Education as a Complex System

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It was a cold rainy day in Cambridge, Massachusetts. Navid was working in his office at E40, one of MIT’s oldest buildings. E40 used to be a factory in the 1930s and was now hosting a large number of students, researchers, visitors, and faculty members. As a postdoctoral researcher, Navid was sharing an office with another postdoc, a long-time friend. Like many other researchers in temporary positions, they were both looking for tenure-track academic jobs. Navid and his friend had different training and areas of interest, but they shared an opinion on the job outlook: it was not a seller's market. Each job opening received hundreds of applications and it was very difficult to compete. Standing near the window and sipping from his cup of coffee, Navid heard Professor Dick Larson knock on the door. Dick was Navid’s supervisor.

As smiling and energetic as always, Dick said: “Professors are like mothers who give birth to new PhDs!” Navid replied: “OK?!”… “What do you think happens if each mother, on average, gives birth to two boys and two daughters?” Dick asked. The answer was easy: “The population grows … until there are enough resources.” Navid replied. Dick returned back to the job market problem: “OK, if we consider faculty members as people who train PhD students, and eventually hood them as new PhDs, like a mom that brings a baby into a new world, they are bringing these new PhDs into the world. What happens if each faculty member, during the whole career, gives birth to two PhDs?” It was easy to follow the logic. The population should grow—unless we have limited faculty slots. If faculty positions are kept constant, only one of the two can replace the adviser and the second person should search outside academia. In simple words, if everyone graduates two PhDs during their whole career, only 50 percent of them can land tenure-track jobs. Faculty members train many more than two PhDs during their careers; in fact, Dick had graduated 20 or more PhD students!

Data have shown that on average each engineering faculty member graduates 7.8 new PhD graduates during their career (Larson et al. 2014). That is, only 1 out every 7.8 graduates can find an academic job in the U.S. Many others take temporary positions in academia (such as postdoc positions) and consequently increase universities' teaching and research capacity, advise students, help faculty members gain more course releases and train even more students. Postdocs also write more papers, which raises the hiring standards of the job.
market. In the same way that businesses may engage in a price war, postdocs create a publication war. These are just examples; many more reinforcing loops exist that work as vicious cycles (Ghaffarzadegan et al 2015). Navid and his officemate were inside this complex system.

Of course complexities of education are not limited to just PhD population growth. It is everywhere within the pipeline of education, from kindergarten to high school to college. While current Western formal education dates back at least 1,000 years, the field is rife with contention and controversy. Multiple stakeholders with competing interests have made education a most complex system. Should we test or not? Should we support school choice competition or the neighborhood public school? How should we incorporate technology in the classroom and at home? Should more material be covered in a shallow manner or is it better “go deep” on fewer subjects? Is it better to move an entire class at one speed through each grade level or to support individualized learning with each student moving at her own pace? How should we provide quality education to all when the quality of schools is dependent on the local property tax base, and thus less affluent communities tend to have poorer schools? How should we improve higher education? Should we have more masters’ and PhD graduates? Should government provide more research and training funding?

Education systems are complicated and improving them requires systems approaches and understanding the complexities.

What is Complex about Education?

There are various reasons why education should be considered as a complex system (Sterman 2000). We offer seven examples:

1. **Education as an interconnected system.**

   Education is a large, interconnected system, represented many times by a pipeline that starts from kindergarten and goes through elementary, secondary, and high school. It continues through college and potentially graduate studies. Currently, postdoctoral training might be a part of the pipeline. These stages are all interconnected; a low performance in school will affect one’s performance at the end of the pipeline. Leverage points for improving higher education might be in kindergarten through ninth grade where many students lose their interest in math after only one poor math class. Furthermore, individuals' performance in school is not only influenced by their own efforts, but also by family members, classmates, teachers, school administrators, course design, technology, financial resources, and many other similar factors. In order to examine such an interconnected system, one needs to have a large domain of analysis.

2. **Education within a system of systems.**

   Education is also coupled with other large systems such as economics, culture, society, and politics. Students in economically disadvantaged families or in families who value formal education less might show a lower performance in class. Lower education can influence one's economic status in the future, making it difficult for such families to thrive. Should we first improve education or the
economy? This is a “chicken or egg” problem. Education is also connected to politics and policy. School budgets or research budgets are influenced by government resource allocation decisions. Education is a part of a large system of systems.

3. **Education is history dependent.**

We cannot change the education system overnight. It takes time—a long time. Many actions are irreversible. Policies implemented when kids are in school may show results 10 to 12 years after they graduate from school or even after college. The economic impact of those policies may need even more time to emerge. At the school level, having one bad math teacher in elementary school can have long-lasting effects on one's interests and skills in math. The system has major delays and some of the delays are in the order of a decade.

4. **Education surrounded by feedback loops.**

As described in the introduction, various reinforcing and balancing loops exist in the education system. Here are some other loops. Good schools train good students, some of whom become future teachers. Good teachers create better classes and train better students. It works similarly in higher education and the way that professors contribute to improving universities and training PhD students. Universities that have better applicants will have better students and better graduates, which will strengthen their brand, attracting better applicants, professors, more funding, and more research opportunities. Predicting such systems' behavior in response to policy interventions is difficult.

5. **Education as a non-linear system.**

Effects of many interventions in the education system are not proportional. Sometimes resources are wasted and effects are very small. Sometimes the system overreacts to policy changes. We have previously shown that a simple increase in research funding has magnified effects on the research community and in the long term can create “severe hangover” when commitments should be fulfilled and funding for new grants need to be cut (Larson et al. 2012). We also showed that a simple retirement age change policy in universities results in an approximately 20 percent decline in faculty opening positions (Larson and Gomez Diaz, 2012). Non-linear systems are difficult to intuit.

6. **Education, policy resistance and unintended consequences.**

A combination of feedback loops, delays, and nonlinearity results in counterintuitive outcomes. Too much incentive for achieving higher grades may result in teaching-to-test strategies, cheating, or other behavioral misconduct for teachers and students. At the university level, increasing funding may not translate to increased productivity and may cause unexpected outcomes such as longer postdoc durations (Hur et al 2015, Ghaffarzadegan et al 2014). Furthermore, students, families, teachers, administrators, and almost all human elements of the education system can react to external changes. Education is
such a sensitive topic that for any action, we see a reaction from various stakeholders.

7. **Education, information asymmetry, and bounded rationality.**

People are not aware of all the information that can influence their choice of school. We know little about reasons for dropout rates and from a cost-benefit standpoint, such decisions do not seem to be particularly profitable or rational. Assuming that simple supply and demand curves governed by rational decision makers are behind all the dynamics of education systems is too simplistic. Our social, cultural, and psychological backgrounds play important roles in making education-related decisions. Equilibrium seems to be a myth; in some fields there are fewer experts than needed and in others more (Xue and Larson 2015). Many people are not simply aware of different career prospects and some may not be analytical enough when making education decisions.

**Contents of this Special Issue**

During the past years the editors of this issue have been studying different aspects of education as a complex system and researching workforce development. They felt it was now time to call for a special issue on this very important problem and collect more diverse—both in content and in methodology—contributions on this topic.

This issue includes a wide range of articles on the topic of education, many using unconventional ideas and thinking “outside of the box” in dealing with commonly noticed problems. The collection offers a variety of examples of studies of education and we hope that it is a first step towards more studies in this area.

The first two studies of this special issue look at different psychology related problems within education systems. First, Hu et al’s focus on humor in improving STEM education. The past mixed evidence on positive and negative effects of humor is hypothesized to be related to the additional cognitive load that humor creates while a student is dealing with an already difficult question. They offer several interesting examples and a method to integrate humor with STEM problem-solving in order to avoid additional cognitive load. Kapmeier et al examine potential effects of formal education on people’s understanding of complex systems. They conduct laboratory experiments with first semester and fifth semester undergraduate students of engineering and business. Their analysis shows that people have difficulties understanding basic complex system problems and their performance is likely to decline as they proceed. Their study corroborates with previous anecdotal evidence that our education systems do not prepare us for understanding complex systems.

The next studies are at organizational, community, or country levels. Zaini et al develop a system dynamics model of university quality as affected by student enrollment, faculty hiring, and university facilities. The model helps study a common policy response in many universities to financial problems through enrolling more students. Kasman and colleague’s study is conducted at the community level, where they apply the group model building method to study high school completion. The method helped community members see the
problem from a complex systems perspective, and find several feedback loops that inhibit education. Cifuentes and Fernandez use the American Community Survey data and conduct a social network analysis coupled with artificial intelligence to explore education as one variable affected by other human-development-related variables such as economics and culture. Their study is an example of seeing education as a part of a more complex socio-economic system.

The final paper of this issue by Larson and Murray is about the authors' past eight year project for improving STEM education through pedagogical changes enabled by technology. In their BLOSSOMS pedagogical model, Larson and Murray develop a novel blended learning approach and redesign STEM class activities. In this approach classes frequently switch between a video recorded by high-quality teachers worldwide and in-class activities guided by the teacher. The videos are about interesting and engaging science and mathematics problems aimed at enriching class active learning experiences. The BLOSSOMS method has been applied in ten different countries including many less developed regions and are translated to several languages. The paper is followed by two short notes, one from Malaysia by Abdullah and Shukor, and the other from Pakistan by Malik reflecting on Larson and Murray’s article and discussing BLOSSOMS’s experience in their countries. They point to the benefits of implementing BLOSSOMS as well as implementation challenges rooted in individuals’ resistance to change and governmental bureaucracy. A successful change in education needs overcoming various cultural, behavioral, and administrative barriers at different levels.

**Future Directions**

More research is needed to understand and improve the education system on all levels. What we know is that education is a complex system. The effects of trivial education policies are often unintended and detrimental. We know that no silver bullet exists for improving the education system; we need a portfolio of interventions throughout the education pipeline and for all students from different ranges of socio-economic statuses.

To understand a complex system, taking a systems approach is a must. We invite researchers to move beyond linear models of education, take systems approaches including (but not limited to) qualitative or quantitative models of education rooted in system dynamics, agent-based modeling, network analyses, operations research, and industrial engineering. Studies of education systems should have a broad boundary of analyses, include human behavior as an important parameter in their problem, measure performance over time, and consider the potential unintended consequences of easy policies.

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References


