Academic Recognition of Fab Academy *

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ABSTRACT

Maker educations and distributed educations are increasing in quantity and quality. This gives a possibility for academia to tap into interesting sources of knowledge outside the physical parameters of the institution, as well as outside formal education and traditional learning methods. However, academic recognition of such learning can be challenging. We explore Fab Academy in comparison with a current university course with the same topic; the amount of work by university standards and whether the assessment methods of Fab Academy are sufficient for academic recognition. The workload of Fab Academy is calculated based on the European Credit Transfer and Accumulation System (ECTS). The contents are compared based on the range of subjects and the deliverables required to pass the courses. We find Fab Academy to be compatible with the university course. Hence, we consider it possible to include in university curriculum Fab Academy content accredited by different universities.

CCS CONCEPTS

• Applied computing~Collaborative learning • Applied computing~Distance learning

KEYWORDS

Fab Academy; Fab Lab; Academic Recognition; Distance Learning; Distributed Learning.

1 Introduction

Non-formal maker educations, also distributed ones, are increasing in quantity and quality. Maker educations have found agile ways to respond to the latest needs of the society [15]. They focus on teaching personal fabrication for citizens, how citizens can make themselves almost anything in a technical and contemporary way [11]. Such skills can be expected to be valuable in the future, specifically to reach the sustainability the society is targeting.

To reach the full potential of personal fabrication, maker education should be included in formal education. Accrediting (i.e. academic recognition) maker education in formal education could be the first step in advancing this goal. Accreditation would increase the credibility of maker education and permit formal educators to stay at the edge of latest developments. This, in its turn, could pave the way to include personal fabrication systematically in formal education.

In this paper, we explore how Fab Labs' distributed maker education could be accredited. Fab Labs can play an important role in education [3]. Fab Lab provides a full set of tools to learn to fabricate and design with the latest digital processes, many of them easy enough for children to use. Over 1600 Fab Labs around the world form a large knowledge sharing network. Fab Academy is a six-month distributed learning process for principles and practices of digital fabrication that uses the tools and processes of Fab Labs.

Some universities are planning to sell their courses on digital fabrication on the web and some, more than 250 institutions, including MIT, share their materials for free [13]. Still, we haven't found a distributed, accredited master's level education for digital fabrication resembling Fab Academy. In this paper, we propose a partial solution for the problem. We investigate whether the quality of Fab Academy has reached a sufficient level to be added into university curriculum "as is" and how the workload compares to ECTS credits [28].

2 Background

2.1 Distance and distributed education

Of all the students of higher education in USA, 28 % participated on at least one course via distance education in 2014 [2]. Of students in pro-profit organizations, the rate was 60 %. Moore defines distance education to be more of a question of psychological distance rather than space and time [19]. The psychological distance refers to the level of dialogue and level of independence of the learner. The psychological distance has an effect on the student's satisfaction with the course and effectiveness of the learning. Effectiveness can be studied comparing graduation rates on different courses. Interaction can have distance between student and teacher, student and student, or student and content of the course [20]. Nowadays, Internet is a common tool in education. It has popularized also interactive learning environments and hence the transactional distance between a student and technology needs to be considered as well [1, 14].

Distance learning methods can be divided into synchronous and asynchronous ones [18]. In synchronous methods, everyone is online at the same time, whereas in asynchronous methods, self-study and interaction occur over a period of time in various forms. As the development of technology continues, the synchronous

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approach has more potential to grow in numbers [26]. Combining these two is found to produce the most effective distance learning method [24]. The synchronous method is less expensive while still offering better accessibility for the students. The asynchronous method offers better flexibility but longer transactional distance between a teacher and a student.

Distance learning incorporating information technology as a tool is by definition distributed learning [4]. Distributed learning supports naturally collaborative learning [25]. The quality of education can be defined by two questions. First, is the instructor expert of the field? Second, can students demonstrate mastery on the subject? [23]. The American Council on Education states "*Distributed learning, rather than distance education, will become the dominant paradigm for higher education – although, in the short term, institutions are confronted with a multitude of challenges associated with the "distance" component.*" [22]

2.2 Fab Lab

Fab Lab is a small-scale digital fabrication and innovation platform, originating from MIT [11]. Fab Labs are defined by four rules: a) public access to the Fab Lab is essential; b) these labs subscribe to the Fab Lab charter [9]; c) Fab Labs share a common set of tools and processes; and, d) Fab Labs must participate in the larger, global Fab Lab network [10]. While Fab Labs are on the way for third digital revolution of digital to physical and ubiquitous fabrication of programmable materials, the value of them comes more of learning the processes than of actual outcome of the processes [12].

A common core toolset for a Fab Lab contains a laser cutter, a sign cutter, a precision Computerized Numerical Control (CNC) milling machine, a large-scale router-type milling machine, a 3D-printer, an electronic workstation and communication devices for video conferences. These tools enable common processes like composites, casting, programming, project management and embroidery. These processes support distributed education and knowledge sharing.

2.3 Fab Academy

One of the most important focus areas of the Fab Lab network is education [17]. The biggest program, Fab Academy, is a six-month distributed learning process for principles and practices of digital fabrication. It consists of twenty weekly workshops and a final project to show how the students can integrate the skills acquired in weekly tasks. Fab Academy is coordinated by the Fab Foundation, an US non-profit organization that emerged from MIT's Center for Bits & Atoms Fab Lab Program with the goal of facilitating and supporting the growth of the international Fab Lab network. According to their site[1], Fab Foundation mission is "*to provide access to the tools, the knowledge and the financial means to educate, innovate and invent using technology and digital fabrication to allow anyone to make (almost) anything, and thereby creating opportunities to improve lives and livelihoods around the world.*"

[1] https://www.fabfoundation.org/index.php/about-fab-foundation/index.html

The active five-month part of the program is considered to require full time participation in the case of low or medium skills in digital fabrication. It is followed with a period of evaluation rounds still requiring some activity from the student correcting the documentation and improving workshop projects not meeting the standards. Fab Academy is based on MIT's course "MAS.863[J] How to Make (Almost) Anything". The lectures are still offered by the MIT over video communication and hands-on work is done locally in about 70 Fab Labs around the world every year. Fab Labs need to have qualified instructors and full inventories to participate in this program. There is no global academic accreditation for the Fab Academy [5]. The diploma is granted by the Fab Foundation. A person granted with the diploma is qualified to found and run a Fab Lab as well as to work as an instructor in Fab Academy.

2.3.1 Implementation

Fab Academy has a unique approach to distributed learning. Fab Labs form a global network to work together. This network has achieved 65 % graduation rate for the last three years, when some MOOC's have as low **as 6.5 %** success rate [8, 16]. Fab Academy addresses the challenges of distributed learning, such as poor transmission quality of the live content, limitations of classroom interaction, challenges in class administration and difficulty of getting help outside synchronous class. The limitations of class administration are related, for example, to in-class examples like why this type of milling bit was successful on milling printed circuit board and why it didn't work on milling wax mould when a student tried. The challenges are tackled as follows [21].

Fab Academy infrastructure has two main components: a video conference system and a project management system. The video conference system is used to broadcast lectures and live communication between the Fab Academy lecturers and the students in the nodes. In addition, it is utilized by experienced Fab Academy instructors (gurus) to provide tutoring to Fab Labs with less experienced instructors. Several cloud-based video conferencing systems have been tested, and currently Zoom[2] is in use.

The cloud-based project management system has multiple purposes: 1) students store the documentation they produce; 2) this information is deployed into a website to build the students' portfolios; 3) students can ask questions from any member of the network; 4) coordination of Fab Academy distributes knowledge (e.g. additional links to learn more about certain processes) and important communication (e.g. change in the schedule of the classes, recalling rules of the course); 5) Fab Academy provides feedback and assessment to students; 6) instructors and the coordination of Fab Academy use the system for internal communication. These last four purposes are implemented through "issues", similar to messages in an online forum.

The two-way video/audio connection between MIT-lecturer and Fab Lab nodes offering Fab Academy is actively developed and tested by the network. Limitations of class room interaction are tackled using a network of local instructors working with the students, supported and supervised by more experienced instructors

[2] https://zoom.us/

online or locally. Challenges of class administration are reduced by online content of examples and wiki pages, as well as documentation of (other) students' projects.

Figure 1 presents the structure of getting help outside class. The ***students*** are physically in the same location with the local instructor. The ***remote guru*** is an experienced instructor nominated by Fab Academy coordinator to assist Fab Labs without experienced instructors (i.e. with more than four years of experience). Gurus provide support both to students and local instructors. The ***regional group*** is formed by a group of Fab Labs, thus having several instructors, including at least one instructor with guru level experience. The goal of these regional groups is to support sharing knowledge among Fab Labs in the same region, as well as providing the expert experience of the gurus. The whole Fab Academy, with all the participants, instructors, lecturers, technical support and coordination, all the knowledge and experience of the system, forms the ***global group***. Communication is carried out asynchronously using issue trackers of the project management tool (GitLab) in widening circles. An online evaluation application is used. Students' documentation is evaluated in contrast to an assessment document and feedback is given through the application [6]. At the beginning of Fab Academy, only local instructors evaluate students. They invite the group of global, experienced instructors, to join the evaluation team when a student has progressed and is a potential candidate to complete the course.

2.4 Fab Academy in University Curriculum

Fab Academy is not part of any university curriculum. Table 1. shows how the Fab Academy is currently accredited in universities [5]. In the University of Oulu, it is accredited per request. The amount of ECTS study credit points has varied over

Figure 1: If local help is not sufficient, the group seeks help first from the remote guru and the final answer is provided by the global group. *Image: Anna Kaziunas France, Bas Withagen, Wendy Neale and Francisco Sanchez[6].*

time from 15 to 25. Having this education as part of curriculum would harmonize the practices.

Fab Lab	Accrediting body	Country	Credit offered	Status
FabLab Siena	University of Siena	Italy	ECTS	A
FabLab Madrid CEU	Madrid CEU University	Spain	ECTS	A
Fab Lab Oulu	University of Oulu	Finland	ECTS	A
Fab Lab Tecsup	Tecsup	Peru	Specialization Diploma	A
Fab Lab Kamp-Lintfort	Rhine-Waal University of Applied Sciences	Germany	Integration with existing degree programs	A
Fab Lab Bottrop	Hochschule Ruhr West University of Applied Sciences	Germany	ECTS	A
Fablab Digiscope	Paris Saclay University	France	Complete diploma	W
Fab Lab Facens	Sorocaba Engineering College	Brazil	Specialization	W
Fab Lab Wgtn	Massey University	New Zealand	Masters level	W
Litchee Lab	Shenzhen University	China	TBD	W
Vigyan ashram Fab-lab	Savitribai Phule Pune University	India	TBD	W
Vigyan ashram Fab-lab	Indian Institute of Technology	India	TBD	W

Table 1. Fab Labs from Fab Foundation's list, offering Fab Academy that universities accredit. (A = active, W = Work in progress.)

3 Methods

In this paper, we explore whether Fab Academy can be included "as is" in university curriculum. We compare Fab Academy with a university course and calculate Fab Academy's amount of work in ECTS by assuming one ECTS to equal 26,667 hours of work. Quality is established by comparing the range of subjects that are offered, as well as how exact definitions for the deliverables are provided for students.

We study the workload of Fab Academy students from Fab Lab Oulu. We compare the requirements to pass the university course titled "Principles of Digital Fabrication" against requirements to pass Fab Academy. Then, we compare assessment. Data is collected by questionnaires presented to Fab Academy students, from Fab Academy students' documentations and from course description in the university database. Furthermore, data is evaluated quantitatively.

4 Results

4.1 Quantitative Study

The questionnaire was sent to all nine graduates of Fab Academy 2018 in Fab Lab Oulu. They were asked to estimate the number of hours dedicated to the course, as well as to provide some qualitative feedback. The response rate was 100%. The education of Fab Academy graduates varied from Master's degree programme students to Doctor of Science (D.Sc.(Tech.)) on various fields: Chemistry, Process and Environmental Engineering, and

Electronics and Communications Engineering. The time the students A-I used for Fab Academy is indicated in Table 2. Doctoral students might have been faster than Master programme students due to their previous experience on acquiring information and documenting results. The Bachelor of engineering is a degree of applied university and the student might already have possessed these working life skills. The Doctor of Science in the program selected a large final project and hence worked more hours than the Doctoral students.

The average hours for Master's degree programme students **is 892.25 hours** and for Doctoral students and Bachelor of engineering 603 and 705 hours, respectively. The average of all students is 764.67 hours, with a standard deviation of 175.18 and a median of 705. The working hours of Master's degree programme students equal to 33 ECTS, while the average of all the students would be just below 29 ECTS.

Corresponding education in MIT, MAS.863[J], is eighteen units and one of MIT unit is approximately fourteen hours of work. Translation of MIT units would lead to (14*18/26.667) = 9.4 ECTS. However, the content isn't exactly the same. The leader of the Center of Bits and Atoms in MIT, professor Neil Gershenfeld, approximates the content to be at least a quarter of more in Fab Academy (i.e. resulting in at least twelve ECTS) and states there are more than one subject added into it. [27]

The background of the students has an effect on the hours required to complete Fab Academy. Previous knowledge of 2D and 3D-modeling, digital fabrication, electronics programming and web design and development is expected. Having knowledge level on these subjects between low and medium is seen to turn the Fab Academy for a full-time study. Our students in the University of Oulu lack the majority of this knowledge, hence we consider the proper amount of ECTS to be close to the number of reported hours.

On the other hand, Fab Academy requires from 16 hours up to 40 hours per week, resulting 658 hours when the program **is 23.5 weeks [7]. This is equal to 24.7 ECTS**. Fab Academy schedule shows twenty one week long workshops and the final project. What it doesn't show is local and global evaluation rounds of few weeks after the presentation of the final project. Students are still fixing and even implementing new things in the weekly tasks or final project. All in all, these calculations indicate that determining the number of hours based on the Fab Academy program results a value close to the average of the reported hours.

4.2 Qualitative study

4.2.1 Course Content

The course "Principles of Digital Fabrication" (521159P), in the curriculum of the University of Oulu, is a mandatory basic study for Computer Science and Engineering students. In addition, it is offered as an optional course to students from all other faculties of the university. It has several elements of Fab Academy in an introductory level. The course is performed in teams of four students. The deliverables of the project-based 521159P are the device built in the course, the documentation of the process and the final presentation with two or three slides to summarize the whole process and project. The 521159P has following requirements for the device built during the course:

(1) It must consist mostly of parts (solid and electronic) you have designed and manufactured in Fab Lab,(2) it needs to have moving parts that are controllable by software (that is, it should have at least one actuator such as motor or servo), (3) it must have at least one sensor and the software needs to react to its readings somehow.

The schedule of Fab Academy 2019 has twenty lectures, nine recitations and four possibilities for final presentation. The schedule is presented in table 3.

Student	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**Mean**	**Standard deviation**	**Median**
Master programme students			924		987		658		1000	892.25	159.65	955
Doctoral students	705	503		600						602.67	101.02	600
Doctors								800		800	-	-
Bachelor of engineering						705				705	-	-
	17th of January - 30th of June: 23.5 weeks								Sum.	764.67	175.18	705

Table 2. Work hours of the Fab Academy students A-I in Fab Lab Oulu 2018 are 765 in average

Date	Lecture	Recitation
January 16	principles and practices, presentations, introductions	
January 23	project management	
January 28		version control
January 30	computer-aided design	
February 6	computer-controlled cutting	
February 11		projects
February 13	electronics production	
February 20	3D scanning and printing	
February 25		tools
February 27	electronics design	
March 6	computer-controlled machining	
March 11		design
March 13	embedded programming	
March 20	molding and casting	
March 25		machines
March 27	input devices	
April 3	output devices	
April 8		programs
April 10	applications and implications	
April 17	break	
April 24	networking and communications	
April 29		economy
April 30	mechanical design	
May 8	interface and application programming	
May 13		education
May 15	machine design	
May 22	wildcard week	
May 27		events
May 29	invention, intellectual property, and income	
June 6	project development	
June 12	project presentations	
June 14	project presentations	
June 17	project presentations	
June 19	project presentations	

Table 3. Fab Academy schedule 2019

The first requirement of the 521159P compares with Fab Academy subjects: Computer-Aided Design, Electronics Design, Electronics Production and Computer Controlled Cutting or 3D-scanning and Printing. The second compares with Output Devices and the third with Input Devices. Furthermore, documenting the course project corresponds with Fab Academy subject Project Management, final presentation corresponds to Project Presentation and working in teams to Mechanical Design and Machine design weeks of the Fab Academy executed in groups.

However, the deliverables are larger and more precisely defined in Fab Academy [6]. General Essentials is a part of the Fab Academy Assessment Guide that explains all the necessary things that are common for all weekly tasks. For example, the General Essentials of Fab Academy Assessments forbids using commercial microcontroller boards, while one can use Arduino and other development boards in 521159P. In Fab Academy, one has to make own versions of electrical control boards. Another example is the third requirement of the 521159P: the produced end result should have at least one sensor, and the software needs to somehow react to its readings. This compares with Fab Academy Assessment "Input Devices" that is defined for the students in detail; how the weekly task is structurally connected with the Fab Academy learning process. A student is instructed that it is unnecessary to re-document parts explicitly documented earlier. Instead, the student should focus on the things currently being learnt, since learning cumulates; so, should the documentation.

In Fab Academy, a group project is given to students every week with the aim to familiarize and study design rule set, safety instructions and basic use of processes. The group project is carried out together with the student group and instructor and collaboratively documented. Individual, weekly projects are then given to each student to learn how to design objects for the process. Students must again make their customized electrical boards with microcontroller and sensor for the task and document the whole process from idea to the final functional and programmed product that can for example show a temperature bar on computer display in real time. Weekly workshops of Fab Academy have also much wider tasks compared to the weekly load of the 521159P, such as "Model (raster, vector, 2D, 3D, render, animate, simulate,…) a possible final project, and post it on your class page." on Computer-Aided Design. The students need to test a wide variety of programs and to select the ones they want to use. Several programs are documented in the process. On "3D Scanning and Printing" week of Fab Academy, students learn 3D-scanning and 3D-printing design rule sets along a task to design something that can't easily be made by subtractive processes. In 521159P, students 3D-print the designed objects with the help of the personnel of Fab Lab.

The 521159P consists of seventeen hours of lectures, midterm and final presentations and self-study. Teaching assistant will be available for students for sixteen hours during the course.

The Fab Academy consists of 60 hours of global lectures, 40 hours of local lectures, 9 hours of specialists' recitations, presentations and self-study. The instructor will be available for the students at least 336 hours during the education, including the local lectures.

4.2.2 Learning Outcomes

In 521159P, the learning outcomes are to learn a process of digital fabrication in Fab Lab. The students learn how to design mechanical parts with CAD for 3D-printing or laser cutting, create basic electronic circuits, and how to control physical objects with microcontroller. In addition, the students learn creative design and problem solving in teams.

In Fab Academy, a set of learning outcomes is defined for each weekly workshop. These outcomes can be, for example, to demonstrate workflows in circuit board design and fabrication and implement and interpret programming protocols. There are 45 learning outcomes specified in Assessment Guide. Some of them cover more than one subject such as evaluate and select 2D and 3D software [6].

4.2.3 Assessments

In 521159P, assessment is based on a group project and requires a functional prototype, as well as documentation of the process. The grades are pass and fail.

In Fab Academy Assessment Guide, a check list is provided for students and used for evaluation as well. For example on Output Week, the check list has four items: 1) Have you described your design and fabrication process using words/images/screenshots, or linked to previous examples?; 2) Have you explained the programming process/es you used and how the microcontroller datasheet helped you?; 3) Have you outlined problems and how you fixed them?; and 4) Have you included original design files and code? There are 85 items to check during evaluation to accept a student's documentation. A set of Frequently Asked Questions is answered to clarify what students found unclear on previous years. General Essentials is to be followed.

As a summary, course content of the Fab Academy is deeper and larger compared to the 521159P. Learning outcomes of the Fab Academy are precisely defined and assessment set to clear evaluation criteria.

5 Discussion

The qualitative study shows that Fab Academy has the required scale, quality and assessment processes to be added in university curriculum without modifications. Based on the

quantitative study, we suggest 25 ECTS for the Fab Academy courses that are integrated into university curriculum. Our recommendation is influenced by the desired granular size of a course in our university (five ECTS), as well as the content of Fab Academy. As one semester is 30 ECTS, this amount fits into the curriculum, leaving room for one additional five ECTS course. Hence, students can concentrate on Fab Academy.

We note that ECTS measures the hours required from the students to study the subject. As the average of the reported hours was higher than 25 ECTS, attention has to be paid in decreasing the workload of the students. Monitoring the workload is important when the studies are extended to new universities. The backgrounds of students vary; hence, the teachers need to observe the situation and increase support as needed to keep the studies in 25 ECTS.

Adding Fab Academy into the curriculum with 25 ECTS would lead to a worldwide increase in value for Fab Academy as a student could include these studies in a university degree recognized in the university. This would also increase the level of knowledge of university students on latest digital fabrication processes targeted to everyone in Fab Labs.

We propose dividing Fab Academy in five courses by subject to be integrated into university curriculum (see Table 4). The division is designed to spread the workload between the courses evenly. We propose to use the same evaluation criteria Fab Academy uses and build an overlay to university system and assessment documentation of Fab Academy [6].

Evaluation is one strength of Fab Academy. Students are evaluated by a group of collaborating global evaluators; Fab Academy instructors with the minimum of four years of experience. Sharing experience in the network improves the consistency and quality of evaluation. Furthermore, peer support helps individual Fab Academy nodes to improve their operations, specifically the newcomers.

These five courses would allow to graduate from Fab Academy as well. If Fab Foundation would accept partial credits, the courses could be divided over more than one year to help to schedule the academic terms. The proposed division is presented in Table 4. We currently have set course codes for these courses we propose at the University of Oulu. There is still a lot of work

Course	**Fab Academy Workshop 1**	**Fab Academy Workshop 2**	**Fab Academy Workshop 3**	**Fab Academy Workshop 4**	**Fab Academy Workshop 5**
Fab Lab Project Management	principles and practices, presentations, introductions	project management	computer-aided design	computer-controlled cutting	invention, intellectual property, and income
Fab Lab Electronics	electronics production	electronics design	input devices	output devices	
Fab Lab Programming	embedded programming	interface and application programming	applications and implications	networking and communications	
Fab Lab Digital Fabrication	3D scanning and printing	computer-controlled machining	molding and casting	wildcard week	
Fab Lab Project Work	mechanical design	machine design	project development	project presentations / Final project	

Table 4. Subjects of Fab Academy and how they are connected to suggested university courses

on this subject, including funding and getting the courses into study guide. The university overlay is going to be tested first time during spring 2019. These five courses can form a specialization to digital fabrication and rapid prototyping in a
degree programme. On the long run, a new Master's programme could be built. This programme could start with a fall semester focusing on a technological or business topic: electronics, computer science, telecommunications, software engineering, mechanical engineering, or economics, **for examples**. The Fab Academy courses would fill the second semester. The third and fourth semesters could be based on Grow with Fab (http://grow.academany.org), focusing on developing further the Fab Academy projects, and business development. Such a degree programme would produce experts that can build product prototypes from scratch, can develop business for these products, and would have more detailed knowledge on the subject studied during the first semester. We expect such experts to be valuable, specifically for small companies and in business, to communicate interdisciplinary projects to experts of different fields.

Fab Academy realizes distributed and collaborative learning that combines synchronous and asynchronous distance learning methods. On one hand, the synchronous method is used for the lectures taught weekly at the same time to all the nodes of the network. On the other hand, students can work online on the weekly projects at their own pace, only coming into a local Fab Lab for hands on part of the project, still having the support of local instructors. The combination of both course delivery methods produces the most effective education [24]. In addition, the asynchronous approach gives more possibilities to integrate Fab Academy into different universities' education.

We suggest gathering more data of the time the Fab Academy students use for the education and whether it correlates on students' backgrounds, to determine if Fab Academy, in fact, teaches working life skills in addition to teamwork and digital fabrication.

Moreover, the challenges of distance education can be tackled while keeping its benefits. The global network, consisting of experts of the field, increases the quality and provides peer support, specifically to teach the new teachers. At the same time, the local instructors take care of face-to-face guidance and thus decrease the psychological distance. Together, the global, regional and local instructors have the tools to realize high-quality distributed education – providing teaching by experts and supporting the students to master the subject.

As a summary, we find based on this study that Fab Academy is comparable to master's level courses, both in quantity and quality. Fab Academy, originated from MIT's course, is ready to be brought back into university refreshed into five courses of five ECTS in the University of Oulu and all over Europe.

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