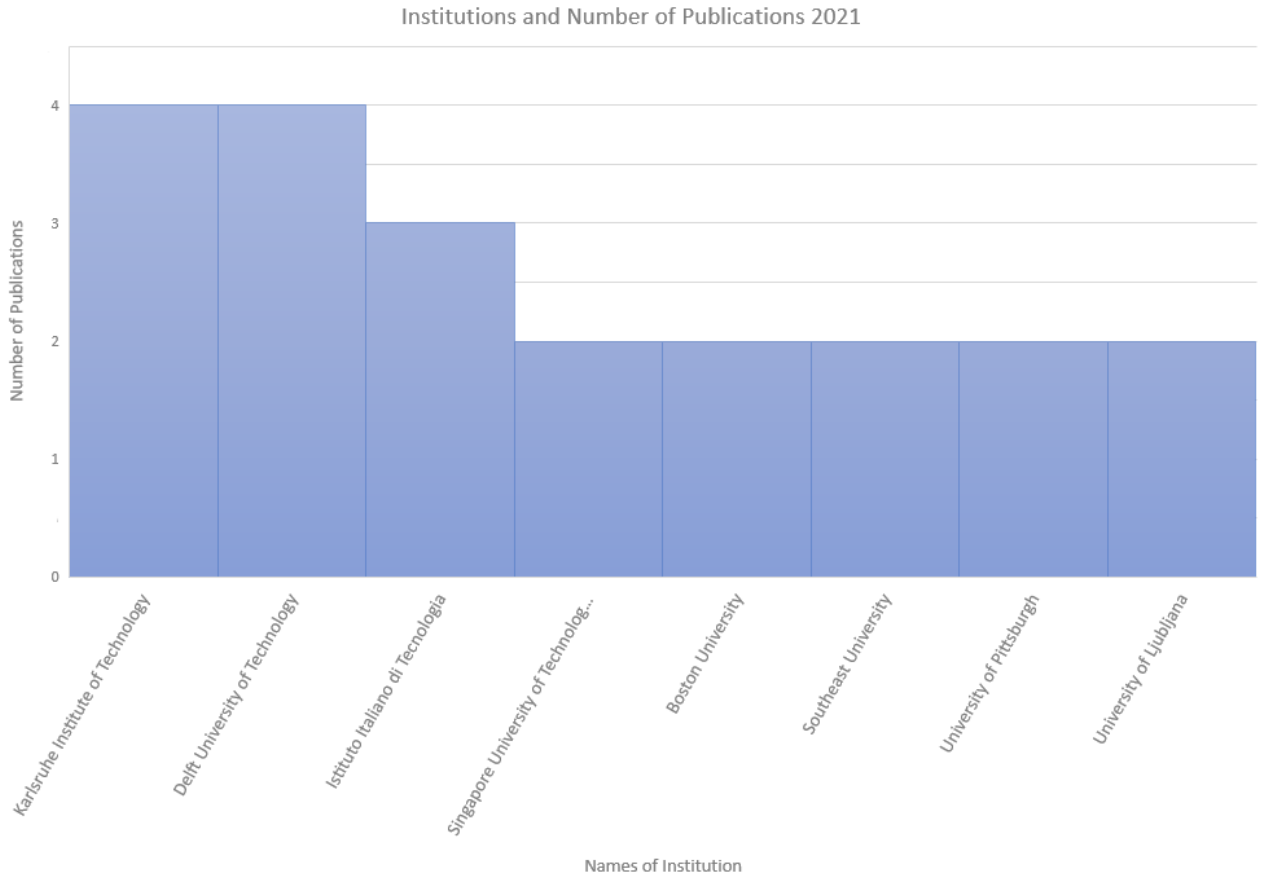

Figure 20: 2021 Histogram of the number of publications based on Institutions

The histogram above is in regards to the number of publications that each institution has made for institutions that produced over 2 publications. This cut-off was done to show off some of the top publication-producing institutions. As can be seen, Karlsruhe Institute of Technology, Delft University of Technology both had a total of 4 publications during the year 2021. Followed by Istituto Italiano di Tecnologia with a total of 3 publications this year, and the following five institutions made 2 publications this year, Singapore University of Technology and Design, Boston University, Southeast University, University of Pittsburgh, and the University of Ljubljana. Although there are only 8 different schools that produced more than 2 publications, a total of 60 different schools made publications this year across the world.

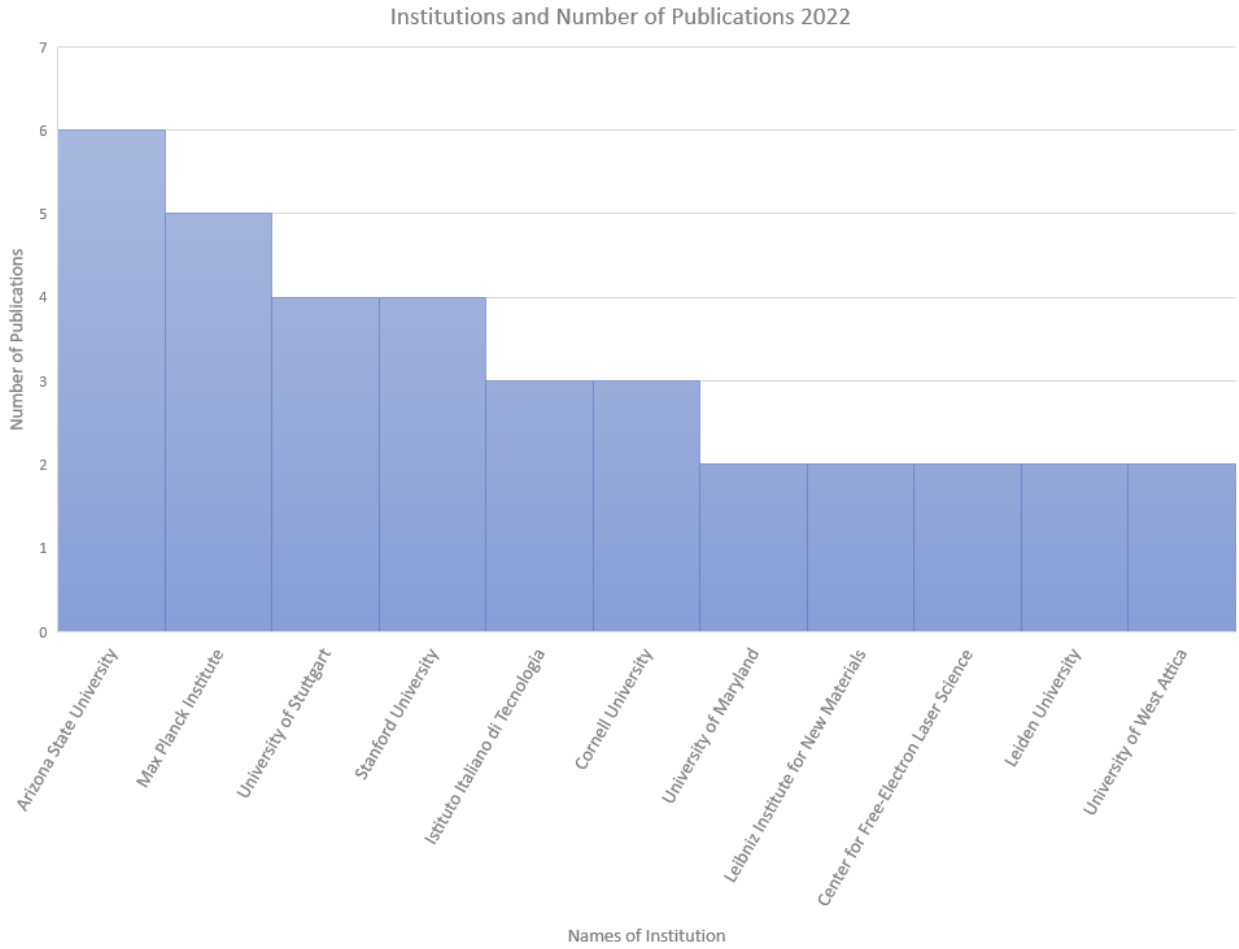

Figure 21: 2022 Histogram of the number of publications based on schools

The histogram above is regarding the number of publications each institution has created over the year 2022. This histogram only has the institutions that published more than 2 publications, as stated previously to allow for the institutions that produced the most publications to be easier to see, and this data, in turn, is more relevant to what is being looked for in this study.

The histogram shows that the institution that created the most amount of publications this year was Arizona State University, with 6 total publications, this was then followed by Max Planck Institute for Intelligent Systems with 5 publications. Then followed by the University of Stuttgart and Stanford University with 4 publications this year, and next was Cornell University and Istituto Italiano di Tecnologia with 3 publications. Then the following institutions made 2 publications during this year, the University of Maryland, Leibniz Institute for New Materials, Center for Free-Electron Laser Science, Leiden University, and the University of West Attica. Although there were only 10 institutions that made over 2 publications there were a total of 80 institutions across the world that made publications during the year 2022.

Word Clouds and Frequency Tables

Title Word Cloud

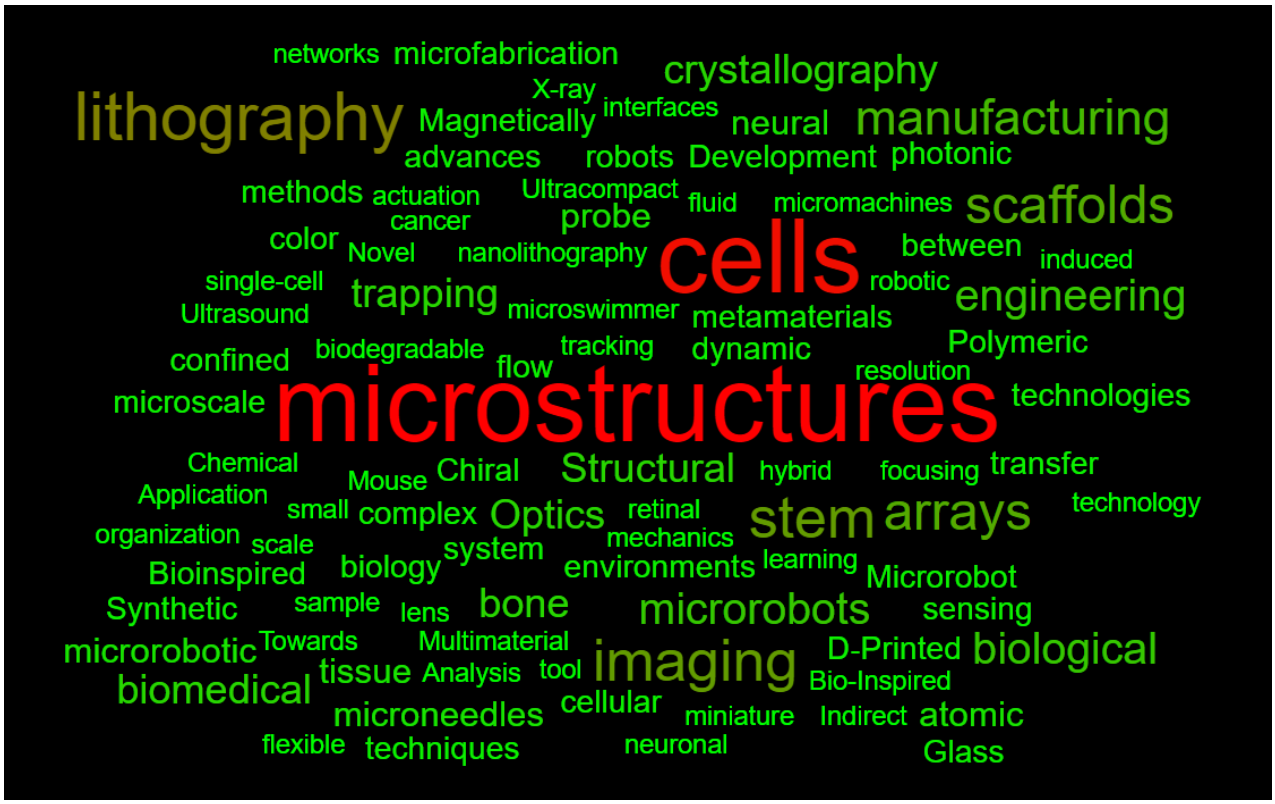

Figure 22: Title word cloud from years 2019-2022

The word cloud above is in regards to the title from the publications that were made from 2019 to 2022. This word cloud shows how cells and microstructures were the main highlights of a lot of these publications that were made. It is important not to just focus on the most frequent words that come up in each of these titles but rather to look at the word cloud as a whole by considering some of the smaller words and medium size words as well.

This being the case some of the words that stand out include neural, microswimmer, biodegradable, optics, bone, tissue, microneedles, and micro-robotic, just to name some examples. Although this word cloud shows off some of the top words in these titles in a qualitative way. This word cloud helps demonstrate that although these reports were filtered by

Nanoscribe and biology there still are many other subsections under these subjects. This word cloud also shows some potential growing fields in Nanoscribe and biology, such as microrobots, microswimmers, microneedles, and more.

Title Frequency Table	
Word	**Instances**
Microstructures	22
Cells	20
Scaffolds	12
Microswimmer	9
Optics	7
Microneedles	7
Bone	6
Tissue	6
Microrobotic	6
Neural	5
Biodegradable	3
Ultrasound	3
X-ray	3

Figure 23: Frequency table of the Titles

The frequency table above is in regards to the title word cloud, the main purpose of this frequency table was to highlight some of the terms that were brought up in the previous section and help put some of the data from the word cloud in a quantitative form. By using this frequency table it can be seen that some of the terms previously discussed in the word clouds can have several times mentioned put next to them, instead of just comparing the size of the words. For example, the term microstructures come up a total of 22 times throughout all of the titles, and micro-robotic which was a term that was mentioned previously came up a total of 6 times in all of the titles in these publications. The frequency table has the job of just making the data from the word cloud which is qualitative into a quantitative form. Without the use of the word cloud,

the data might be overwhelming to digest so the word cloud skill plays a role in putting some of these terms into perspective as to their overall occurrence.

Abstract Word Cloud

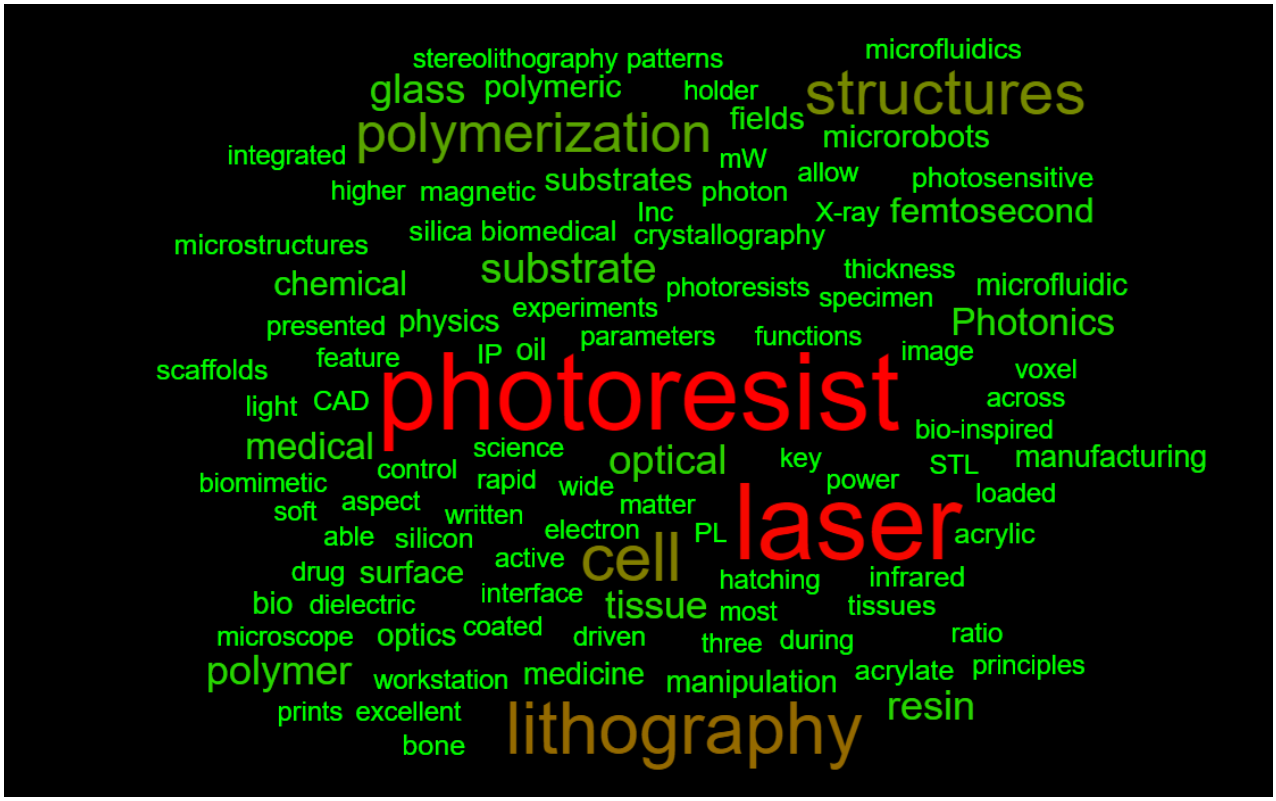

Figure 24: Abstract word cloud from years 2019 to 2022

This word cloud above is regarding all of the abstracts from publications throughout the years 2019 to 2022. This word cloud paints a different picture when compared to the word cloud about titles, such that the word photoresist which is the top word of this word cloud is not seen in the title word cloud. There are some other differences between these two word clouds such that some of the smaller words that are seen on the title word cloud are not found on this word cloud, such as microswimmer, biodegradable, neural, and microneedles to name a few. This could be due to the abstracts of these publications diving into more detail and making use of different terms than the ones used in the titles.

Some terms that are less prevalent in these publications but could be a revolutionary field with these Nanoscribe 3D printers in this word cloud include, optics, the medical field, glass, microfluidic, medicine, micro-robotics, silicon, acrylic, and bones. Some of these fields that are related to biology such as medicine could be a new way to treat a specific disease that could save a person's life or the term bones which could be a new way to imitate the cell structure of a bone that could help the body when it comes to repairing the damage. These are just two examples of what some of these publications are concerning.

As previously stated, one of the issues with the word cloud is due it only shows data qualitatively, which means it is not easy to digest the data as numbers as that is not possible to do with a word cloud. This issue with the word cloud only being qualitative can be resolved by including a frequency table which would then make this data quantitative, these frequency tables can be seen below regarding the title word cloud and abstract word cloud.

Abstract Frequency Table	
Word	**Instances**
Photoresist	67
Cell	49
Structures	39
Optic	25
Tissue	22
Medical	18
Glass	17
Microfluidic	11
Medicine	9
Microrobots	8
Silicon	8
Acrylic	5
Bone	4

Figure 25: Frequency table of the Abstracts

The frequency table above is about the abstract word cloud, this table looks at some of the highlighted terms from the paragraphs above. This frequency table allows the qualitative data from the word cloud to be turned into a quantitative data set which is necessary for being able to fully digest the data presented.

This frequency table allows for terms from the word cloud to have the number of occurrences of this term in the abstract to be listed. For example, the term “photoresist” was the most common in the word cloud but this does not pertain directly to biology, as it was one form of microfabrication, which can be assumed was one of the most common ways these objects were being created and Nano 3D printing was used as an alternative to this microfabrication method. According to the frequency table, it can be noted that there were 67 instances of this term in all of the abstracts, or for the term “tissue” which was a smaller term than photoresist there were a total of 22 occurrences throughout the abstracts. Overall, this frequency table allows the digestion of important terms from the word clouds while also giving more context to the word cloud so some terms have the number of instances it occurred in the abstracts.

Conclusion

The data mining that was done throughout this study has shown the opposite of what was expected. It was expected that looking through the years 2019 to 2022 there would be a steady increase in the number of publications. But instead, the trend started with a high amount of publications in 2019, the amount being 102, in 2020 there were 52 publications which is a 49% decrease in the number of publications. While in 2021 there were a total of 73 publications which is still a 29% decrease in the number of publications compared to 2019. This trend is the opposite of what was expected initially before data mining started.

While in 2022 there were a total of 105 publications which is only a 3% increase compared to the year 2019. This is what would have been expected when data mining but rather than just an increase in one year, an increase in all of the years after the baseline of 2019 was anticipated. The reason why these results contested the initial expectation was due to the Covid-19 pandemic. This pandemic shut down colleges and universities along with their labs. This meant no research was being done with the Nanoscribe printers during this shutdown. Even after the initial shutdown, it took nearly 2 years for the rate at which the publications that were being made pre-pandemic to recover.

Since the Covid-19 pandemic negatively affected the number of publications from 2020 and on, it would be safe to say that the pandemic interrupted innovation, this is due to most of the labs that contribute to innovations in society being shut down as they were seen as non-essential to the government and the only laboratories that were remaining open during this time were labs that were contributing to the potential Covid-19 vaccine. So this being the case since economies and labs were shut down the pandemic was able to interrupt the process of innovation for a period of at least 2 years, and the Covid-19 effects are still being felt to this day with most economies worldwide recovering.

This study was a simple way to demonstrate some of the information and data that can be collected from manually scrubbing these documents, but if this was to be redone, using a combination of the total amount of citations a publication received could be added to the heat maps to help show the countries that made the most contributions to the scientific community. Another way this study could change would be by using a custom heat map script that would instead of only showing countries and states that made publications would rather show off the schools' exact locations that way gaps in these publications' locations can be seen. Thus, this

allows companies and institutions to take advantage of this geographic gap in publications and will allow them to allow students in this region to get ahold of this technology that will change the future.

The data collected from the years 2019 to 2022 shows some of the primary locations where these publications were being made, using this data the colleges and universities can pull some of their resources together to create labs such as the LEAP facilities at Worcester Polytechnic Institute. By having colleges and universities collaborate, it will allow for easier access to potential game-changing capital equipment such as the Nanoscribe 3D printer.

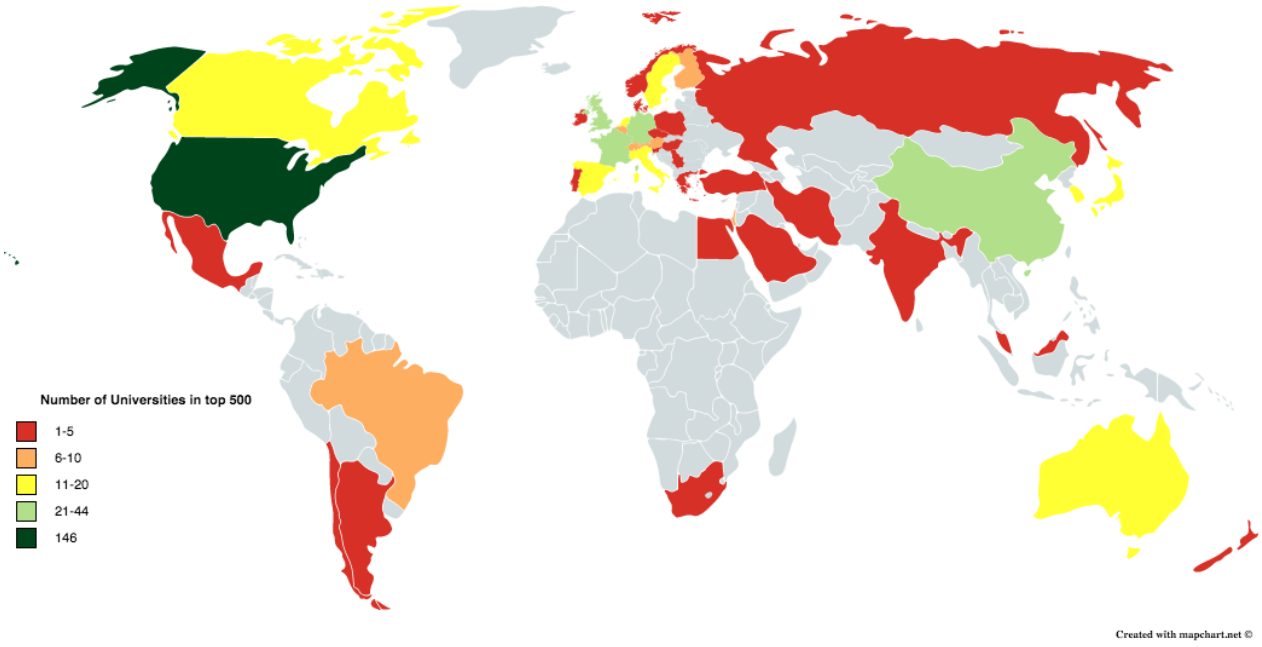

Figure 26: Heat Map of the top 500 institutions in the world (Georgios, 2023).

The heat map above is with the top 500 institutions in the world, this can be compared to the world heat map of publications from the years 2019 to 2022. It can be seen how similar these 2 world heat maps appear, nearly every country on the world heat map that has made a publication, is represented on the top 500 institutions' world heat map. Although these heat maps

there are a few exceptions of these countries that are not on the top 500 institutions that can be seen on the world heat map of the publications. Some of these exceptions include Lithuania, Romania, Slovakia, and Syria just to name a few.

Although there are some differences between these two heat maps it can be safe to assume that a lot of these Nanoscribe publications are coming from the top 500 institutions, with a few exceptions. One way that this could be confirmed would be to compare a list of the top 500 institutions compared to the list of all the schools that made a publication to Nanoscribe and biology.

By using some of the data collected in the heat maps, the spots that are entirely missing access can be identified and the schools as previously stated can collaborate to get access to a Nanoscribe 3D printer. This will make the startup cost and the cost of maintaining this machine more reasonable and justifiable for the school. Having some institutions work together similarly to the LEAP facilities in Massachusetts will lead to the growth of this Nano 3D printing field that in turn will lead to more innovations and better the world in many different fields. Some of these fields that nano 3D printing would be able to innovate on would be biology, chemistry, photonics, and more.

Subject	Number of Publications (2019)	Number of Publications (2020)	Number of Publications (2021)	Number of Publications (2022)
3D printing	26,799	32,093	31,443	22,665
3D printing and Biology	3,810	4,557	5,525	6,209
Nanoscribe and Biology	176	122	125	105

Figure 27: Table with the number of publications per year based on the subject.

The table above is about the number of publications that were found on Google Scholars when specifying the year and subject. This is to allow for the comparison in the number of publications each year to understand if the Covid-19 pandemic only affected Nanoscribe and biology in this small sample. This table is comparing just the number of publications with no thresholds for citation amounts.

As can be seen the number of publications for the subjects “3D printing” and “3D printing and Biology” do not follow the same trends when compared to the subject “Nanoscribe and Biology”. This is the opposite of what was expected, but there could be a few reasons to explain the uptick in publications in both “3D printing” and “3D printing and Biology” which is possibly due to this research that could have been done at home. This is because most standard 3D printers such as FDM or SLA models are a commodity and can be purchased for personal use and are relatively inexpensive. This meant this research could get done without the need for a lab to be open.

While the sudden decrease in publications in regards to “3D printing” is potentially due to a chip shortage from 2021 to 2022 that could have made producing 3D printers difficult. This in turn would slow down the number of publications that were being made throughout this time.

Digging deeper into the subject of biology nano 3D printing can also make advancements in the medical field, microstructures, microswimmers, and microneedles. Such as when it comes to the advancement of micro stents in the medical field rather than using subtractive microfabrication to create a micro stent, this type of nano 3D printing technology can create a micro stent with more precision and better tolerance than the previous microfabrication technique. This trend of using these types of nano 3D printers for biological purposes has decreased throughout this study until the year 2022, but this can be attributed to the Covid-19 pandemic. When observing the year 2022 it can be seen how the number of publications is on a constant increase this can then be attributed to the restrictions and labs opening back up, thus more research and publications are being made with this type of technology.

It can also be assumed that if this study was to be redone in future years the smaller terms that were occurring throughout the titles and abstracts would end up as larger words in the word

clouds and frequency table. This is due to more institutions and research groups contributing to these fields of research regarding biology and nano 3D printing. As can be seen, this nano 3D printer called the Nanoscribe 3D printer is capable of a multitude of different applications, which is the reason it is so innovative and has a lot of potentials to innovate in many different subjects this was just an example of how it was able to affect the subject of biology.

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