A Combinatorial Optimization of Consumer Behaviour: A Case Study of BYJU'S

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***Abstract*—Online education surged during the pandemic with governmental support like e-learning in India. Ed Tech forecasts changed due to COVID impacts, affecting both GDP and ac- cess to resources. Post pandemic, ed-tech companies faced challenges as demand shifted back to in-person learning. Overcrowding, unsustainable growth, and failing to adapt to hybrid models led to failures. Regulatory changes and funding constraints further impacted the industry. The combinatorial problem of matching Ed-Tech companies to success factors effectively analyse the situation in this paper we study the mathematical aspect of decline the education tech industries. . Using Hall's Marriage Theorem, we can argue that Byju's and other companies like it were unable to match to enough favourable conditions, leading to their decline. As the theorem predicts, without a sufficient number of favourable conditions available for all companies, some companies will inevitably fail to match and thus face decline.**

***Index Terms*—EdTech, combinatorics, Byjus, Bipartite Graph, Hall's Marriage Theorem**

1 INTRODUCTION

Online education has seen rapid growth globally, especially during COVID-19 pandemic. This trend driven by the increasing the demand for flexible and accessible learning option the government of India also supports and promote online education by intuitive like e- learning by the National education Policy (NEP) because they want to spread education on the remote areas. Ed-Tech market forecasts are based on statistics from previous years, trends and expert opinions, but they have all changed significantly due to limi- tations caused by the COVID-19 pandemic. According to Global Ed Tech Report 2020 coronavirus had a multidirectional effect on the EdTech market. Negative results are GDP slowdown, a decrease in education income, especially in the corporate sector, and an in- crease in debts citizen and providers. Positive results include increased access to resources and digital acceleration. The first phase of the COVID-19 pandemic led to an immediate shift in supply chains opportunities. Education was less disruptive than corporations, as the value proposition for 1 training can be transmitted over the Internet. Govern- ment support has been expanded, but does not compensate for all losses. Education is undergoing a huge experiment in distance learning and will move into the second phase of the pandemic with a deeper use of Ed-Tech platforms. A prolonged global economic downturn will reduce business costs for education and training, even more than the first wave of COVID-19. Education will be affected, but partially isolated by the government. The recession will increase the demand for retraining and extend the time in education. Private investment capital will migrate to educational and training organizations with digital delivery capabilities. Significant capital remains uninvested and unclaimed. The government tax base will be reduced, but will seek to protect funding for education and training through direct financing and indirect incentives. COVID-19 required the massive introduction of digital technology, and for a significant part of the economy, virtual oper- ation will continue and be improved to increase efficiency in times of crisis. Education is undergoing a similar digital transformation. The end of the COVID-19 pandemic caused significant challenges for many ed-tech (educational technology) companies. While the pandemic accelerated the growth of the ed-tech sector due to the sudden need for remote learning, its conclusion brought about changes in consumer behaviour, funding, and de- mand. Below is a detailed explanation of why some ed-tech companies struggled or failed after the pandemic. During the

Pandemic Schools, colleges, and workplaces transitioned to remote setups, creating an urgent need for online learning tools. Ed-tech companies saw a surge in users and revenue. As restrictions eased, many institutions returned to in-person education. Parents, students, and teachers preferred traditional classroom set- tings, leading to a significant drop in the demand for purely online solutions. The Ed-tech sector became overcrowded as start-ups and established players rushed to capitalize on the surge in demand. Venture capitalists heavily funded Ed-tech companies, leading to rapid but unsustainable growth. With declining demand, the market could not support the vast number of players. Many companies found it difficult to differentiate themselves, leading to intense competition and failures. Many users adopted Ed-tech solutions out of necessity during the pandemic but did not remain loyal once the need diminished. Retaining customers required continuous innovation and engagement, which some com- panies failed to provide.Many Ed-tech companies expanded rapidly, focusing on acquiring users rather than building sustainable revenue streams. They offered heavy discounts or free trials to attract users, which hurt profitability. As venture capital funding dried up in a more cautious investment climate, companies with weak revenue models struggled to survive. Ed-tech companies often invested heavily in technology, marketing, and talent acquisition during the pandemic boom, these high fixed costs became a burden, forcing layoffs, cutbacks, or shutdowns. Many institutions adopted hybrid learning (a mix of in-person and online), reducing reliance on fully online solutions. Companies that failed to adapt to hybrid needs or provide tools for both in-person and online scenarios lost rel- evance. Governments worldwide introduced stricter regulations for ed-tech companies to ensure transparency, 2 fair practices, and data privacy. A company that could not com-ply with these regulations or failed to adapt their business practices faced fines, bans, or customer mistrust. The pandemic highlighted the drawbacks of excessive screen time and the lack of personal interaction in online learning. As people sought more holistic and interactive learning experiences, companies that focused solely on digital content without addressing these concerns lost traction. The post-pandemic period saw global economic challenges, including inflation and recession fears. Families and institutions prioritized spending on essentials, reducing budgets for supplementary Ed-tech services. Investors also became cautious about funding speculative ventures, affecting the ability of Ed-tech companies to secure capital. There are some Examples of Struggling or Failed Ed-Tech Companies

- Byju's (India): Although still operational, Byju's faced significant losses, layoffs, and valuation drops due to aggressive acquisition strategies and over-reliance on loans during its rapid expansion.
- VIPKid (China): The company suffered after the Chinese government introduced reg- ulations restricting for-profit tutoring, leading to a massive loss of its business base.
- K12 (USA): Some online charter schools reported declining enrolment as students re- turned to physical schools.

In this paper we study the mathematical aspect of decline the education industries.

2 LITERATURE REVIEW

Abhishek Bansal, Shreyas Pophalkar, Chandni J. Vidani (2023) [1] studied and provide a comprehensive review of the Ed-Tech sector in India by examining its current state, iden- tifying key trends, and exploring the factors contributing to its growth and challenges. It investigates the diverse range of educational technologies being employed, including online platforms, mobile applications, virtual classrooms, and adaptive learning systems. Victor V. Timchenko, Sergey Y. Trapitsin, Zoya V. Apevalova 2021[2] discussed and identify new factors for the correction of existing forecasts by analyzing intermediate business results for the first half of 2020, the opinions of analysts and futurologists. The task was difficult due to the lack of relevant information and the on-going limitations of the pandemic, but thier work are extremely important precisely in times of crisis and limitations to identify new risks and opportunities. The interest of their research extends to the Russian Ed-tech market. Tanmaya Mishra, Bindiya Gupta. Bhumika Achhnani 2024[3] studied the dark side of indian ed-tech

companies such as The Indian Ed-tech en- vironment reveals numerous disconcerting features, the increasing integration of Ed-tech platforms in school education has led to growing worries over screen addiction an mental tiredness among children.

Rajkumar Ashok Kankariya, Khushali Oza,Ragini Bhat,2024[4] study highlighted the SWOT of the EdTech Startups in India, and also comparatively analyzed the marketing strategies, financials, acquisition and merger strategies of leading startups in India. The study also highlighted the challenges faced by the EdTech Industry in India. The re- searcher found that the EdTech startups have significantly revolutionized the Education Industry in India.

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3 METHODOLOGY

In present work we are focusing on the use of bipartite graph and Hall marriage theorem

.in our research [5] A bipartite graph is a graph whose vertices can be divided into two disjoint sets such that no two graph vertices within the same set are adjacent. For our analogy, the two sets represent:

1. Set A (Services Offered by Ed-Tech Companies): This set includes various online courses, tutoring sessions, educational apps, etc.

2. Set B (Needs of Students and Parents): This set includes different learning require- ments, preferences for subjects, modes of learning, etc.

A perfect match means every vertex in Set A (services) is connected to a unique vertex in Set B (needs). This would ensure that each service offered by the EdTech Company meets a specific demand.

Here is a simple diagram of a bipartite graph for this scenario:

Set A (Services)		Set B (Needs)
Service 1	−→	Need 1
Service 2	−→	Need 2
Service 3	−→	Need 3
Service 4	−→	Need 4

Each arrow represents a matching between a service and a need. During the pandemic, there was a perfect matching, ensuring that every service met a particular need. Post- pandemic, the matching might be disrupted, leading to services not meeting current needs, resulting in a mismatch and subsequent decline.

Let's consider

1. Set A: Online Math Tutoring, Coding Classes, Science Experiment Kits, Language Learning Apps.
2. Set B: Math Tutoring Need, Interest in Coding, Science Project Requirement, Desire to Learn a New Language.

Set A (Services)		Set B (Needs)
Online Math Tutoring	−→	Math Tutoring Need
Coding Classes	−→	Interest in Coding
Science Experiment Kits	−→	Science Project Requirement
Language Learning Apps	−→	Desire to Learn a New Language

However, if post-pandemic preference changes, and there's less interest in online learning:

Set A (Services)		Set B (Needs)
Online Math Tutoring	−→	Math Tutoring Need
Coding Classes	−→	Interest in Coding
Science Experiment Kits	X	Science Project Requirement
Language Learning Apps	X	Desire to Learn a New Language

Online Math Tutoring and Coding Classes still find matches. Science Experiment Kits and Language Learning Apps don't meet the current demands. This disruption illustrates the mismatch between services and needs, leading to financial strain and the need for realignment by Ed-Tech companies. Hall's Marriage Theorem is a mathematical concept in combinatorics that deals with perfect matchings in bipartite graphs. In simpler terms, it ensures that in a given situation, there is a way to pair up elements from two sets such that each element from the first set is matched uniquely to an element from the second set. Now, applying this concept to the decline of the Ed-Tech industry, particularly using BYJU'S as a case study:

1. Two Sets: Set A: Represents the variety of educational resources and services offered by Ed Tech companies (like online courses, tutoring, etc.).

Set B: Represents the diverse needs and preferences of students and parents.

2. Matching Principle: For EdTech companies to succeed, there needs to be a perfect match between the services offered (Set A) and the needs of students (Set B). This means that every service (or educational resource) must find a corresponding demand from the users.

3. Initial Success: During the pandemic, there was a strong match between the online education services (Set A) and the needs for remote learning (Set B). This led to the rapid growth of companies like BYJU'S.

4. Post-Pandemic Shift: As traditional in-person classes resumed, the needs of students and parents shifted. This resulted in a mismatch between the online services offered by EdTech companies and the actual demand. The perfect matching was disrupted.

5. Financial Strain: Just like in Hall's Marriage Theorem, if not every element of Set A (services) can find a unique match in Set B (needs), then some services become redundant or irrelevant. This results in financial strain, layoffs, and the decline of these companies.

6. Adaptation and Survival: To survive, Ed-Tech companies need to adapt by diversifying or reshaping their services to align better with the current needs of students and parents. This reestablishment of a perfect match is crucial for their recovery and future growth. In essence, the decline in the Ed-Tech industry, as seen with BYJU'S, can be partially understood through the lens of Hall's Marriage Theorem: the disruption of a perfect match between services and user needs. For the industry to thrive again, a new balance and perfect matching must be found.

4 PROPOSED MODEL

English mathematician Philip Hall proved the theorem in 1935[6]. It is a result in combina- torics that specifies when distinct elements can be chosen from a collection of overlapping finite sets. This theorem used in matching problem, College admission problem. We can model the decline of Ed Tech companies using combinatorics by imagining a situation where a company must select from a set of favourable conditions to succeed. Each con- dition represents a critical factor contributing to their growth and sustainability. The absence of a favourable condition can be viewed as a" failure." Let us consider the uni- verse U be the set of all possible conditions that could impact the success of an Ed Tech company.

$U =$ {High Demand, Market Saturation, Funding, Customer Engagement, Profitability, Regulatory, Environment, Economic Conditions}

Favourable condition the set $F \subseteq U$ represents favourable conditions

F = {High Demand, Customer Engagement, Profitability}

Unfavourable condition the complementary set $F^c \subseteq U$ represents unfavourable con- ditions. If companies are unable to select enough favourable conditions from F and are instead constrained by elements from F^c the decline in growth happen.

$F^c = U - F =$ {Market Saturation, Funding Problems, Regulatory Scrutiny, Poor Economic Conditions}

Success Probability The probability of success for an EdTech company could be mod- elled as combinatorial problem where the company must choose a certain number of favourable conditions to thrive. Suppose a company must satisfy at least k favourable conditions to succeed, where k is a threshold that represents the minimum number of key success factors.

Number of Ways to Select Favourable Conditions The total number of ways to select any k favourable conditions from F is given by:

where $|F|$ is the number of favourable conditions

Number of Ways to Fail Similarly, if a company picks a set of conditions and it in- cludes too many from F it will fail. The number of combinations where the company picks fewer than k favourable conditions is:

where m is the total number of conditions the company faces.

4.1 Decline Scenario Ed-Tech companies are declining because, in many cases, they are operating in environments where $m - k$, or the number of unfavourable conditions, is too large. In

a combinatorial sense, the" decline" happens when there are more ways to fail than to succeed because the pool of unfavorable conditions F has grown dispropor- tionately larger than the pool of favorable ones F. Thus, the probability of success, given by the ratio of favorable outcomes to total outcomes, decreases as the number of unfa- vorable conditions increase. To analyze the decline of education technology (EdTech) companies using Hall's Marriage Theorem, we need to model the situation in terms of
bipartite graph matching. Here's a step-by-step approach to framing and solving the problem:

4.2 Understanding Hall's Marriage Theorem

Hall's Marriage Theorem provides a condition for determining whether a perfect matching exists in a bipartite graph. Specif- ically, in a bipartite graph G = (A, B, E), there exists a matching that completely matches every element of set A to set B if and only if for every subset S of A, the num- ber of neighbors of S in B is at least as large as the number of elements in S. Formally

$\forall S \subseteq A, |N(S)| \geq |S|$

where A and B are two disjoint sets. E is the set of edges connecting elements of A to elements of B. N(S) is the set of all neighbors of S in B.

4.3 Modeling the Ed-Tech Decline Problem

To apply Hall's theorem, we need to define appropriate sets A and B, and the relation- ships between them. Let us consider

Set A (Companies): Each element represents an Ed-Tech company that needs to thrive by satisfying certain favorable conditions

Set B (Favorable Conditions): Each element represents a specific favourable condition necessary for an Ed-Tech company's success. Based on the initial combinatorial model, let us define B = High Demand, Customer Engagement, Profitability These are the fa- vorable conditions F identified earlier. An edge exists between a company C in A and a favorable condition f in B if company C can successfully satisfy condition f . This relationship can be influenced by factors such as resources, expertise, market positioning, etc.

4.4 Applying Hall's Marriage Theorem To determine whether all Ed-Tech compa- nies can be successfully matched to at least one favorable condition, we assess whether
Hall's condition is satisfied

4.5 Evaluating Hall's Condition

For every subset S of companies A, the number of unique favourable conditions N(S) that these companies can satisfy must be at least as large as the number of companies in S:.

$\forall S \subseteq A, |N(S)| \geq |S|$

4.6 Implications: If Hall's Condition is satisfied there exists a matching where every company is matched to at least one favorable condition. This scenario suggests that, in theory, all companies have the potential to thrive by meeting the necessary conditions. If Hall's Condition Fails, there exists at least one subset of companies S where $|N(S)| < |S|$. This means that the number of available favourable conditions is insufficient for the num- ber of companies in S to be matched. Consequently, some companies will fail to satisfy the required conditions, leading to decline. Given the current landscape where Ed-Tech
companies are declining, it's likely that Hall's condition is not being met. because with B = High Demand, Customer Engagement, Profitability, there are only three favorable conditions. During the pandemic, many Ed-Tech startups emerged, increasing the size of set A. As the number of companies —A— grows, and if each company requires multiple favorable conditions to succeed, the fixed number of conditions in B becomes insufficient. For subsets S of companies where $|S| > |N(S)|$, Hall's condition fails, indicating that not all companies can be matched to the necessary conditions. Companies that cannot be matched to sufficient favourable conditions will struggle to sustain operations, leading to
a decline in the sector. Consider a simplified example:

Let Set A represent 5 Ed-Tech Companies C_1, C_2, C_3, C_4, C_5

And Set B represent 3Favorable Conditions f_1, f_2, f_3

Then the Possible Relationships are:

- C_1 can satisfy f_1 and f_2
- C_2 can satisfy f_1
- C_3 can satisfy f_1 and f_3

- C_4 can satisfy f_3
- C_5 can satisfy f_1 and f_3

And Assessing Hall's Condition:

- Subset $S = \{C_1, C_2, C_3\}$
- $N(S) = \{f_1, f_2, f_3\}$
- $|N(S)| = 3, |S| = 3 \longrightarrow$ (Condition Met)
- Subset $S = \{C_1, C_2, C_3, C_4\}$
- $N(S) = \{f_1, f_2, f_3\}$
- $|N(S)| = 3, |S| = 4$ (Condition not Met)

Since there's at least one subset S where $|N(S)| < |S|$, Hall's condition fails. This implies that not all companies can be matched to favourable conditions, leading to some com-

panies' decline. By modelling the decline of Ed-Tech companies through Hall's Marriage Theorem, we observe that: The limited number of key favourable conditions relative to the growing number of companies leads to unmet requirements for many companies. Companies unable to satisfy essential conditions cannot sustain growth or profitability, contributing to the overall decline in the Ed-Tech sector. This combinatorial perspective highlights the critical imbalance between available favorable conditions and the increasing

number of companies needing to satisfy them, offering a structured explanation for the observed downturn in education technology enterprises.

5. Case Study: The Decline of Byju's (An Indian Ed-Tech Giant)

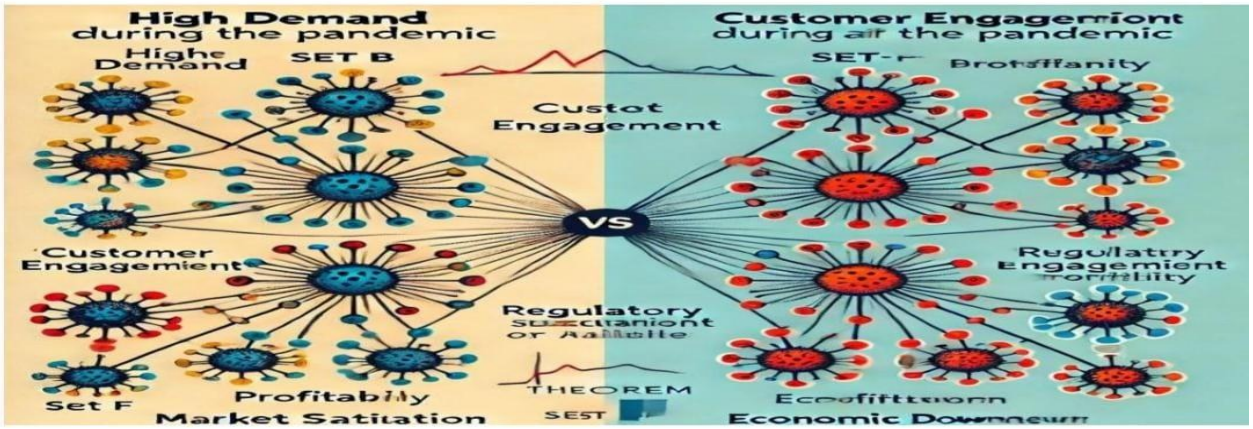
Byju's is one of the largest education technology companies in the world, having experi- enced rapid growth during the COVID-19 pandemic. However, after 2021, the company started to face significant challenges, leading to layoffs, a decrease in valuation, and an overall decline in its market position. We can use the combinatorial model and the Hall's Marriage Theorem approach from earlier to understand why Byju's and other similar EdTech companies faced difficulties. Byju's Founded in year 2011, from 2011 to 2019 the growth of company is very slow but during COVID-19 pandemic the growth of company is very high, The Business Model of Byju's was Online learning through a mobile app, offering interactive video lessons for K-12 students, competitive exam preparation, and other learning tools. Byju's was once hailed as the future of learning, especially during the pandemic, when online education became the primary mode of learning worldwide. Its massive expansion included international acquisitions, heavy marketing, and billions of dollars in venture capital funding. The success of Ed-Tech companies like Byju's relied on a few key favorable conditions. During the pandemic, there was a surge in demand for online education solutions as physical schools were closed. Byju's capitalized on interac- tive video lessons and personalized learning tools to engage students effectively. Byju's relied on paid subscriptions, partnerships, and aggressive marketing strategies to gen- erate revenue. During this period, we saw that from hall marriage theorem condition met. After the pandemic, the environment changed drastically With so many players entering the EdTech space, competition increased significantly. Other companies, like Unacademy, Vedantu, and new startups, began competing for the same audience, reduc- ing Byju's market share. Many customers found it hard to stay engaged after the initial excitement. High churn rates and users not renewing subscriptions became a major chal- lenge. As the venture capital funding environment tightened in 2023, Byju's, like many other startups, found it harder to raise funds to fuel its growth. In India, the govern- ment started scrutinizing online education platforms and private coaching institutions. The stricter regulations around K-12 education put Byju's under pressure. The global economic slowdown meant that many middle-class families were no longer willing or able to pay for premium educational 9 services, especially when cheaper alternatives became available post-pandemic. In this duration we saw from Hall marriage theorem condition are not met.

So we saw that how we can discuss the decline of Byju's by our praposed model.

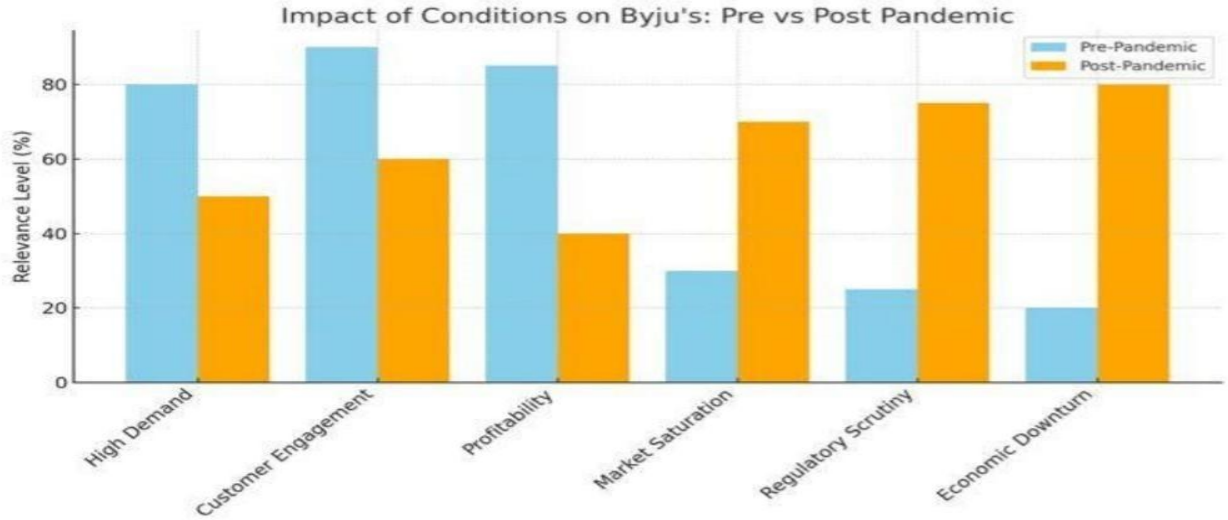
6. Graph Interpretation

In this scenario, Byju's represents one of the companies C_1 in the graph, trying to con- nect with favorable

conditions. At its peak, Byju's satisfied most of these conditions, but post-pandemic, many of those connections weakened.



In our graph framework Byju's initially had connections to High Demand, Customer Engagement, and Profitability during the pandemic. Post-pandemic, High Demand de- creased as physical schools reopened, disconnecting Byju's from this condition. Profitabil- ity also became an issue due to high customer acquisition costs, marketing overspends, and a funding crunch, causing Byju's to lose its connection to this condition. In terms of the bipartite matching problem, Byju's found itself in a situation where Fewer favorable conditions (set B): The available favorable conditions became fewer as demand fell and the company faced financial difficulties. Growing challenges set *F* The unfavorable con- ditions (market saturation, regulatory scrutiny, and economic downturn) outpaced the favourable ones. Using Hall's Marriage Theorem, we can argue that Byju's and other companies like it were unable to match to enough favourable conditions, leading to their decline. As the theorem predicts, without a sufficient number of favourable conditions available for all companies, some companies will inevitably fail to match and thus face decline. Byju's response to these challenges included Byju's laid off over 2,500 employees in 2022 to cut costs. The company reduced its aggressive marketing campaigns. Byju's sought to renegotiate its loan terms as financial pressure increased. By 2023, investors began to express concerns over the company's financial management, leading to a reduc- tion in Byju's valuation. The bar chart compares the conditions of Byju's during the period before the pandemic (baseline period) and the conditions during and after the pandemic (during and after the pandemic).



Favorable Conditions: (Pre-Pandemic), Since schools were closed in the pandemic, online education was highly in demand and had high relevance. Byju's engagement was high on its platform because students were switching to online learning. Favorable factors enabled Byju's to remain profitable even in a scenario of high customer acquisition costs. Unfavorable Conditions: (Post Pandemic), As the ed-tech sector's competition intensi- fied, it became difficult for Byju's to grow. Ed-tech firms came under government and regulatory authorities' scrutiny, thus making it tougher to expand. The period after the pandemic witnessed major economic disruptions which reduced the disposable income, thus impacting the ability of Byju's to acquire new customers.

Market	Pre pandemic	Post pandemic
High Demand	Scored 80 % since there was a greater need for learning online.	Decreased to 50 % with the increased reopening rates of schools creating lower de- mand.
Customer Engagement	Reached 90%, reflecting ac- tive users during lockdowns	Fell to 60%, as students returned to physical class- room
Profitability	Was strong (85%) as Byju's capitalized on the growing demand	Dropped to 40%, impacted by overspending on market- ing and acquisition costs.
Market Saturation	Had low relevance (30%) as Byju's dominated the mar- ket.	Rose sharply to 70%, re- Flecting intense competi- tion.
Regulatory Scrutiny	Minimal (25%) because the edtech industry was rela- tively unchecked	Increased to 75% as gov- ernments imposed stricter rules.
Economic Downturn	Had negligible relevance (20%).	Peaked at 80%, severely affecting Byju's operations and customer acquisition.

The graph can also be interpreted in the light of Hall's Marriage Theorem. Before the pandemic, favorable conditions (such as high demand, customer engagement, and prof- itability) were far more than unfavorable conditions. This gave Byju's a good match between its operations and market needs. However, post-pandemic the number of fa- vorable conditions decreased drastically, while unfavorable conditions increased. This mismatch created an imbalance, as Byju's could no longer "match" itself to enough fa- vorable conditions. According to Hall's Theorem, when there are insufficient matches, the system (Byju's) becomes unstable, leading to challenges like declining revenues, lay- offs, and financial pressure. It captures how the favourable conditions have dwindled and how the unfavorable ones have been rising, making clear the kind of problem that Byju's faced in the post- pandemic scenario. It also reveals the systemic issues of playing in a competitive, regulated, and economically unstable playing field.

7. CONCLUSION

Byju's case illustrates how the failure to maintain connections to essential favorable con- ditions can lead to a company's decline. The combinatorial problem of matching Ed- Tech companies to success factors (using Hall's Marriage Theorem) effectively models the situation. When the available favorable conditions (such as demand and profitabil- ity) decrease, companies that cannot secure enough of these conditions will falter, as seen with Byju's. The challenges faced by Byju's are common across the Ed-Tech indus- try, where post-pandemic market saturation, reduced demand, and economic pressures have affected many companies that thrived during the COVID-19 period. Here is the bipartite graph representing the rise and decline of Byju's, highlighting its connections to favourable conditions during its growth phase and unfavourable conditions during its decline Companies must adapt to complement

traditional education systems rather than replace them. Revenue diversification and cost optimization are crucial for long-term survival. Offering personalized, interactive, and gamified learning experiences can help retain users. Compliance and ethical practices are vital to maintaining trust and credi- bility.

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