Keith Chang, Kyle Griffith, Brandon Martinek, Brian Sevin, Zachary Trela, Mike Zimmerman
Harnessing Complexity in Creating Engineering Online Education

139

Harnessing Complexity in Creating Engineering Online Education

Keith Chang, Kyle Griffith, Brandon Martinek, Brian Sevin, Zachary Trela, Mike Zimmerman, Texas Tech University, Mechanical Engineering Department, Lubbock, Texas, 79409, USA, Email: kyle.griffith@ttu.edu

The main objective of this paper is to examine the complexity of creating an online education system aimed at engineering and working professionals displaced by automation in the near future. Online classes are becoming more popular among universities and community colleges for their lower costs, ease of access, and geographically diverse student body. Although online classes are being adopted in higher education there are still problems to cope with this technology driven educational model. This research paper investigates these factors and their relationships affecting online education. Exploration of the factors affecting online education produced unsurmountable issues which led to the conclusion of a hybrid education system that would be superior to both online and current education systems.

Keywords: Online education, blend education, complexity in education, generic education.

1 Introduction

From 1980 to 2014, the average cost of college tuition increased by nearly 260 % [1]. As a result, student debt has skyrocketed. According to Forbes, as of 2018, borrowers owe a collective $1.5 trillion in student debt [2]. The high cost of education isn't isolated to college. Education at the K-12 level is also very expensive. For instance, the 2017 budget for the United States Department of Education was $69.4 billion [3]. According to the US Department of Education, the budget "makes crucial investments that build on the Administration's work to advance educational equity and excellence, support teachers and school leaders, and promote college affordability and completion." The United States spends an immense amount of money on education. However, despite the massive budget, the quality of education hasn't improved. Case in point, since 1970, test scores in reading, math, and science have remained stagnant. As seen in Figure 1, spending has grown incredibly but scores have remained constant [4].

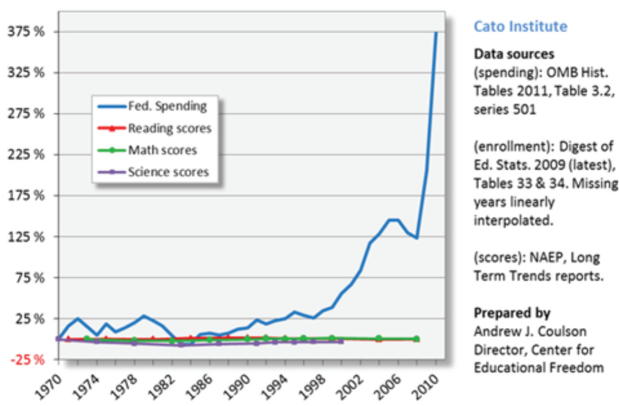Furthermore, the U.S. educational infrastructure

Figure 1: Spending vs. Test Scores [4].

is crumbling. On average, U.S. school buildings are 45 years old [5]. Outdated buildings can cause significant educational problems. For example, according to the Washington Post, due to failed boiler systems, schools in Maryland never warmed beyond 40 degrees. Infrastructure problems will only worsen as the population of the United States is projected to increase to 398 million by 2060 [6]. Education is one of the most important factors that contribute to a country's success. Also, more than ever, a college education is a prerequisite for upward mobility. According to Eduardo Porter from the New York Times, "Men with only a high school diploma earn about a fifth less than they did 35 years ago." [7] For this reason, we are proposing a convenient and affordable world class online educational experience to students in the United States. Our proposal includes a fully integrated online approach. Instruction will be delivered online by exceptional educators. Moreover, our educational experience will be interactive through video conferences and online discussion activities. Courses will be paired with interactive assessments and activities as well as evaluations to ensure courses are fully comprehensive and effective. As noted by Sean Reardon, of the Center for Education Policy Analysis at Stanford, "the achievement gap between more affluent and less privileged children is wider than ever" [7]. This proposed program aims to eliminate that gap by delivering a standardized high-quality educational experience to all students regardless of income. David Pritchard along with three other researchers at MIT conducted a study to assess the viability of online education. Their findings were published in the International

Review of Research in Open and Distance Learning. The study showed that in an online MIT course, "the amount learned is somewhat greater than in the traditional lecture-based course" [8]. Accessibility, convenience, and consistent education across income levels are just few advantages of online education. In addition, students would be able learn from anywhere which would reduce the burden currently placed on educational infrastructure.

Also, commuting to and from school would vanish. This would reduce pollution due to transportation, and it would save time for both children and parents. As the cost of education continues to explode, and as the achievement gap between income classes grows wider it is apparent that a fully comprehensive online educational experience is needed.

2 Factors affecting Online Education

Ten overarching design factors have been identified in order to address the goal of creating an advanced online educational platform.

2.1 Funding

Funding is a design factor that could be especially problematic. In order to attract the most talented educators, meaningful benefits must be offered. Furthermore, a significant amount of funding would be invested into equipment, servers, and other overhead costs. Difficulty in securing funding most precisely stems from the fact that our program is not profitable. However, the virtual educational platform would be most appropriately funded by government-based funding, social programs, and or philanthropical sponsors.

2.2 Faculty

Selecting instructors and building a network of educators is a primary design factor for the proposed online educational platform. Prerecorded lectures would be delivered to students through an online platform. These lectures would be available at any time allowing greater flexibility for students. Frequently, students will need extra help or clarification to supplement the curriculum. Educators would be made available at specific times throughout the week

to virtually communicate with students and build meaningful educational relationships.

2.3 Academic Integrity

An educational platform of any kind is established on its reputation, quality of staff, and students. Academic integrity is integral to education systems, as this will build credibility and create value behind the certifications and degrees. In order to ensure a high level of academic honesty students will be required to be physically present at a designated testing facility for the midterm and final exams. All efforts to mitigate academic dishonesty and further the enhance reputation of the virtual learning platform will be taken.

2.4 Social development

The proposed educational platform provides the unique ability for individuals, regardless of social economic status, to achieve an advanced degree. The current state of higher education is vastly expensive, this is partly in due to the various non-academic ventures traditional university pursue. The proposed virtual platform will limit the operational costs associated with a traditional classroom allow for a reduction in cost for the students.

2.5 Societal Interest

A transition period between current school systems and this modern version of teaching could make or break the entire program. Formal and professional recognition must be perceived as an equivalent or superior replacement of the current education system. Educational brand recognition from society as a whole is invaluable approval. Perhaps most importantly, proof of graduation from courses of the program need to be taken seriously by potential employers as an achievement not a certificate. If the program is taken seriously by employers and professionals more students will be eager to join. Measures to attract incoming students will be made to ensure a high initial enrolment rate. Furthermore, the board and shareholders will aim to increase resources at a linear rate to prepare for future enrolment growth.

2.6 Cost to Deploy

To get the program off the ground infrastructure is essential; a website crash on day one would lose a large chunk of support and interest from the public. To avoid this, servers capable of sudden and heavy traffic need to be in place and tested before launch. The website to access the courses must also be easily navigable and professional. This means web designers need to be contracted to create and test the website before it receives heavy traffic. The lectures online need to be taught by certified professionals who may or may not volunteer their time to film. If they do not volunteer their time, they need to be paid for their lectures before deployment of the program. Government funding would help and may be likely if it can be pitched as a cheaper alternative to public schools.

2.7 Affordability

The program is primarily meant to be an affordable alternative for individuals with lower income for whom higher education is too costly. With this prerogative it is imperative to keep the price low despite whatever costs are faced by the program. Additionally, infrastructure must be provided to ensure that even places without access to high speed internet can utilize the program.

2.8 Transition to system

The transition stage for students from the current school system to the online interactive system is difficult task. It will be tough for the students to acquire the credible documents they would receive with the current education platform. The difficulty is also on the developer's side in making this platform motivating and attractive to the students. Much like a traditional classroom has required lectures, students will be required to participate in virtual assignments to ensure a high level of academic involvement. Student motivation and enthusiasm will stem from the provided interesting and interactive virtual lectures.

2.9 Adaptability

The adaptability of curriculum to changing times will require, at minimum, an annual platform wide update. Along with updating curriculum, there will be a need for a cyber security team to protect the
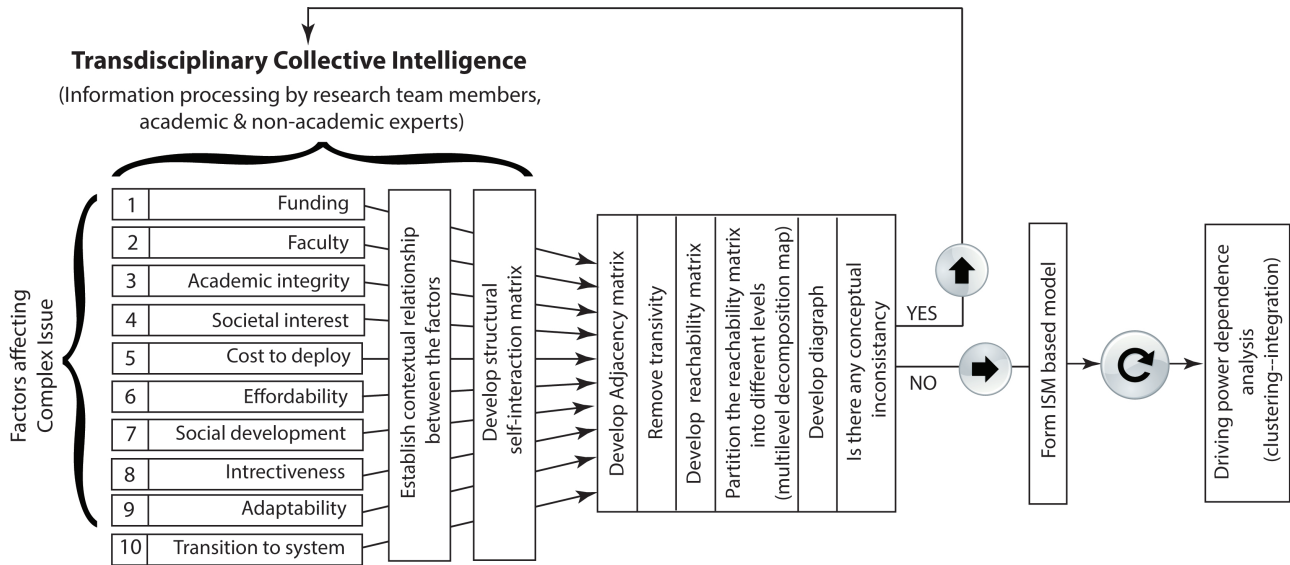
Figure 2: Sequence of activities to develop ISM model.

platform from people trying to corrupt/alter it. Updating the platform will be a difficult and highly burdensome task. The cost of a cyber security team can be relatively high depending on how secure the platform needs to be.

2.10 Interactiveness

The nature of remote or distance learning can often lead to a minimally engaged student audience during lectures. Furthermore, the removal of face to face interactions between students and faculty limits possible professional connections and networking opportunities. The proposed virtual learning platform will host physical or skype based offices hours in addition to networking events in order to promote student engagement.

3 Results and Discussions

3.1 Interpretive Structural Modeling

Interpretive Structural Modeling (ISM), atransdisciplinary tool for dealing with complex issues. It was first proposed by Warfield in 1973. It is a computer-assisted learning process that provides good understanding of how different factors are related to each other. This methodology helps researchers to structure the factors affecting the complex issue in a meaningful manner to develop collective intelligence to overcome challenging complex problems. General activities to build an Interpretive Structural Modeling are shown in Figure 2.

Figure 3: Spending vs. Test Scores [4].

3.2 Structural Self-Interaction Matrix (SSIM)

Through extensive literature search, the structural self-interaction matrix shown in Figure 3 is created. In this figure, a 'V' is placed if the 'i' factor affects the 'j' factor. An 'A' is placed if the 'j' factor affects the 'i' factor. An 'X' is placed if both factors affect each

other. Lastly, a '0' is placed if neither factor affects the other. The SSIM matrix is used to determine which factors will affect one another. In developing structural self-Interaction matrix, if the relationship between factors is week, we assumed that there is no relationship between factors.

As shown in Figure 3, 'V' shows Academic Integrity affects Adaptability (see third row). The reason for this is, as with any online education, policing academic dishonesty is very difficult. This means complex solutions will need to be implemented on the platform. Societal Interest is shown to affect Affordability. For the program to become affordable one of two things must happen; the government needs to contribute to the funding or enough students need to sign up so a lower price per student can still keep the servers maintained and employees paid.

In this complex problem it is shown that Funding is affected by Cost to Deploy. An easy correlation can be made between these two factors because the Cost to Deploy must be covered by Funding before any student applies for the program. Funding is also affected by Transition to System. Transitioning to this new form of education could happen slowly and locally–in which case lower funding would be required–or quickly go internationally–in which case a large amount of funding would be required to handle the influx of students. Faculty is also shown to be affected by Transition to System with a similar correlation. The speed of transition will determine the need for faculty and the rate at which new faculty members will need to be hired. Social Interest is affected by Transition to System as it would increase interest from students if the transition is done smoothly. Affordability is affected by Adaptability because the simpler of a program is on the web design side the more affordable it will be. When adaptability is key to the website however, the cost of the program increases. Interactiveness is shown to be affected by Adaptability through the web design as well. The more adaptable the website is the more interactive it can be for students. Interactiveness is also shown to be affect by Transition to System. This correlation is due to the unknown ease and speed of transition to the new system as it will affect the ability for the service to provide an interactive system to an unknown amount of users.

The 'X' in the SSIM is used to show the factors affect each other. This is seen in Faculty and Cost

of Deployment being interdependent. This is due to Faculty raising the Cost of Deployment and the Cost of Deployment of other components of the program affecting the amount of Faculty that can be hired. Academic Integrity and Interactiveness affect each other through web design of the program. It will need to be capable of answering questions from students quickly while still being able to catch potentially dishonest students exploiting answers. Societal Interest and Social Development are interrelated due to the stigma students might put with having classes online, lowering the interest from the public. In order to mitigate this Social Development is also interrelated to Interactiveness and Adaptability as the interaction from the program could lead to a normal social development through adaptable strategies from the program. Adaptability and Transition to System will be interdependent because the ability to transition to the new system will depend on how adaptable the program is and the more adaptable the system is the more likely an easy transition will be.

The '0' denotes no relation between the two factors, this can be seen in all combinations of two factors not previously mentioned.

		1	2	3	4	5	6	7	8	9	10
Funding	1	1	0	0	0	0	0	0	0	0	0
Faculty	2	0	1	0	0	1	0	0	0	0	0
Academic Integrity	3	0	0	1	0	0	0	0	1	1	0
Societal interest	4	0	0	0	1	0	1	1	0	0	0
Cost to deploy	5	1	1	0	0	1	0	0	0	0	1
Effordability	6	0	0	0	0	0	1	0	0	0	0
Social development	7	0	0	0	1	0	0	1	1	1	0
Intrectiveness	8	0	0	1	0	0	0	1	1	0	0
Adaptability	9	0	0	0	0	0	1	1	1	1	1
Transition to system	10	1	1	0	1	1	1	0	1	1	1

$\mathbf{A} =$

Figure 4: Adjacency matrix.

3.3 Adjacency Matrix

The adjacency matrix ($\mathbf{A}$), shown ins Figure 4 is developed by transforming the SSIM into a binary matrix by substituting V, A, X, and O by 1 and 0 per the schema described below for each element.

- When V, (i,j)th entry becomes 1 and (j,i)th entry becomes 0.
- When A, (i,j)th entry becomes 0 and (j,i)th entry becomes 1.
- When X, (i,j)th and (j,i)th entries become 1.

Keith Chang, Kyle Griffith, Brandon Martinek, Brian Sevin, Zachary Trela, Mike Zimmerman
Harnessing Complexity in Creating Engineering Online Education

144

- When O, (i,j)th and (j,i)th entries become 0.

3.4 Reachability Matrix with Transitivity

The transitivity matrix, shown in Figure 5 is created by applying the transitivity rule to the initial reachability matrix. Transitivity states that if factor A is related to factor B and factor B is related to factor C, then factor A is related to factor C.

Figure 5: Reachability matrix with transitivity.

3.5 Final Reachability Matrix

To create the final reachability matrix, the rows and columns are summed using the Reachability Matrix with Transitivity. The summation of the columns gives the dependence while the summation of the rows gives driving power. Figure 6 is the final form of the relationships of all the factors involved with the complex issue. Having 10 factors as shown in figure 6, the total driving power is 57 and the dependence is also 57. The driving power and dependence will be used to classify the factors into four clusters - autonomous, dependent, linkage, and Independence, later.

Figure 6: Final reachability matrix.

3.6 Level Partition

The online calculator is used for the first level of partitioning and the remaining two levels were created using the SSIM. The previously obtained driving force and dependence help to classify the factors into groups. These groups positions are determined by the separation of the antecedent set and the reachability set. From these two sets an intersection set is determined. The factors common in the reachability set and the antecedent set are included in the intersection set. The intersection set is the set of factors that appear in both the reachability and antecedent sets. If the reachability and intersection sets are the same, the factor belongs in the top level and are removed for the next iteration. This iteration process is repeated until all the levels are identified. As shown in Table 1, factors 1, 6, and 8 are found to be at level I. Hence, it will be positioned at the top level group in the ISM hierarchy. This process is repeated until the complex problem is decomposed to all its levels. The factors along with their reachability set, antecedent set, intersection set and levels, are shown in Tables 1, 2, and 3. These levels help to build the diagraph and ISM model.

As shown in Figure 7, the association of sets and binary relations through matrices can now be converted into graphical form by using theory of diagraphs. If there is a relationship between factors i and j, the connection between factors will go from i to j. Finally, the diagraph can be converted into the ISM based model to give a broad representation of the interrelationship between the factors. Figure 7, shows that there are no isolated factors. Furthermore, factors 1 and 2 represents the linear mapping which preserves the acyclicity properties of the systems while factors 3,4,6,7, and 8 are more intertwined and will require more careful design planning to address each of the factors requirements.

Figure 8, driver-power-dependence diagram, is developed by importing the driving power and dependence of each factor. All factors affecting system performance have been classified into four categories. Cluster one includes autonomous factors. Factors 1, and 2 have low driving power and low dependence; thus, they can be ignored in designing educational platform.

There are no factors placed on the boundary lines; therefore, each factor is well placed in each of their respective clusters. The factors in the linkage cluster

Table 1: Level I (first iteration)

Variable	Reachability Set	Antecedent Set	Intersection Set	Level
1	1	1, 2, 5, 9,10	1	I
2	1, 2, 5, 10	2, 5, 9, 10	2, 5,10	
3	3,6,7,8,9,10	3,7,8,9,10	3,7,8,9,10	
4	4,6,7,8,9	4,5,7,8,9,10	4,7,8,9	
5	1,2,4,5,6,8,9,10	2,5,9,10	2,5,9,10	
6	6	3,4,5,6,7,9,10	6	I
7	3,4,6,7,8,9,10	3,4,7,8,9,10	3,4,7,8,9,10	
8	3,4,7,8,9	1 2 3 4 5 6 7 8 9	3,4,7,8,9,10	I
9	1,2,3,4,5,6,7,8, 9,10	3,4,5,7,8,9,10	3,4,5,7,8,9,10	
10	1,2,3,4,5,6,7,8, 9,10	2,3,5,7,9,10	2,3,5,7,9,10	

Table 2: Level II (second iteration)

Variable	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,5,10	2,5,9,10	2, 5,10	II
3	3,7,9,10	3,7,9,10	3,7,9,10	II
4	4,7,9	4,5,7,9,10	4,7,9	II
5	2,4,5,9,10	2,5,9,10	2,5,9,10	
7	3,4,7,9,10	3,4,7,9,10	3,4,7,9,10	II
9	2,3,4,5,7,9,10	3,4,5,7,9,10	3,4,5,7,9,10	
10	2,3,4,5,7,9,10	2,3,5,7,9,10	2,3,5,7,9,10	

Table 3: Level III (third iteration)

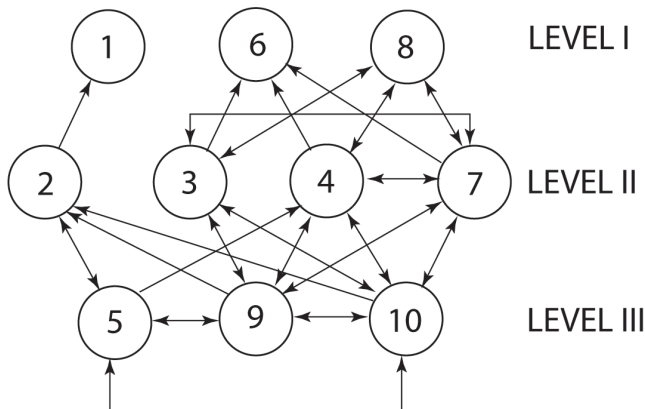| Variable	Reachability Set	Antecedent Set	Intersection Set	Level
5	5,9,10	5,9,10	5,9,10	III
9	5,9,10	5,9,10	5,9,10	III
10	5,9,10	5,9,10	5,9,10	III

Figure 7: Digraph based on reachability matrix.

must be given extreme importance due to their high driving power and dependence power. It is important to note that there are 3 components in this cluster thus emphasizing the complexity of this issue. The independent cluster includes factor 5 with a strong driving power yet weak dependence. This component

is the key driver for this system. This MICMAC analysis is very important to fully develop a solution for this complex virtual education concept.

This research paper brings forward a new online interactive approach to the education system. Factors 10 and 9 are located in the linkage cluster with both very high driving power and dependence. Factor 10 and 9, adaptability and interactivness respectfully, must be treated with the utmost respect as both factors are extremely important. The adaptability of curriculum to changing times is a factor to consider when designing this online interactive system, because the curriculum at any level of education changes every year. Therefore, the system needs to be up to date with the latest changes.

To ensure the students learning, the interactive ability of the courses is a factor to consider to keep the students interested. This factor can be handled by creating a very interactive system that engage and motivate the students to learn. Factor 5, cost to deploy, is located in Cluster IV with a strong driving
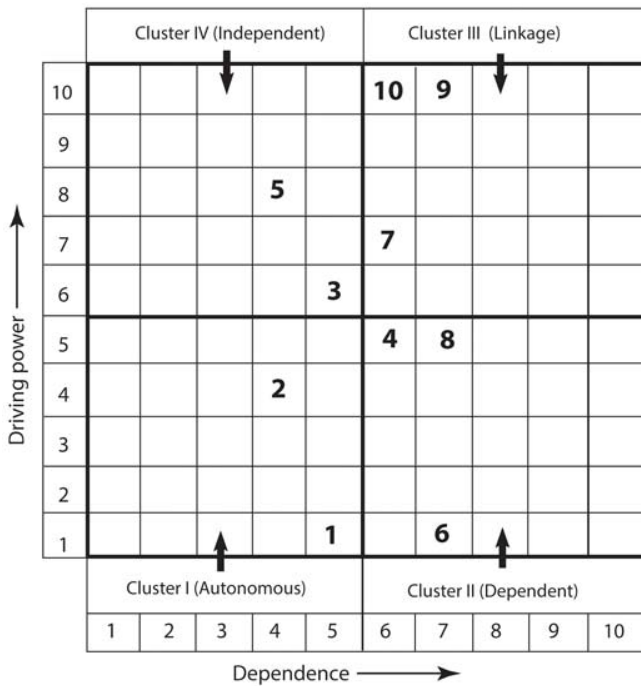
Keith Chang, Kyle Griffith, Brandon Martinek, Brian Sevin, Zachary Trela, Mike Zimmerman
Harnessing Complexity in Creating Engineering Online Education

146

Figure 8: MICMAC Analysis.

power yet relatively low dependence. The cost to deploy the virtual Learning platform is a key driver for the systems performance. This factor requires maximum attention so that the system functionality does not go out of control.

4 Cyclomatic Complexity

Cyclomatic complexity metric was developed by Thomas J. McCabe in 1976 and it is based on a control flow representation (graph which consists of nodes and edges) of the program [10]. Mathematically, the cyclomatic complexity, M is calculated by

$$M = E - N + 2P \qquad (1)$$

where

E = the number of edges of the graph
N = the number of nodes of the graph
P = the number of connected components

The number of edges shown in Figure 7 is 21, the number of nodes is 10 and the number of connected components, P is equal to 1. Then, the cyclomatic complexity M of the digraph given in Figure 7 is

$$M = 21 - 10 + 2 \times 1 = 13 \qquad (2)$$

McCabe stated that, "The particular upper bound that has been used for cyclomatic complexity is 10 which seems like a reasonable, but not magical, upper limit. Therefore, we can conclude that the egucational system that we are considering is complex and it should be carefully designed and planned.

5 Conclusions

Online classes are becoming more popular among universities and community colleges. Although online classes are relatively inexpensive to offer and can reach a more geographically diverse student community than traditional classes, there are problems to cope with this technology driven educational model:

1. An online instructor cannot guess the mood, participation and engagement level of the students because this mode of education eliminates the human connection that a face-to-face teaching environment provides.

2. It takes a highly self-motivated and independent student to complete an online course successfully.

3. If instructors aren't well trained to handle the technological details of an online class, their effectiveness in teaching will diminish.

4. And most importantly, certain hands-on courses cannot be handled by an online class setting.

One proposed solution to address above mentioned problems is hybrid mode of education. That is, blended learning – courses that mix digital and in-person elements could be the future of higher education. This mode of education has been used successfully almost two decades at Texas Tech university through "Transdisciplinary Graduate Program on Design, Process and Systems" [9].

The fourth industrial revolution is fueled by emerging technology breakthroughs in fields such as artificial intelligence, robotics, autonomous vehicles, 3-D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing (World Economic Forum, 2016). The technological advances outlined above will disrupt the job market in sectors that can be easily automated.

The impact of technological, demographic and socio-economic disruptions on business models will be felt in transformations to the employment landscape and skills requirements, resulting in substantial challenges

for recruiting, training and managing talent. (World Economic Forum, 2016)

The most severely disadvantaged group of individuals will include the working professionals whom do not possess a diversified skill set or the tools and education necessary to adapt to the multidisciplinary marketplace. In conclusion, this paper motivates the need for an educational system that can meet the issues plagued by the current technological advances. The proposed transdisciplinary hybrid education platform will be tailored to the engineers and working professionals inconvenienced by the fourth industrial revolution. This mode of education shall; build common knowledge, prepare generic design tools, and refine industry standard techniques. The generic nature of the proposed design tools will allow for rapid adaptability in the workforce. This newly developed sense of adaptability will allow for the students to apply their skills to both a multitude of disciplines and variety of industries.

References

[1] Jackson, A. (2015, July 20). This chart shows how quickly college tuition has skyrocketed since 1980. Retrieved from https://www.businessinsider.com/this-chart-shows-how-quickly-college-tuition-has-skyrocketed-since-1980-2015-7

[2] Friedman, Z. (2018, October 26). Student Loan Debt Statistics In 2018: A $1.5 Trillion Crisis. Retrieved from https://www.forbes.com/sites/zackfriedman/2018/06/13/student-loan-debt-statistics-2018/

[3] U.S. Department of Education. (n.d.). Retrieved from https://www2.ed.gov/about/overview/budget/budget17/budget-factsheet.pdf

[4] Missouri Education Watchdog. (n.d.). Retrieved from http://missourieducationwatchdog.com/

[5] Cohen, R. (2018). Public school buildings are falling apart, and students are suffering for it. Retrieved from https://www.washingtonpost.com/news/posteverything/wp/2018/01/08/public-school-buildings-are-falling-apart-and-students-are-suffering-for-it/?noredirect=on&utm‾term=.db59b71e0ee4.

[6] U.S. population growth projections 2015-2060. (n.d.). Retrieved from https://www.statista.com/statistics/183481/united-states-population-projection/

[7] Porter, E. (2017). Education Gap Between Rich and Poor Is Growing Wider. Retrieved from https://www.nytimes.com/2015/09/23/business/economy/education-gap-between-rich-and-poor-is-growing-wider.html.

[8] Chandler, D. L., & MIT News Office. (2014). Study: Online classes really do work. Retrieved from http://news.mit.edu/2014/study-shows-online-courses-effective-0924.

[9] Ertas, A., Frias, K. M., Tate, D., Back, S., (2015). Shifting Engineering Education from Disciplinary to Transdisciplinary Practice. *International Journal of Engineering Education*, Vol. 31, No. 1(A), pp. 94105.

[10] McCabe, T. J., (1976). Describing Cyclomatic Complexity, *IEEE Transactions on Software Engineering*, Vol. 2, No. 4, p. 308.