Model Based Study of Higher Education of Engineers

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Abstract

In this paper we present our approach combining empirical quantitative questionnaires and qualitative interviews with system dynamics modeling and simulation. Our preliminary researches show that to improve the attractiveness of engineering studies at a university various efforts may be taken such as the improvement of the success rate of engineers within the related industry sector, a higher quality of practice-oriented teaching and more cooperation between universities and companies. In contrast, an expansion of enrollment of students will lead to an opposite effect.

1. Introduction

To improve the attractiveness of engineering studies for young people has significant importance, especially in a country like China where manufacturing has been and will be a major industry in its economy. Despite the expansion of high education in China the industry experiences difficulties finding good engineers. The companies have to take great effort in training engineers by themselves. There is a gap between engineering education and engineering practice. Researchers both from educational background and engineering professions have attempted to change this situation [22, 18, 17]. The results, however, are not satisfactory [27]. The apparent gaps still exist and even become bigger in recent years. The higher education expansion in China directly results in the amount of engineering graduates significantly surpassing the demand of labor markets [34]. The job market for Chinese engineering graduates is now more severe than before. Many students have to work in unrelated areas.

Generally, researchers attribute this gap to ineffective teaching methods such as insufficient practical experience [18], lack of communication skills [2], insufficient capability of transferring knowledge in new environments [20]. There is not only a competence gap [15], but also a demand gap. One the one hand, the constrained education resources as well as the limited practical collaboration projects with industries cannot equip engineering graduates with sufficient competitive skills. On the other hand, the oversupply situation even hampers the careers of engineering graduates and forces them to work in engineering-unrelated positions. It’s imperative to provide feasible solutions so as to bridge the gap in China.

A couple of Chinese researchers discussed this problem from a theoretical perspective [26, 31]. Only few of them investigated the fundaments of this problem or provided solutions based on quantitative analysis.

In this paper we present our approach combining empirical quantitative questionnaires and qualitative interviews with system dynamics modeling and simulation. Our preliminary researches show that to improve the attractiveness of engineering studies at a university various efforts may be taken such as the improvement of the success rate of engineers within the related industry sector, a higher quality of practice-oriented teaching and more cooperation between universities and companies. In contrast, an expansion of enrollment of students will lead to an opposite effect.

In the following Section 2 we introduce some related works. Section 3 describes our recent research study at the Shanghai University. We present and discuss our preliminary results in Section 4. Section 5 concludes this paper.

2. Background

Higher education is an interesting field for the application of system dynamics research. A taxonomy of system dynamics models of educational policy issues has been presented by [5]. From a general point of view, a university model contains four sectors: students, quality, faculty and facility [36].

Students as paying customers of universities justify a closer investigation. Applications, admissions, enrolled students, drop-outs, graduated students, reputation of the university, and the available budget for the students are the stocks of the system dynamics model presented in [16]. Funding and capacity planning, students sector, research and publications may additionally be in focus [21] as well as curriculum in development and in use, faculty, tenure track and tenured faculty [6].

Many researchers have also paid attention to the interaction of the university with the world outside. For example, a system dynamics model which targets increasing the number of students both capable and interested in pursuing careers in science, technology, engineering, and mathematics has been presented by [24]. Both economic benefits and prestige factor for desiring enrollments were discussed in [23]. The student sub-model may include research output by students while the growth of project clients and innovative companies may also be taken into account [25]. On the other side, unemployment due to time delay because of changing markets has been addressed in [4]. Not only engineering students' admission and graduation, but also the post graduates' employment status was modeled and simulated in [19].

In 2011 China established a "plan for educating and training outstanding engineers (PETOE)". An overview about the reform focus and innovation model of PETOE has been given in [11], along with certain specific requirements on training standards, reform of curriculum systems, enterprise training program, and internationalization. It has often been criticized that the Chinese higher education for engineers today puts too much focus on the teaching of basic knowledge and neglects practice oriented training. Too few teachers are facing too many students, and too few internship positions are available [13]. Establishing problem/project based learning (PBL) [9] or dedicating the last course year to practice ("3+1") [35, 37] are thus among the suggestions to build a more practice oriented curriculum system [10] for the implementation of PETOE. An engineering education accreditation (EEA) has been requested [12].

One critical success factor of PETOE is constructing a teaching staff which is competent for this task [7, 33]. Intensive cooperation between the universities and the enterprises on the one side, the establishing of a teaching staff with both academic and industrial background on the other side have been seen mandatory in [13, 32]. It has been pointed out that it takes a period of eight to ten years to become a qualified engineer so that the higher education can only be a part of the entire program [14]. It has to be remembered: As well as depending on academic education and training the later process of successful professionalization relies to an extremely high degree on the long-term biographical interests and attitudes as a whole [28]. PETOE should be implemented in cooperation by universities and enterprises [1] or divided into the university working program and the professional training programs [8].

3. Model supported study of higher education of engineers

Our current model supported study of higher education of engineers starts with the building of a causal loop diagram which is based on a professional biographic concept [29]. We are interested in the individually preceived reafference structure in which the past (the origin and the pathway) leads biographically via the study in the presence to the future (professional development) [30].

3.1 A causal loop diagram

The first step of our model based study of higher education of engineers is to sketch a causal loop diagram. As shown in Figure 1 our causal loop diagram contains two reinforcing feedback loops:

1. When the students experience a more practice oriented education, they will have a better onboarding process. This will lead to a higher starting salary which generates motivation for younger students to enroll in practice oriented learning so that a even better practice oriented education will take place.
2. On the other side, when the students have a more practice oriented education, they can be more successful in their work and the industries are more willing to cooperate with universities. That will generate even higher motivation and capability for practice oriented teaching so that students can have an even more practice oriented education.

The two reinforcing loops are a double-edge sword. It could work surely to generate more practice orientation of education and better equip engineering students for their work. However, it is also possible to trap everything on the low level, which means little practice orientation of education, no cooperation, no motivation for practice orientation of education.

3.2 Quantitative survey and qualitative interviews

The aim of the survey is to understand the real learning activities of students, their study goals and professional aspirations, as well as their subsequent placement in the labor market in the context of their personal history, their canon of values and their experiences.

The biographical questionnaire contains 75 questions, organized mainly in seven sections:

- Statistical personal data
- General attitudes, comments, sense of self, self-awareness
- Educational trajectories of university and their attractions
- Rising ups of competencies, professional cognition structure, skills
- Career plan, future and hopes
- Ecological conditions of urban living
- Social embedding (at present, in the past, in the future)

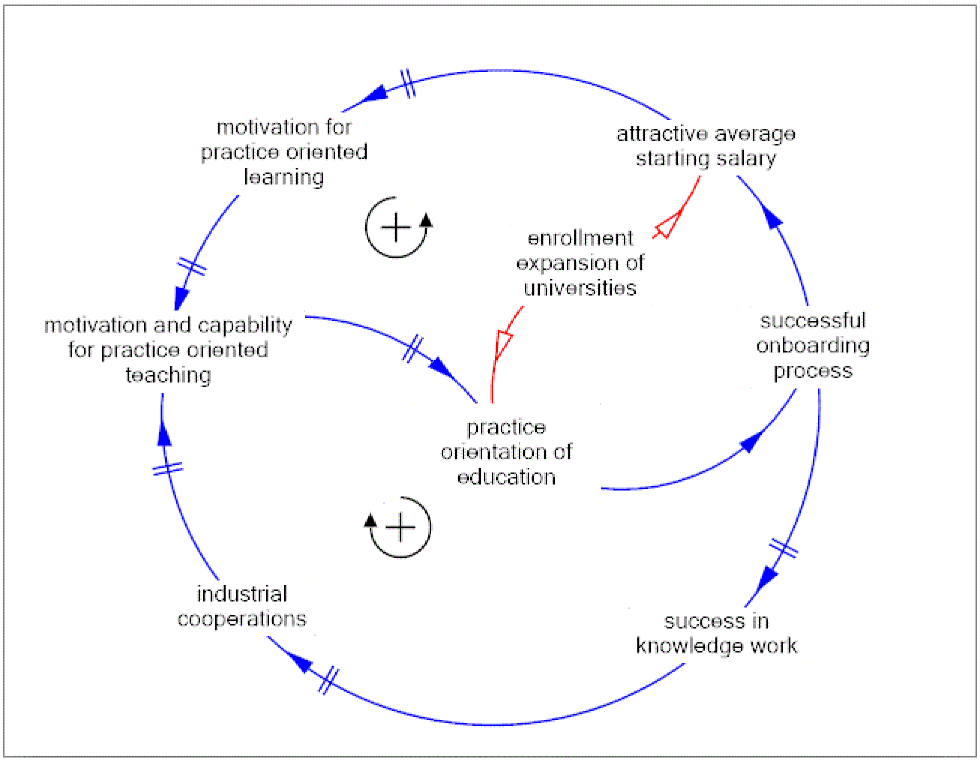

Figure 1: A causal loop diagram as a starting point of the study of higher education of engineers

The questionnaire is complemented by several semi-structured biographical depth interviews [3]. The interview guide used has six sections:

- Decision for an engineer study
- The current situation at Shanghai University
- Family
- Gender
- Values
- Suggestions

Regarding the causal loop diagram in Section 3.1 both the quantitative survey and the qualitative interviews are focused on the upper feedback loop (Figure 1): if and how the students are motivated for a practice oriented study; if they expect a successful start into their professional career and if they expect an attractive starting salary.

4. Preliminary results and discussion

4.1 Preliminary results

From Sep. 8th to 18th, 2015, 94 engineering students in Shanghai University took part in the online survey. 43 (45.7%) were female; 19 (20.2%) were 18-22 years old (undergraduate students), 71 (75.5%) were 23-27 (graduate students) and 4 or 4.3% were over 27 years old. Table 1 shows all questions of which the answers were statistically "negative". It is conspicuous that 60 (63.8%) students didn't choose an engineering major as their first wish.

Table 1: Answers to selected questions

	1: Strongly agree, 5: Strongly disagree					
	1	**2**	**3**	**4**	**5**	**Avg.**
My university is high ranked	3	25	56	9	1	2,79
My major at my university is highly competitive	7	35	41	11	0	2,60
Are you convinced that the studies at this university will support you above-average compared to other Universities and their offers?	1	30	50	12	1	2,81
An engineer's job is associated with high social benefits	4	37	40	13	0	2,66
An engineer's job has attractive working time regulations	1	28	40	21	4	2,99
An engineer's job has fair chance of advancement	6	38	42	8	0	2,55
An engineer's job has good working conditions	4	28	35	22	5	2,96
An engineer has a higher social status and income compared to other professions	9	34	38	12	1	2,60
The housing situation in Shanghai is good	10	33	41	9	1	2,55
My home town is not backward in comparison with Shanghai	6	3	9	33	43	4,11
Are the conditions of working and living actually more easy for you compared to the generation of your parents?	14	31	27	16	6	2,67
I will always feel higher pressure in the future and receive less support by my organization, my family, my friends and my lover	11	34	34	12	3	2,60
I'd rather be a technical leader than in a managerial leading position	9	33	36	16	0	2,63
I will be highly mobile in my career	2	17	43	30	2	3,14
	Yes				**No**	
My major was my first wish	34				60	

It is noticeable that 56 engineering students (59.6%) answered that they still do not know if they want to become an engineer. Table 2 shows nine correlations which can be classified as statistically significant. The participants who do know that they want to become an engineer seem statistically to have a stronger support by their parents, a more developed home town, and altogether a more positive and proactive attitude to engineering as a profession, to their education program by the university and towards the future.

Table 2: Decision to become an engineer and its correlations to some opinions

	1: Strongly agree, 5: Strongly disagree						
When did you first think of becoming an engineer?	At the age 6-18, N=38		Not yet, N=56				
	avg.	stdv.	avg.	stdv.	t-value	diff.	P-value
After completing my studies at my university I will continue to improve my professional knowledge as much as possible	2,05	0,73	2,55	0,76	3,18	0,50	0,002
My parents encouraged me to study engineering	2,05	0,70	2,39	0,76	2,21	0,34	0,029
I'd rather be a technical leader than in a managerial leading position	2,39	0,75	2,79	0,93	2,16	0,39	0,034
An engineer's job is relatively stable	2,42	0,68	2,13	0,63	2,15	-0,30	0,034
I am interested in engineering	2,05	0,80	2,36	0,64	2,03	0,30	0,045
Will you still be happy in ten years with your choice of becoming an engineer?	2,16	0,75	2,43	0,68	1,81	0,27	0,074
Are the conditions of working and living actually more easy for you compared to the generation of your parents?	2,45	1,25	2,82	1,01	1,60	0,37	0,113
My home town is not backward in comparison with Shanghai	3,89	1,09	4,25	1,13	1,52	0,36	0,132
Are you convinced that the studies at this university will support you above-average compared to other Universities and their offers?	2,32	0,70	2,55	0,78	1,50	0,24	0,136

Based on the data we obtained from the survey, we did in-depth interviews with five engineering students at Shanghai University. All five students are master students coming from various universities, where they did their undergraduate studies. They all reported very little practical training during their undergraduate studies and couldn't perform the most fundamental tasks required for engineers. The internship requirements for undergraduate students had been just a short visit to some company. There was no real hands-on experience involved, as the companies and universities all had safety concerns. About half of their fellow students ended up not working as engineers after graduating from university. Those graduates who find engineering jobs have to learn how to do practical work when onboard and have to pass certain assessments set by the engineering authorities in China.

4.2 Stock and flow diagram

Based on the causal loop diagram in Section 3.1 and the quantitative questionnaire described in Sections 3.2 and 4.1 we develop our stock-and-flow model starting with the naming of involved state variables. As shown in Figure 2, five stocks in the first row — `Motivated`, `Studying`, `Graduated`, `Employed in related areas` and `Successful` — depict a possible successful career of an engineer while the other two stocks — `Quality` and `Capacity for practice oriented teaching` — are used to describe the state of a university providing service and support for the development of such a career.

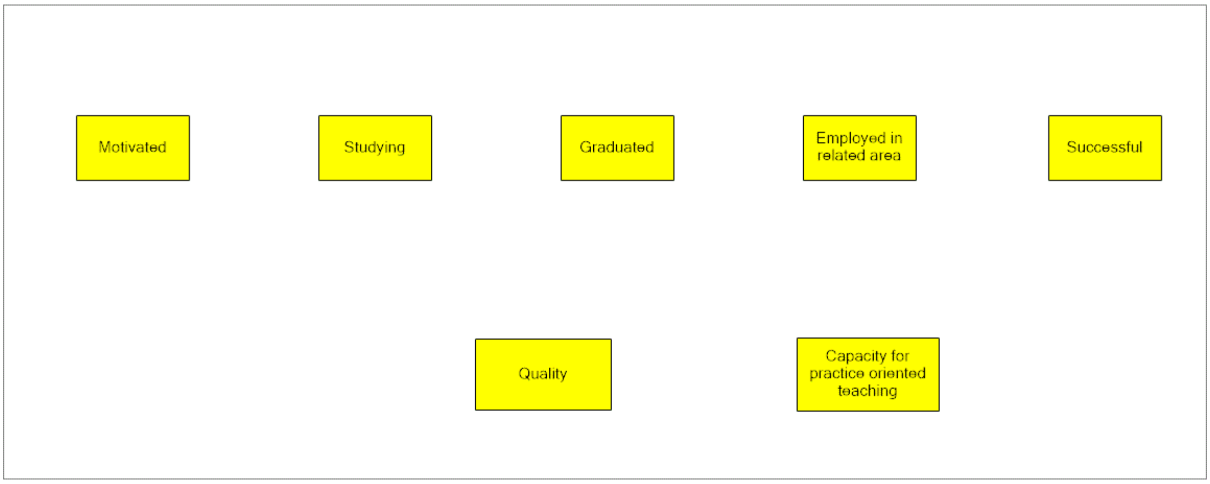

Figure 2: Seven stocks depicting a possible career of an engineer and the state of a teaching institution

As shown in Figure 3, to `motivate` young people for an engineer career is a key responsibility of a teaching institution. In the specific context of China, due to the college entrance examination system `Admission score relative` can be seen as a KPI of a specific university major.

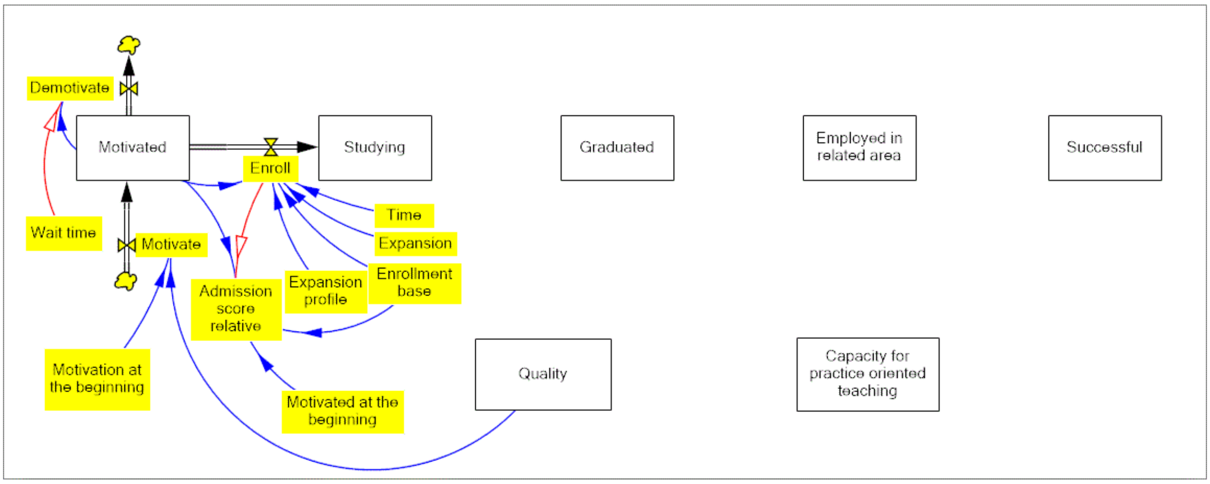

Figure 3: Admission score as a key indicator

When students have completed their four-year study at university they become Graduated. Those who find a job related to their major become `Employed in related area`, and `Starting salary relative` is a key indicator in this part of the model. Those who haven't found a job in a related area is an outflow from graduated, `change` their career and leave the chain of a successful development of engineering (Figure 4).

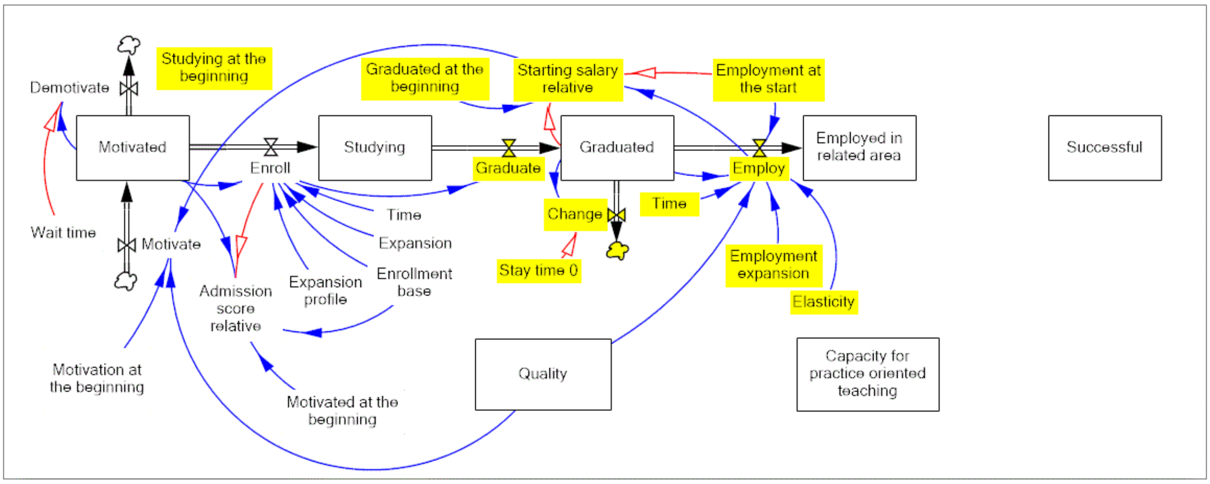

Figure 4: Starting salary relative as a key indicator

Over the time, as newly employed engineering graduates accumulate knowledge and skill in their work, some of them become `Successful` (high salary and good social status). The `Successful relative` is a key indicator for this part of the model (Figure 5).

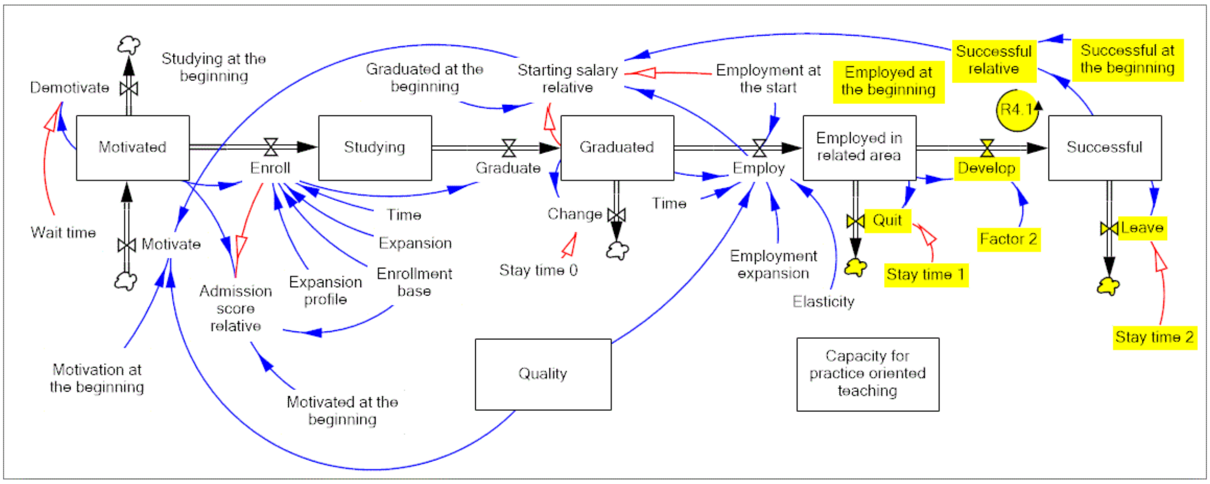

Figure 5: Successful relative as a key indicator

The quality of the engineering education is a key factor affecting the employment of the graduated students. If the students are well educated, the starting salary will be high, and that will attract more motivated students to start an engineering major. The quality of the engineering education also directly appeals to more motivated students. Over the years, when graduated students become successful engineers in the industry, it is easier for a university to `Cooperate` with companies, which in turn will offer opportunities for undergraduate students to get practical experience. And this is an important aspect of the quality of engineering education in China.

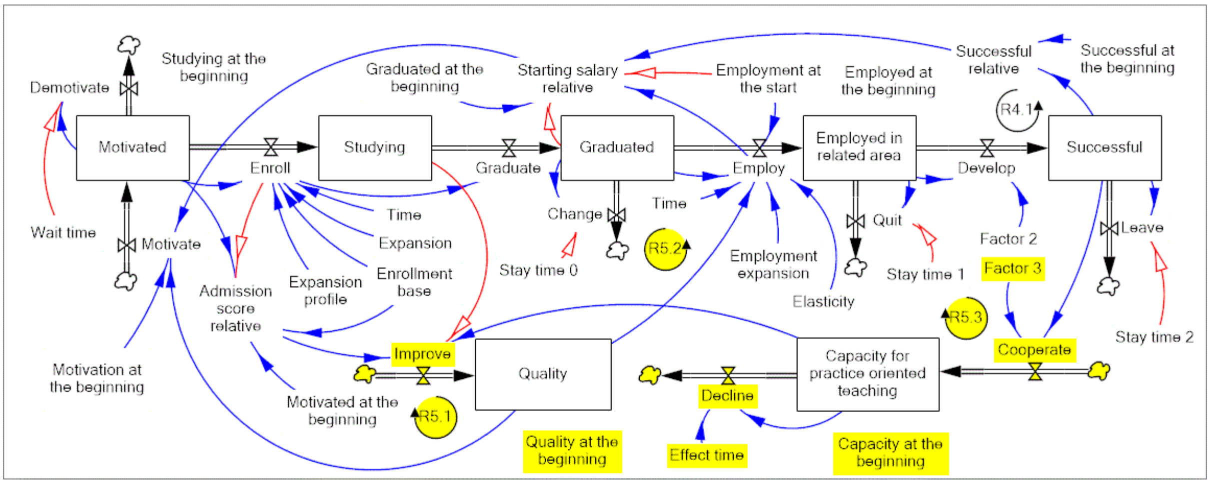

Figure 6: Closing the loops

Above, we have explained the model structure. The setting of parameters and equations are listed in following tables.

Table 3: Stocks (Endogenous)

Variable	**Equation (Description)**	**Dimension**
Motivated	= INTEG (Motivate-Demotivate-Enroll, Motivated at the beginning)	Person
Studying	= INTEG (Enroll-Graduate, Studying at the beginning)	Person
Graduated	= INTEG (Graduate-Employ-Change, Graduated at the beginning)	Person
Employed in related area	= INTEG (Employ-Develop-Quit, Employed at the beginning)	Person
Successful	= INTEG (Develop-Leave, Successful at the beginning)	Person
Capacity for practice oriented teaching	= INTEG (Cooperate-Decline, Capacity at the beginning)	Dmnl
Quality	= INTEG (Improve, Quality at the beginning)	Dmnl

Table 4: Flows (Endogenous)

Variable	**Equation (Description)**	**Dimension**
Motivate	= Motivation at the beginning*Quality*Starting salary relative	Person/Year
Demotivate	= max(0,Motivated/Wait time)	Person/Year
Enroll	= min(Motivated*2,Enrollment base *(1+Expansion*Expansion profile(Time)))	Person/Year
Graduate	= DELAY FIXED(Enroll, 5 , Enrollment base)	Person/Year
Change	= Graduated/Stay time 0	Person/Year
Employ	= min(Graduated, Elasticity(Quality) *(1+Employment expansion(Time)) *Employment at the start)	Person/Year
Quit	= Employed in related area/Stay time 1	Person/Year
Develop	= Employed in related area*Factor 2	Person/Year
Leave	= Successful/Stay time 2	Person/Year
Cooperate	= Successful*Factor 3	Dmnl/Year
Decline	= Capacity for practice oriented teaching/Effect time	Dmnl/Year
Improve	= Capacity for practice oriented teaching*5/Studying*Admission score relative-1	Dmnl/Year

Table 5: Auxiliaries (Endogenous)

Variable	**Equation (Description)**	**Dimension**
Admission score relative	= Motivated*Enrollment base/Motivated at the beginning/Enroll; Lookup = (0.165,0.702), (1,1), (4.65,1.35),(9.57,1.49)	Dmnl
Starting salary relative	= Employ*Graduated at the beginning/Employment at the start/Graduated*Successful relative; Lookup = (0.5,0.5),(1,1),(5,5)	Dmnl
Successful relative	= Successful/Successful at the beginning	Dmnl

Table 6: Constants (Exogenous)

Variable	**Equation (Description)**	**Dimension**
Motivation at the beginning	= 500	Person/Year
Capacity at the beginning	= 250	Person/Year
Enrollment base	= 250	Person/Year
Employment at the start	= 80	Person/Year
Motivated at the beginning	= 420	Person
Studying at the beginning	= 1250	Person
Graduated at the beginning	= 80	Person
Employed at the beginning	= 680	Person
Successful at the beginning	= 270	Person
Quality at the beginning	= 1	Dmnl
Elasticity	= (0,0.7),(1,1),(3,1.5)	Dmnl
Factor 2	= 0.02	Dmnl
Factor 3	= 0.31	Dmnl
Wait time	= 1.9	Year
Stay time 0	= 0.5	Year
Stay time 1	= 10	Year
Stay time 2	= 20	Year
Effect time	= 3	Year
Expansion profile	= (0,0),(2,0),(3,1),(10,1),(11,0),(30,0)	Dmnl

Table 7: Constants (Intervention)

Variable	**Equation (Description)**	**Dimension**
Expansion	= Fraction of expansion	Dmnl
Employment expansion	= (0,0),(30,0)	Dmnl

4.3 Discussion

The behavior of our model can be discussed based on different scenarios. The initial parameter setting creates an equilibrium situation where the `Motivated` remains at 420, `Studying` remains at 1250, `Graduated` remains at 80, `Employed in related areas` remains at 680 and `Successful` remains at 270. The `Quality` of engineering education stays at level 1 throughout the simulation run, as shown in Figure 7.

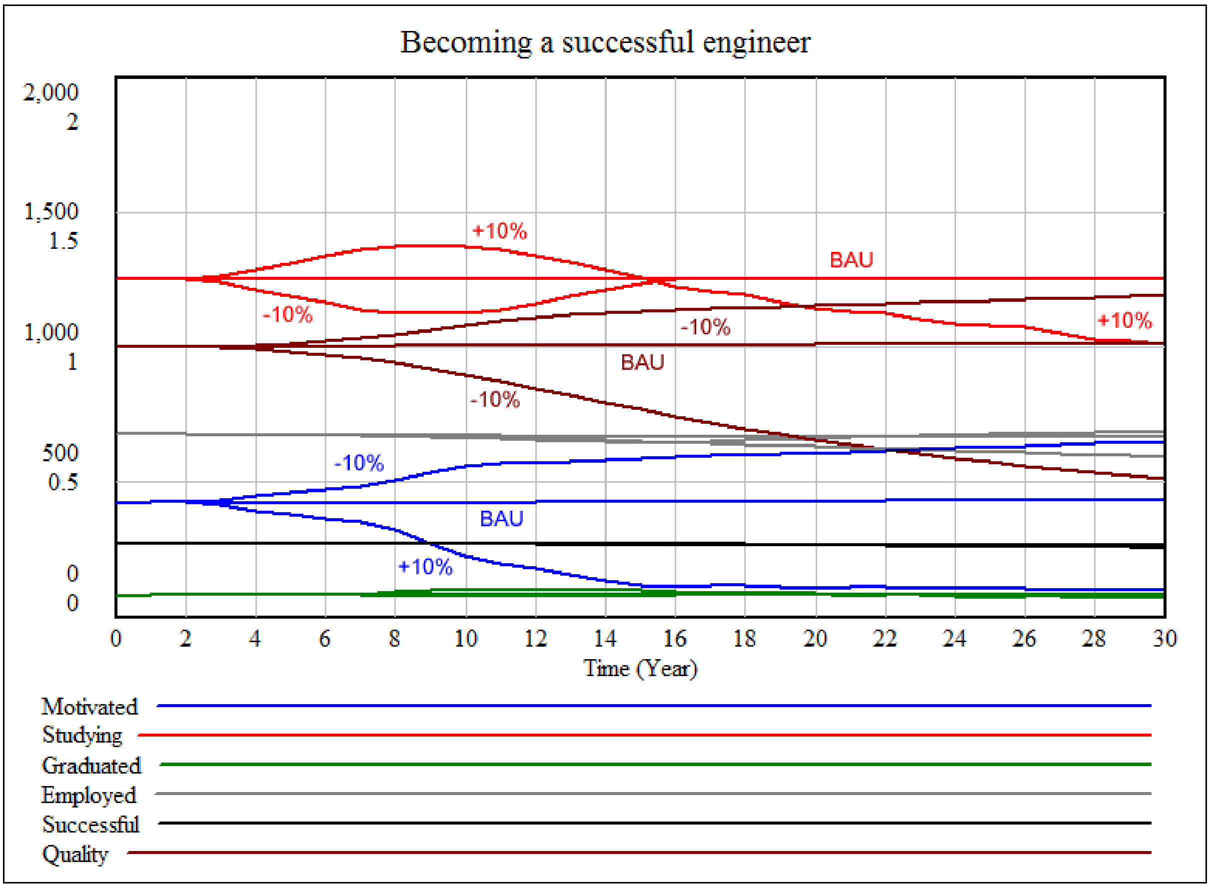

Figure 7: Model behavior

Two other simulation runs are carried out based on two other scenarios: one is that we expand our enrollment by 10% and the other is that we contract our enrollment by 10% (`Expansion` by -10%), as shown in Table 8.

Table 8: Scenario setting

Category	**Input values of Scenario Variables**
Base:	No change (BAU)
S1: Expansion	Expansion = 10%
S2: Reduction	Expansion = -10%

In the scenario enrollment expand by 10%, we find that the `Studying` increases immediately. However, the `Quality` of engineering education starts to fall. This in turn causes the `Motivated` to drop and over a span of several years, the `Studying` actually decreases to a level even lower than before the enrollment expansion.

On the other hand, in the scenario enrollment contraction by 10%, the opposite happens. The `Studying` decreases soon after the implementation of the policy. But the quality of engineering education increases as students now have more resources per person. This then raises the starting salary for engineering graduates and then causes the `Motivated` to increase and over a span of several years, the `Studying` actually comes to the same level as before the enrollment contraction. The quality of engineering education increases by 20% over the simulation time period. Even though the Employed in related areas drops a little bit at the beginning, it is higher in later years.

5. Conclusions

5.1 Insights for policy makers

When facing an increasing need for engineers in industry, an intuitive policy would be to enlarge the enrollment of engineering students and this is what the Chinese government did. However, the system dynamics model and its simulation results clearly show counterintuitive results: China is worse off with an enlarged enrollment. When the universities admit more engineering students, the teaching facilities, especially those for practical learning, such as labs, are not enough. This forces many courses to change from practical learning to theoretical learning. The quality of the engineering education is significantly reduced. As students have less practical experience, they are less capable in the eyes of the employers, thus reducing the starting salary of engineering students. Many graduates work in unrelated areas making these four-year bachelor studies less valuable to them than it should be. Fewer students are motivated to study engineer and fewer students can be enrolled. In contrast, if the universities improve their practical teaching, making students more qualified for their future work, then the graduates could have a higher starting salary because of more demand for engineers on the job market. Better equipped from the beginning, the students will have a better chance to be successful in their future career. In this way, being an engineer would be an attractive career path for more people, which could eventually reduce the gap of engineer demand and supply and also reduce the gap between engineering education and real world practice.

5.2 Findings for system dynamics model building

During the model development process, we used a questionnaire to collect quantitative data and interviews to collect qualitative data. Both quantitative data and qualitative interviews provided us with a sound basis for our modeling work. Especially the detailed information obtained from the interviews were helpful for the building of this system dynamics model.

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