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Research Article

Fractal Curriculum: A Trend in Curricular Reform

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Abstract

The purpose of this study is to introduce a curriculum called fractal curriculum that is being implemented at Indian Institute of Technology Hyderabad (IITH), one of the chain of 23 elite institutes in India. This article was brought together by introducing the existing system of higher education in India, defining the fractal curriculum and describing it. This fractal curriculum allows a more flexible approach to teaching, by introducing students to open-ended research projects early on in their undergraduate education. This curriculum design encourages students to compose their own curriculum to better match their interests and passion. It further fosters a greater breadth of knowledge within students. In addition, this type of curricular design also allows learners to become life-long learners by motivating them to gain knowledge in subjects of their interest

Key Words

Fractal curriculum • Curricular reform • Curriculum design

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India, being one of the densely populated countries in the world, with a population of more than 1.2 billion people (All India Council for Technical Education, 2017), emphasizes that one of the key drivers of development of the country is education (Vaish, 2010). With the recognition of the importance of education, the Indian government shows a strong desire to develop a system of higher education to match with the global competition in producing citizens who are highly trained technical personnel (Sebaly, 1973). Under this stress to compete with the world in terms 157 of development and ever-growing population, Indian higher education has strived to satisfy the student demand to meet the educational needs of the society. Within India, the system of higher education is coordinated by the Ministry of Human Resource Development (MHRD) and administered by the University Grants Commission (UGC) that monitors the accreditation mechanism, quality, and promotes reforms. Under this governance, the higher education sector has 753 universities established under various sectors of the country and 41,435 colleges in India as of 2016-2017 academic year (University Grants Commission, 2017).

Among these universities and colleges in India, Indian Institutes of Technology (IITs) are considered prestigious engineering and technology-oriented institutions, which are declared as "Institutes of National Importance" by the government of India (All India Council for Technical Education, 2017). After independence from the British rule in India in 1947, excellence in science and engineering education was believed to be crucial for transformation from an underdeveloped and technologically backward nation into a modern advanced nation. One of the significant schemes by the Indian government was to build a chain of IITs to provide advanced education in science and engineering to produce highly technical personnel to contribute to the economic growth of India (IITs, 2017). This movement resulted in the foundation of the five IITs with the help of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Soviet Socialist Republics (U.S.S.R), Germany and the United States of America (U.S.A) (Sebaly, 1973). IITH is one of the eight IITs that were founded in 2008, which is located in a city called Hyderabad in southern India.

Admission into these IITs is extremely competitive in India. The admission to these prestigious institutes is administered through all India standardized test called Joint Entrance Exam (JEE). The first IIT-JEE examination was administered in 1960 in April and is continued thereafter every year (Subramanian, 2015). Their acceptance rate is very low and the student must score a rank within the top 20% to be able to be admitted into the IITs. In 2016, only 27,152 students were given admission into these IITs when around 1.3 million students appeared for the examination (Inside Higher Ed, 2017). The students who take this IIT-JEE exam go through a very intense training program during their junior and senior high school years.

Need for Curricular Reform

With its foundation laid in the twenty first century, IITH is a rather young institution, which sought a new vision into the area of undergraduate curricular innovation. The perceived role of higher education according to IITH is to convey knowledge, create knowledge, create and develop ideas, develop these innovative ideas to help future citizens to create a better society. The current generation of students who enter into IITs are often been subjected to many hours of after-school intensive training, which are mostly geared to performance on competitive exams and not necessarily to foster a love of learning (Inside Higher Ed, 2017; Annual Reports, 2017). Students often arrive at the IITs with lower to no motivation for further rote learning.

Regarding the development and research in higher education, "the obvious strategy, steady as she goes, is doomed to fail; the one thing you don't do in the path of an avalanche is stand still!" (Barber, Donnelly, & Summers, 2013, p. 2). In addition, Barber et al. (2003) suggest that the solid classical buildings of great universities may look permanent but the storms of technological and globalization changes now threaten them. In India, technological and globalization developments have changed various other prominent fields like banking, economy, healthcare and technology already; however, education has not been up to the speed. Thus, IITH proposed that there is a necessity for IITs to graduate students who are lifelong learners equipped with technical knowledge who serve as creators of jobs rather than mere job seekers. Thus, the administrators at IITH along with faculty members suggested that there is an urgent need across India for a fresh approach to education of the highly competitive students who are weary of rote learning (External Peer Review, 2017; Fractal Academics, 2017). There are some additional reasons for the curricular reform proposal from IITH policy makers such as:

- The traditional university is being unbundled
- Learning providers are emphasizing learning by practice and mentorship
- Administrators will need to have a keen eye toward creating value for their students

Although the purpose for reform was identified, there were still lingering questions that forced the administrators to research on curricular innovations that would allow learners to be motivated to learn. Some of the questions were as follows:

- Does the curriculum need complete overhaul?
- What are the appropriate models of teaching and learning now that the traditional lecture seems out-of-date?
- Which students should be targeted?
- What global allowances will be necessary?
- Why low attendance?
- Are students motivated?
- Why uneven student interest?
- How to bridge between theory and practice?
- How can the relevance of non-technical topics be integrated into technical areas?
- How much flexibility is possible?
- How can we allow interdisciplinary research?
- Has the three credit hour system outlived its utility?

To address these questions, the administration at the IITH made its initial attempts to introduce and implement Fractal curriculum.

Description of Fractal Curriculum

With the higher education system in India being administered centrally and the system in implementation for so many years, curricular reform is a challenging task for any institution. To address these questions and the challenges, IITH has introduced a new "fractal approach" to its curriculum (Fractal Academics, 2017). This allows a more flexible approach to teaching, by introducing students to open-ended research projects early on in their education. It encourages students to compose their own curriculum to better match their interests and passion. It further fosters a greater breadth of knowledge within students. Such experimentation with curricula is much needed in India, and efforts of IITH in breaking the ground in curricular reform are revolutionary (Annual Report, 2017). In order to provide some answers to the curriculum related difficult questions stated above, IITH first started with fractional credit courses by dividing their typical 3-credit course that has 42 contact hours into courses with 0.5, 1.0, 1.5, 2.0, 2.5, and 3 credits (Fractal Academics, 2017).

What are Fractals?

In simple terms, a fractal appears to repeat a similar pattern throughout all levels regardless of the different levels of magnification (Goff, 1998). Historically, the cross-sectional view of Romanesco broccoli in figure 1 is used as an example of self-similar complexity in nature. From the figure, the distinguishing patters of hills and valleys remain virtually identical at different levels of magnification when compared with the cross-sectional view of broccoli under a microscope or the vegetable as a whole from a distance (Kiraly, 2012).

Figure 1. An Example of Fractal Nature Observed Through a Leaf, Cross-Section of Broccoli and Water Patterns on a Stone (Kiraly, 2012)

Similarly, the self-similarity characteristic of fractals can be seen in branches and roots of plants and trees, shape of a snowflake, mountain range, craggy coastline, and the structure of the human vascular and nervous systems. It is noted that the mathematicians who are fractal geometricians, emphasize that self-similar structures are found everywhere in nature "unlike the perfect Euclidean forms that children learn about in school and that we often utilize to impose rigid order on both artifacts and human activity" (Kiraly, 2012, p. 84). Educational and social settings also display fractal interactions as well (Goff, 1998; Kiraly, 2012). Because of the complexity and uncertainty of the nature of classrooms resulting from the intertwining of learners' individual knowing, collective knowledge and cultural identities, as self-similar aspects of the same phenomenon, which can thus be understood only in their relationships with other elements within the structure. Thus, in curricular perspective, fractal nature is a suitable way of understanding complex classroom structures, both structurally and operationally (Caena & Margiotta, 2010). Fractionation already occurs in many areas of science and life like

fractional dimension, images, architecture, and Isotope fractionation, in distillation, food, fractional derivatives, fractional transforms and other complex areas of science (Fractal Academics, 2017).

Building Blocks

The building blocks of the fractal curriculum are the introduction of 1 credit hour courses for broader knowledge and 2 credit hour courses for deeper knowledge on the single subject. Numerous breadth courses are offered that are typically a 1-credit hour to help build a broad perspective and depth courses, which are 2-credit hours are offered to build on the foundation set by the breadth courses. The first two semesters expose students to all the basic tools required for the rest of their undergraduate program. In addition, measures are taken to seek a balance between technical and non-technical courses to reduce stress when students enter IITH. The curriculum potentially makes students ready for internships or apprenticeships right after the first year. The fractal curriculum allows a set of advantages to various members of IITH.

- For undergraduate students, this curriculum allows the option to choose from various elective courses by providing access to a wide variety of courses allowing increased exposure and preparedness for research. It also allows students to have more research and/or project time from each extra course helping in the foundation for product development
- Allows interdisciplinary research along with flexibility for students to better tailor their coursework and choose from across various departments
- Introductory 1 credit technical courses provide students a window into crucial topics, and
- Allows faculty to be mentors than mere lecturers by allowing them to explore various methods of pedagogy, teaching strategies and potentially lower teaching load by offering summer courses, and teaching their own research work.

Figure 2. Example of Fractal Courses within First Two Semesters

Course Number	Course Name	Credits	Segment	When it runs in a Semester					
				1	2	3	4	5	6
Semester 1									
ID1035	Independent Project	1	16						
CY1017	Environmental Chemistry-I	1	12						
ID1041	Engineering Drawing	2	16						
ID1054	Digital Fabrication	2	16						
ID1100	Fluid Mechanics-I	2	46						
ID1130	Engineering Statics	2	13						
ID1171	Fabrication Lab - I	2	16						
ID1303	Introduction to Programming	2	36						
MA1110	Calculus-I	1	12						
MA1220	Calculus-II	2	36						
	Total	*17*							
Semester 2									
CE2020	Construction Materials	1.5	46						
CE3512	Introduction to Environmental Engineering	1	12						
CY1020	Dynamics of Chemical Systems-I	1	12						
EE1330	DSP	1	34						
ID1140	Thermodynamics - I	1	12						
ID1150	Thermodynamics - II	2	36						
ID1160	Solid Mechanics - I	2	13						
LAxxxx	LA/CA Elective	2							
MA1130	Vector Calculus	1	12						
MA1140	Linear Algebra	1	34						
MA1150	Differential Equations	1	56						
ME1030	Dynamics	2	46						
	Total	*16.5*							

The motivation behind the fractal academic program was to divide the focus of the faculty among teaching and to involve industry partners in some aspects of academics. According to the policy makers at IITH, the student enthusiasm, their commitment, and their output were added benefits for continuing to develop more fractal courses. Based on the overall success of fractional credit courses, they developed a complete 4-year curriculum called as Fractal Academics. Given below is an example of fractal courses within first two semesters in a undergraduate program at the IITH (IIT, 2017).

The core of fractal academics includes the breadth courses that are of 1 credit, while depth courses are typically of 1.5 to 2.5 credits. This fractal division of courses is planned within a discipline to disintegrate the academic program to for faculty to focus on teaching and involving students in real time projects in an industrial environment, providing a more holistic education, and in the long run giving students the choice to design their curriculum.

First Implementation

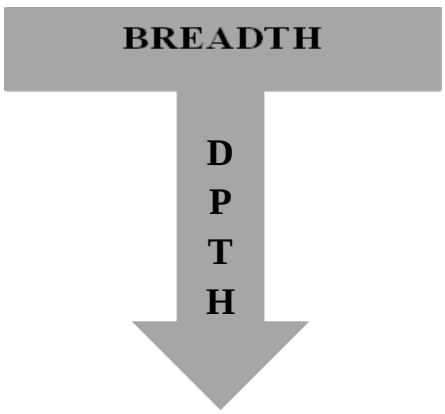
Fractal academics was first implemented at the IITH for the Electrical Engineering department in August 2013. From Aug 2014 all engineering departments followed Fractal Academics. IITH faculty developed this program and is constantly evolving based on feedback from students and faculty (Annual Report, 2017; Fractal Academics, 2017; IITH, 2017).

Philosophy behind Fractal Curriculum

In order to sustain the ever-changing world, "fractal-like sensibility, with its emphases on attentiveness and responsiveness to the immediate, is the one that must be embraced" (Davis & Sumara, 2000, p. 840). The key idea behind implementing fractal curriculum is to atomize courses, provide breadth and depth, emphasize courses in liberal arts as well as creative arts, emphasize project work, and create an interactive learning ambiance. In this approach the students will be well equipped to handle challenges of any job or challenges of post graduate education (Annual Reports, 2017).

This fractal academics is a very different view of curriculum in which instructors must still work together to determine appropriate learning goals (Fowler, 1996). The main philosophical strategy is to allow students to gain knowledge not only in depth about their chosen discipline but also a broader knowledge over multiple disciplines making their degree multidisciplinary (IITH, 2017). The term IITH policy makers used for this is called "T" model as shown in figure 3.

Figure 3. "T' model



Some peculiar advantages of using fractal academics are given below (Fractal Academics, 2017):

- Encourages student creativity to think differently
- Enhances current/older system
- Is motivated by the success of fractional credit courses
- Is based on faculty experience at IITH
- Allows faculty research to be easily modularized into 1-credit courses rather than a full 3-credit course
- Is more flexible and allows for incorporating cutting edge research into curriculum
- Allows exposure to topics and details
- Core courses offered early on during the first three semesters
- Helps students make informed decisions on their specialization choices
- The slow track program can benefit from the larger pool of technical and non-technical courses on offer
- Will helps students in finding jobs in competitive world

According to the external review report of IITH, using fractal curriculum increased the allowance for project based courses from 2% to 14 % by allowing students to gain deeper knowledge about subjects.

Initial Attempts

As a result of initial attempts, a typical 3 lecture course with 3 credits leading to 42 lecture hours in a semester has been divided into fractional credits of 0.5, 1, 1.5, 2.0, 2.5, 3.0 having 7, 14, 21, 28, 35 and 42 lecture hours respectively. Along with fractal courses, the fractal academics allowed students to have double majors, choose to have a major and a minor in their degree, offered core electives, free electives, science electives and LA/CA electives.

Fractal academic program at IITH was designed with utmost care and focus given to students which has following strengths when implemented. Fractal curriculum was designed and implemented to

- Foster creativity
- Better exposure to larger number of topics
- Allow more flexibility in breadth and depth
- Allow Interdisciplinary and undergraduate research
- Enhance easier implementation of slow track program
- Develop holistic education
- Despite the benefits of implementing fractal academics listed above, it has some challenges that lend themselves for the reason to critique. The cons of implementing this curriculum are:
- Hard time finding instructors for non-technical courses
- Time management
- Subject courses spread too distant resulting in losing focus
- Distracting/context switching
- Affecting placement

In addition to the above listed cons of implementing this fractal curriculum, there are some challenges while implementing this curriculum. The following section narrates the challenges while implementing this curriculum.

Challenges in Implementing Fractal Curriculum

In addition to the above challenges, prior research suggested that participants described it as "a journey of many journeys of interpretations" (p. 327) resulting in productive misunderstandings (Caena & Margiotta, 2010). To this end, despite the careful planning that has been put into developing this new curricular reform, choosing from a variety of course options will lead to confusion and stress among students that they may or may not feel comfortable sharing with their faculty advisors at the undergraduate level. This is especially true if the faculty advisor is also one of their instructors and an administrator. Further, the new generation of IITs not only aims at high-quality undergraduate education, but also, even from their very founding, a high-quality postgraduate education and research.

Although, IITH is renowned for research in highly technical subjects like environment and energy, digital communications, design and manufacturing, and nanotechnology and nanoscience, they lack in research about their instructional practices. Research in instructional practices and strategies are equally commendable which would help them improve their instructional strategies and at the same time improve their program by making sufficient modification through their professional development for faulty program.

Furthermore, more often than not, the students would have to learn "how to use the system themselves and then perform the task at hand under considerable time pressure" (Kiraly, 2012, p. 89). This is especially true when faculty advisors are not available for the students to discuss the program. In addition, it also adds tremendous amount of pressure on faculty members to manage their teaching, research, administrative load and service. Finally, there is no evidence that the curriculum defines objectives for teaching and learning while designing, implementing and delivering the curriculum. Defining objectives during the designing phase of the curricular reform to have a more defined program would give a scope for students to understand the expectations from an individual course or semester or the entire program. This will also help new faculty to understand the system better since this is the first implementation of fractal curriculum in India.

Definition of Terms

Below are some terms IITH faculty defined to help clarify new terminology related to fractal academic program (Fractal Academics, 2017).

Credit. The quantitative measure of recognition given to a course, stated in semester hours. Typically, a theory course running for a full a semester with three contact hours per week would be 3 credits. Similarly, a lab course with the same number of contact hours would be 2 credits.

Major. The primary set of discipline-specific coursework pertaining to the student's department/discipline

Minor. Additional basket of coursework done from a discipline different from the student's original discipline (and would find mention in the final degree)

Double Major. Coursework pertaining to two departments/disciplines and leading to two separate degrees.

Additional Course. An additional course taken by the student over and above the minimum credit requirements of the degree.

Pre-requisite. The preliminary requirement, usually successful completion of another course that must be met before a course can be taken.

Elective. Course chosen by the student, which would be a part of his/her, degree requirements.

Free Elective. A course of the student's choice, to be selected from the any department (subject to meeting the pre-requisites)

Core Elective. A course of the student's choice, to be selected from the same department (or offered by a different department, but identified as "core" by one's department)

LA/CA Elective. A course of the student's choice, to be selected from the Liberal Arts and Creative Arts category

Science Elective. A course of the student's choice, to be selected from the Math, Physics & Chemistry list of courses

Fractal Segment. The part or duration of a semester in which a particular course is offered.

Conclusion and Implications

In summary, the fractal curriculum developed and implemented by IITH faculty was an influential curricular reform in India to encourage students to be innovative and graduate with degree resulted from the courses that they chose out of their passion. This fractal program also allowed students and faculty to be more flexible with their choice of courses to include in their program. This engaged student body has more chances to become highly effective and active workforce that is essential for the development of the country. In addition, the research and project-based curricula will allow students to learn with passion and engage in their learning process allowing them to shift away from rote learning techniques. However, some details need to be addressed to refine the fractal curriculum to accommodate better instructional and learning experiences for faculty as well as students. The studies on this could be further extended in terms of defining learning objectives, learning and instructional strategy inclusion, integrating educational technology to accommodate technological needs of the students in preparing them for the technologically sound workforce and fostering research skills through lower credit course from the beginning of degrees.

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