Abilities required for the foreseeable future and their development in higher education of science and engineering

Ryunosuke Kikuchi
Departamento de Ciências Exactas e do Ambiente, ESAC – Instituto Politécnico de Coimbra
Bencanta, 3040-316 Coimbra, Portugal
Kikuchi@mail.esac.pt

Abstract - **Under the Bologna Process, 45 European nations have pledged to make three years the standard time for their undergraduate degrees, and this system seems to be spread worldwide; however, a problem lies with knowing how to effectively provide higher education in the shortened period. This subject is discussed considering companies' requirements for future engineering graduates. The EU aims to create a strong and lasting society through high academic knowledge, and the British companies studied in this paper require knowledge-related skills (application, theory and creativity) of future graduates. The current achievement-based education is considered suitable for meeting companies' requirements, but it is necessary to reinforce practical skills. Japanese companies prioritize spiritual factors (communication, motivation and activity/vitality) rather than knowledge achievement in their recruit plans - so-called Theory Z management; however, it is considered that the Japanese education system (automatic promotion without repetition) currently lowers graduates' will to work. It is necessary to take measures to heighten graduates' communication competency and will to work.**

Key Words- Achievement-based promotion, automatic promotion, Bologna Process, competence and Theory Z.

INTRODUCTION

The Bologna Process was launched in 1999 when Ministers from 29 European countries met in Bologna (Italy) and signed a declaration establishing what was necessary to create a European Higher Education Area (EHEA) by the end of the decade [1]. The broad objectives of the Bologna Process become to remove the obstacles to student mobility across Europe, to enhance the attractiveness of European higher education worldwide and to establish a common structure of higher education systems across Europe [1]. Under the Bologna Process, 45 European nations have pledged to make three years the standard time for their undergraduate degrees by 2010 [1]. Since this intergovernmental process aims to promote the European education system worldwide, 3-year degrees may be adopted by many countries in the near future; 3.5-year degrees have also been adopted by some Japanese universities (e.g. the Waseda University School of Commerce) [2]. However, a problem lies with knowing how to effectively provide higher education in the shortened period.

According to the National Academy of Engineering [3], tomorrow's graduate will need to collaboratively contribute expertise across multiple perspectives in an emerging global economy that is fueled by rapid innovation and marked by an astonishing pace of technological breakthroughs. Rapid changes in the worldwide engineering enterprise are creating a compelling rationale for us to rethink how to realize higher education of science and engineering [4].

COMPULSORY EDUCATION

The European situation and the Japanese situation are also compared because there is a clear difference in compulsory education between Europe and Japan.

Repetition in primary education. The term used in this section is explained first: repetition rate – the proportion of students who enroll in the same grade more than once to the total number of students in that grade. The repetition rate is *ca* 30% at French primary schools [5], *ca* 50% in German compulsory education [5], *ca* 20% in basic education in Latin America [6], and almost 0% in Japanese compulsory education [5]. The high repetition rate does not necessarily indicate that students are incompetent; it depends upon complex social factors (e.g. poverty) in developing countries [7]. In developed countries, the repetition rate seems to mainly depend upon whether students master a set of defined learning competences. Since there is a repetition system, students cannot move up to the next grade till they have mastered the defined competences; to put it differently, this system can be considered as a method for guaranteeing the educational quality at each grade.

Problems associated with low repetition rate. According to an interpellation at Japan's Diet [7], repetition is undesirable given national sentiment and parents' feelings. First of all, repetition would look bad because the repetition rate is almost null in Japan, so a repeater and his/her family may be afraid of losing face. Secondly, Japan is the most aged society in the world - 21% of the total population was aged 65 and over in 2005 [8]. In addition, the total fertility rate has also declined to 1.2 (cf. 2.1 in the USA and 1.9 in France) [8]. As children and young people have become fewer in number, the aged society has come to spoil them.

In Japan, most students currently move up to the next grade as they grow older, i.e. this is an automatic promotion system; in this case, it seems difficult to guarantee educational quality. The threat of repetition is an instrument that a teacher uses to keep students in line [9], and this threat seems to be particularly effective in the case of schoolchildren with low understanding. Without the backup of a repetition system, the following serious problems are often reported in Japan [10]: schoolchildren cannot sit quietly in class, and this phenomenon frequently leads to the breakdown of order in class; students like to disrupt class at lower secondary schools, and this also results in the breakdown of order in class; teachers find it difficult to establish a rapport with problematic students because even a calming hand placed on a raucous student's shoulder creates an uproar among parents and the mass media; and students who grew up at such dysfunctional schools are committing horrible crimes, but these young offenders are protected by the Juvenile Act (this Act's revision is under discussion).

Abolition of repetition and militarism. The repetition system had been applied in Japan till the late 19th century [11]. It is estimated that the repetition rate in primary education varied between 20% and 30% in Japan at that time [11]. If students complete compulsory education regardless of academic achievement, it is natural that their academic competences will vary widely; however, this wide variation was regarded as within the tolerance range by the then government [11]. Educational priority was placed not on academic achievement but on physical development, discipline, national morality, social cooperation and loyalty to one's own country. In order to realize this educational concept, the then government thought that it would be best to educate students in same-age groups, and the graduation of all students within the defined period became important [11]. In 1900, the Japanese government decided to change from achievement-based promotion to automatic promotion in compulsory education [11]. There is no denying the influences of militarism on this educational change; the Russo-Japanese War developed out of the rivalry between Russia and Japan, and this war began in February 1904 when the main Japanese fleet launched a surprise attack on the Russian naval squadron at Port Arthur [12]. In the resulting Treaty of Portsmouth, Japan gained control of the Liaotung Peninsula and the South Manchurian railroad, as well as half of Sakhalin Island.

Educational expenses. Japan's militarism came to an end following World War II; however, the automatic promotion system is still in force after more than 100 years. Automatic promotion without repetition can minimize educational expenses [9], but there is doubt as to whether Japan is continuing automatic promotion for economic reasons.

Government-industry cooperation, a strong work ethic, mastery of high technology, and a comparatively small defense allocation (1% of gross domestic product) helped Japan advance with extraordinary rapidity to the rank of second most technologically powerful economy in the world [13]. Overall real economic growth had been spectacular in Japan - a 5% average in the 1970s, and a 4% average in the 1980s. Growth slowed markedly in the 1990s, averaging just 1.7% [13]; householders are therefore cautious about spending. Among various expenditures (base of average household), educational expenditure (including cram school, after-school lessons, etc.) accounts for the greatest portion at 57%, second is food expenses at 39% and third is consumer durables at 25% [14]. This is because Japanese school expenses are very high and average US$5,202 per year on the basis of primary education; cf. US$3,621 in France, US$3,490 in Germany, and US$3,206 in the UK [15]. The burden on households as a result of schooling payments is significant [14]. The poorer the family, the greater the burden of education spending. In Thailand, for instance, poor households spend 47% of their income on education while the average for all households is 16% [16]. Viewed on the basis of the rate of educational expenses to family budget, Japan is the poorest country in the world; hence, efforts to reduce the schooling fees would clearly be effective in easing the economic burden on the people of Japan.

QUALIFICATION IN HIGHER EDUCATION

It is pointed out that the repetition system has the advantage of passing the responsibility for failure onto the students themselves rather than onto teachers and/or the school [9]; so there is doubt as to how the repetition system is actually operated in European higher education.

Repetition and learning outcomes. In terms of answering the above-mentioned question, an example is given on the basis of our current course: 220 students of the Environmental Engineering Course (abbreviated as LEAM in Portuguese) in the agricultural engineering unit (abbreviated as ESAC in Portuguese) of Coimbra Polytechnic Institute [17]. In order to complete the LEAM course, the students are required to pass all the programs - 64 course subjects and 2 practical trainings (1.5 months and 5 months). A student becomes a subject repeater if he/she cannot achieve a set academic level based on the curriculum. Based on our internal data during September 2004 to July 2005, the failure rate by subject type is presented in figure 1. In this figure, all the subjects are classified into 4 types for convenience: general education of science (mathematics, chemistry, etc.), general education of humanities (foreign languages, sociology, etc.), basic education subjects for specialty study (statistics, hydology, etc.) and specialized areas (ecotoxicology, waste treatment, etc.).

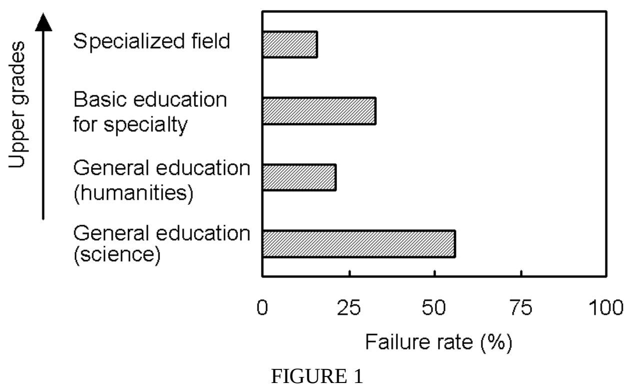

FIGURE 1
FAILURE RATE BY SUBJECTS IN ENVIRONMENTAL ENGINEERING COURSE OF COIMBRA POLYTECHNIC INSTITUTE (2004-2005)

Figure 1 shows that the failure rate dramatically decreases from 58% in general education subjects (scientific area) to 15% in specialized fields (perhaps more difficult). Specialized subjects are usually based on general education subjects such as mathematics, physics, etc., and the students who have mastered the general education subjects learn the specialized subjects: this seems to help students to effectively master the advanced study in higher education of science and technology. It is reported that a repeater often shows an increase in his/her probability of academic success [18]. The tendency shown in figure 1 supports this reported fact. Consequently, achievement-based promotion may increase overall educational efficiency.

Portugal *vs.* Japan. Although it is advantageous that repetition frequently increases learning outcomes [18], its weak point from the standpoint of course management is that the number of students at lower grades is greater than that at the upper grades [11]. Two courses associated with environmental technology are compared from the viewpoint of the distribution pattern of students: the above-mentioned LEAM Course in Portugal [17]; and the Environmental Design Course offered by the Faculty of Engineering of Osaka Sangyo University in Japan [19].

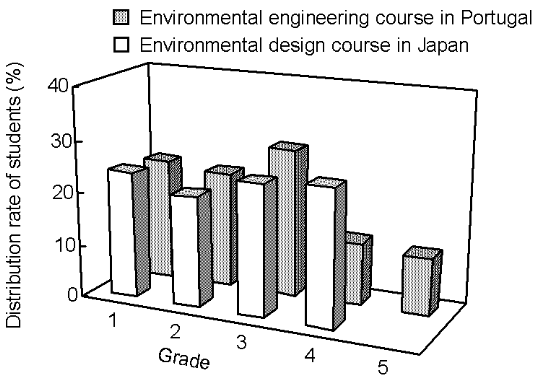

FIGURE 2

DIFFERENCE OF DISTRIBUTION IN THE NUMBER OF STUDENTS BY GRADE BETWEEN ENVIRONMENTAL ENGINEERING COURSE IN COIMBRA POLYTECHNIC INSTITUTE (PORTUGAL, 2004-2005) AND ENVIRONMENTAL DESIGN COURSE OF OSAKA SANGYO UNIVERSITY (JAPAN, MAY 2004)

As seen in figure 2, the number of students is less in the upper grades of environmental engineering course (Portugal), that is, the lower grades and the upper grades are unbalanced in the distribution of students. This indirectly indicates that the repetition rate is high at the lower grades and the students who have come through repetition are better able to increase their learning outcomes at the upper grades. Figure 2 shows that the distribution rate of the number of students is almost balanced among the grades of environmental design course (Japan); the most probable reason is the low rate of repetition (2.8% [19]). The Japanese Ministry of Education strictly restricts the cases where the defined quota of students in each class can be exceeded and the repetition rate in higher education can be increased. If the repetition rate at a university increases, the Ministry warns that the university's guidance is not suitable for the students; hence, repetition is seldom enforced in Japanese higher education. This may imply that Japanese college students graduate at the end of their prescribed years at school whether they study or not.

GENERAL LABOR CHARACTERISTICS

Powerful industry is achieved through the efforts of not only engineers but also workers, so labor characteristics are outlined first. Three typical indexes are presented to compare labor characteristics. As seen in figure 3 [15], Japanese workers have the shortest working hours. France is the most comfortable country for workers because the labor cost index is low and French workers are productive. Germany seems to be able to compensate for its high labor cost with good labor productivity. In the UK and Japan, the labor conditions are not favorable: in the UK the unit labor cost index is high and the labor productivity index is low; and the Japanese unit labor cost index is just average, but labor productivity is comparatively poor. Given these circumstances, attention is focused on the UK and Japan in the next section.

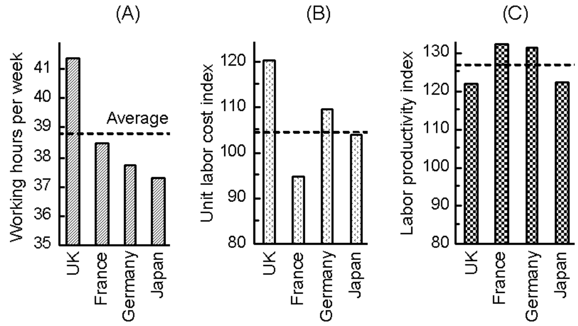

FIGURE 3

GENERAL SITUATION OF LABOR IN EUROPE AND JAPAN (REVIEWED IN 2000): (A) WORKING HOURS, (B) UNIT LABOR COST INDEX (100 = BASE OF 1990) AND (C) LABOR PRODUCTIVITY INDEX (100 = BASE OF 1990)

PRIORITY FOR FUTURE GRADUATES

It is reported that reinventing higher education of engineering requires the interaction between industry and academe [3], so competency required of future graduates is discussed from the viewpoint of the companies expecting to hire such graduates.

EU strategy goal. In the European Union (EU), it is important to achieve the EU strategy goal (i.e. the conclusions of the Lisbon European Council in March 2000) which aims to deliver stronger, lasting growth and to create more and better jobs [20]. This ambitious goal as a knowledge-based society carries both opportunities for personal advancement and the threat of being left behind. The Bologna Process sets the aim of improving the quality of both higher education and human resources across Europe in order to contribute to the EU's ambitious goal [1]. A questionnaire survey was used to identify current shortage areas among civil engineering, electrical/electronic engineering and system engineering [21]. British companies identified graduates in information technology (IT) and materials as being key to their future growth [21].

Promising fields in Japan. After the questionnaire about promising fields was sent to Japanese engineering companies and manufacturers, 401 usable responses were received [22]: the results are summarized in figure 4. The most promising field is the environment. It is considered that the Kyoto Protocol (the international treaty on climate change) that entered into force in 2005 will be reflected in

Japanese companies' strategies; it is estimated that the market and the number of employees in the environment business will increase from JPY30 trillion (19 billion Euro) and 800 thousand employees in 2000 to JPY58 trillion (36 billion Euro) and 1.3 million employees in 2020 (based on the reviewed data [2]).

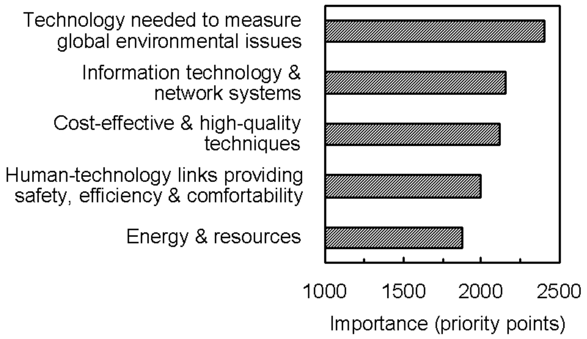

FIGURE 4
PROMISING FIELDS OF ENGINEERING AND TECHNOLOGY IN 10 YEARS IN JAPAN: 1ST PRIORITY = 10 POINTS, 2ND PRIORITY = 9 POINTS …10TH PRIORITY = 1 POINT PER QUESTIONNAIRE (2005)

Priority for graduates in UK and Japan. Educational systems, labor characteristics, social targets and perspectives on future industry are reflected in a company's employment plans. Summarizing the questionnaire responses from 444 British companies [21] and 401 Japanese companies [22], a comparative picture is drawn in figure 5 to show the companies' priorities for future graduates.

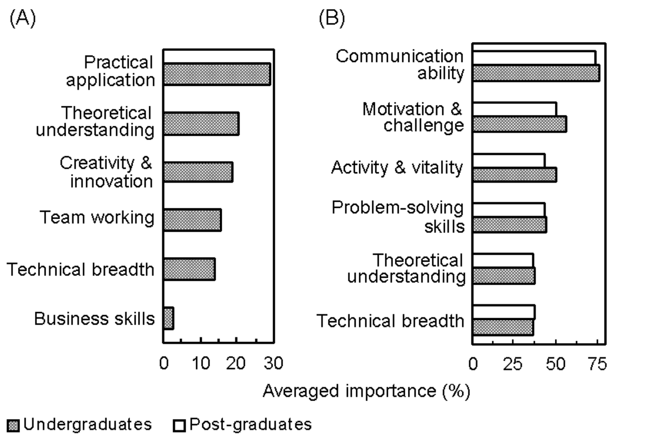

FIGURE 5
COMPANIES' PRIORITIES FOR FUTURE ENGINEERING PROGRAM GRADUATES: (A) AVERAGED IMPORTANCE (CHOICE OF 1 PRIORITY) OF BRITISH COMPANIES FOR UNDERGRADUATES IN 2006; AND (B) AVERAGED IMPORTANCE (CHOICE OF 5 PRIORITIES) OF JAPANESE COMPANIES FOR UNDERGRADUATES AND POST-GRADUATES IN 2005

In terms of priorities for skills of future engineering graduates, British respondents present the following order of priority in shown in figure 5A: practical application, theoretical understanding and creativity & innovation. As seen in figure 5B, Japanese companies set the following priorities for engineering program graduates: communication, motivation, and activity. In Japan, most students come through the automatic promotion system of compulsory education and the semi-automatic promotion system of higher education. As Japanese companies are well aware of these circumstances, it is considered that they put priority on factors other than the academic achievement of knowledge.

REQUIREMENT AND DEVELOPMENT

British companies put priority on knowledge-based factors when it comes to requirements of future graduates, and Japanese companies put priority on spiritualistic factors (figure 5). It is important to know how to effectively provide the fitness required by companies; this subject is discussed.

Application, understanding and creativity in UK. Over one-third of responding companies consider that shortages and skill deficiencies will impact on new product development, business growth and recruitment costs [21]. The greatest concern is with the ability of graduates to apply their knowledge to real industry. Over the past 10 years, the number of expensive practical/project works has fallen, and a reliance on computer-based models has increased in place of real experiments [21]. It is important to achieve "Bologna Compliance" within the shortened course period and fill the gap between the top requirement (practical application) and the present situation (a decrease of practical works at university), so universities will need government support to manage the additional costs for compliance achievement and reduction of the gap, and the Higher Education Funding Council will need to recognize these costs.

The author's experience during 8 years of environmental engineering education indicates that students wish to pass with high marks so they focus on textbooks and lecture notes; and what is worse, some cheat on tests. The author caught 7 students cheating during 2000-2006 (there is no clear penal provision in cases of cheating in the LEAM course). Instead of giving their own thoughts, some students prefer to use an answer directly derived from text books and/or the internet. The graduation thesis would seem to be a good chance for students to develop their creative and innovative abilities; however, when students write their graduation theses, they often reproduce an answer written in a book and/or on an internet site. The scientific method for students to achieve their goal may be summarized as follows: they must be curious, make observations, ask questions and try to solve problems [23]. However, curiosity becomes an educational problem. In the current diplomaism society, many students go on from high schools to universities whether they really want to or not, and they end up being uninterested in their courses; consequently, they do not want to study outside the bounds of a topic by reading more material than is necessary.

According to research on understanding of mathematics [24], two main factors undermine students' learning process – the lack of pre-requisite knowledge and the inconsistent terminology used by a teacher or teachers in the class. For appearance' sake, lecturers focus more on theory. Furthermore, lecturers sometimes may not be aware of the state of the art, and they may not have experience in any commercial plant or real industry; hence, it is important for lecturers to understand the difference between an industrially viable product and a laboratorial demonstrator.

Although there may not be an absolute method to develop the above-mentioned competences, the following approaches are at least advisable: students need to have their own thoughts on the relevant subject without quoting textbooks (or published information) verbatim; they should better prepare for lectures by clarifying ideas in their own minds in advance; depending upon a student's wishes, it may be necessary to the some extent for a dean to allow that student's change of course on a case basis; lecturers should reconsider the quality and quantity of lectures; lecturers should be consistent with terminology in the class; and teaching staff should introduce a more interdisciplinary approach [25]-[26], that is, provide a study of the theoretical base and exemplary practices.

Communication, motivation and activity in Japan. It is considered that Japanese universities do not provide a systematic approach for students. This can be compared with the LEAM course as follows: the two issues of environmental technology (the top ranking promising field) and cost-effective techniques (the 3rd ranking promising field) shown in figure 4 are linked in the LEAM course. After learning each treatment technology, the students study its cost performance in the upper grade of the course (lecture code No. 763). BATNEEC means "the best available technology not entailing excessive costs", and this concept is now gaining attention in Europe in the area of environment management. Based on this concept, since 2001 the author has given students in the LEAM course a lecture of the relation between environmental technology and cost performance; that is, the two subjects are systematically taught in a lecture. Since the BATNEEC concept has not been generalized in Japan [27], Japanese teachers do not need to link technology with cost in any environment-related lecture. Considering the top priority for future graduates cited by Japanese companies, the key point is whether teachers feel the necessity of a systematic approach (i.e. well-organized lecture) to improving Japanese students' communication ability. Many universities in Japan are putting effort into foreign language education (English in particular) [11], not into communication; they may think that language is equal to communication. It is well known that language has evolved over the years as a "tool" for communicating symbolic meaning. Communication must aim to create good interpersonal relationships, so a variety of factors must be required to achieve it – physiology, sociology, humanities, culture, etc. In the LEAM course, the same teacher is in charge of three subjects – English, technical English and Communication [17]. Thus, the pedagogic program given to students is consistent. However, in Japanese faculties of engineering, a teacher of English gives a lecture of English, and a teacher of technology usually gives a lecture of technical English, and there is little lecture of communication encompassing the above-mentioned factors. It may therefore be necessary for course organizers to reinvent the current educational program in order to improve students' communication ability.

As stated above, the Japanese government prioritized spiritual factors in the 1900 educational reform from achievement-based promotion to automatic promotion; this spiritualism must have heightened students' will to study and work in the Japanese environment of automatic promotion. By contrast, physiologic pressure that results when a student must repeat a grade produces the same result in an environment of achievement-based promotion. Spiritualism and the Japanese education system must have been indivisible in terms of ensuring that workers were up to the task of meeting the nation's needs, and the Imperial Rescript on Education (*Kyooiku Chokugo*) of 1890 was Japan's greatest support of spiritualism at that time [28]. A part of the then Japanese government's translation (1890) of this rescript is presented – "…pursue learning and cultivate arts, and thereby develop intellectual faculties and perfect moral power; furthermore advance public good and promote common interest…". During the USA's occupation of Japan (i.e. after World War II), American authorities abolished this rescript as an anti-democratic document [28]. Even so, Japanese spiritualism remained alive because the Japanese people realized that diligence and motivation were indispensable for post-war recovery and the following high economic growth. Since the 1990s, the growth rate has slowed and the Japanese economic miracle has come to an end [13]. Moreover, the number of young people has decreased, and the number of graduates from high schools (potential college students) is almost equal to the full enrollment quota for colleges in Japan [11]. Candidates have no difficulty in passing an examination to enter college [29]. Japanese spiritualism (that complemented automatic promotion so well) has now faded away. In the semi-automatic promotion system, Japanese college students may graduate at the end of their prescribed years at school whether they study or not. Since they grow up in the less motivating circumstances of compulsory education and higher education, it is natural that they become week-kneed (cf. Japanese workers have the shortest working hours – figure 3A). Japanese managers tend to use the humanistic/self-actualization approach to heighten workers' motivation [30]; i.e. not a results-based system but a system where spiritualism is emphasized. Course organizers should contemplate introducing work-related subjects (e.g. working life study) to the undergraduate course in order to heighten students' will to work.

CONCLUSIONS

The following simple picture can be drawn to illustrate the situation in Europe: the EU is headed for a knowledge-based society to deliver stronger and lasting growth; higher education regards students' knowledge acquisition as important and applies achievement–based promotion to maintain the prescribed level of that acquisition; and European companies (e.g. in the UK) prioritize the academic quality of graduates such as competence in application and theory as well as creativity. Thus, society's goal, higher education's function and companies' requirements for engineering graduates are largely consistent in spite of some problems such as reinforcement of students' practical skills.

By contrast with Europe, the Japanese picture is not so simple because Japan has its own peculiar mismatch between companies' expectations and higher education: the management style deployed in Japan is often referred as to Theory Z (reported by William Ouchi [31]), which stresses the need for enabling the employees to become generalists (rather than specialists) and increase their knowledge of the company and its process/production through job rotation and continual training. The key point of Theory Z is that the employees are motivated not only to do their work but also to make the company succeed [30], so this type of management tends to place more reliance on spiritual factors such as employee morale, responsibility etc. Automatic promotion and pedagogic training of the spirit (e.g. character building) were once inseparable in the Japanese education system; however, the former has survived while the latter has almost vanished. With the system of semi-automatic promotion, many Japanese students graduate at the end of their prescribed years at college regardless of whether they study or not, so it may be natural that they become week-kneed; this situation threatens to become worse. If Japanese companies wish to continue management based on Theory Z, higher education has a serious problem with how to send motivated and qualified graduates out into society. It is now necessary to reconsider the relation between higher education's target and recruiters' requirements.

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