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Stanisław WALUKIEWICZ*
Aneta Anna WIKTORZAK*

MEASURING HUMAN CAPITAL IN EDUCATION

We consider education as a number of multistage creative processes and analyse one of them – teaching knowledge (Process P1) in detail. We describe the idea of a virtual production line (VPL) in the sense introduced by Walukiewicz in 2006 as an extension of Henry Ford's classical production line (CPL). Teachers connected by the Internet provide education to students on a VPL – a kind of virtual belt – teaching a given set of subjects (tasks), offering knowledge by a prescribed methodology, etc. In contrast to a CPL, teachers on a VPL will use their brain power mostly and divide the teaching process into a number of tasks in what is called "self-organization of a VPL". Thus, a VPL shall be defined as a division of labor into tasks, while a CPL will just remain a partition of labor into a fixed number of jobs (tasks). Next, we introduce the value of human capital represented by a given student as a measure of P1 efficiency and compare it with the indicators used so far. In Poland, the problem is that different skills of students are not measured within one, integrated system. We propose a solution to this problem and furnish relevant field study results.

Keywords: *human capital, virtual production line (VPL), classical production line (CPL), efficiency of education*

1. Introduction

We first introduce the concept of general education as a number of creative processes and analyse two of them: teaching knowledge (process P1) in detail and teaching skills (process P2) in brief. While P1 has been around for centuries, skills-oriented teaching (P2) was brought into practice some 30–40 years ago and has become increasingly popular ever since its debut. In other words, we apply systems or input-output analysis to education, considered as a sector (part) of a market economy. Then

*Systems Research Institute of the Polish Academy of Sciences, ul. Newelska 6, 01-447 Warsaw, Poland, e-mail addresses: Stanislaw.Walukiewicz@ibspan.waw.pl, Aneta.Wiktorzak@ibspan.waw.pl

the question of the economic efficiency of that sector can be formulated. Similar treatments of education are presented in [1, 2, 4].

The strategic aim of our study is to evaluate the efficiency of P1. We use the concept of a virtual production line (VPL) in the sense introduced by Walukiewicz in 2006 – a natural extension of a classical production line (CPL). While we describe a VPL in education in Section 3 and in the next Section use it to model P1, in Section 5 we discuss our research results and in the Conclusion we formulate three recommendations which we strongly believe will be relevant not only for Polish but worldwide education.

2. The methodology

We consider a school where the processes P1 and/or P2 are in place as a system or a firm *F* (see [11] and [14] for the appropriate definitions) with its inputs and outputs and with its more or less defined objective (Fig. 1), so the question of how efficient the processes P1 and P2 are can be rephrased as:

What is the value of a given school *F* at a specific time *t* – *V*(*F*, *t*) in a relevant education market?

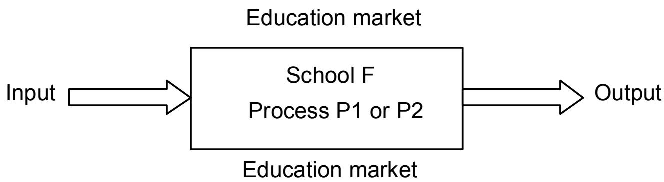

Fig. 1. School *F* as a system

Here, the natural unit of time is the school year, which in Poland is between 1st September in one year and 31st August in the next year. In other words, we consider a given school *F* as a (closed) black box with its inputs and outputs, and ask about the economic efficiency of the processes P1 within that box. Thus we apply classical systems analysis and, obviously, compare schools at the same level of education. The main aim of a school is to increase the human capital represented by each student, as well as the capital represented by its students as a whole.

To answer the question above, we need to consider absolutely all the assets of a given school (firm) *F* at time *t*. Walukiewicz [11] (see also [10]) introduced the so called orthogonality principle and proved that all assets of a given firm can be partitioned into two disjoint forms: tangible and intangible assets, with intangible assets further partitioned into human and social capital and tangible into financial and physical capital. Thus we arrive at the fundamental equation which says that the value of a firm F at a moment t equals the sum of the values of these four forms of capital (assets), that is

$$V(F,t) = v(FC,t) + v(PC,t) + v(HC,t) + v(SC,t) \tag{1}$$

for any moment t in the "past", "present" or "future" of firm F (see [7–9] and [14] for details). So, although these four forms of capital closely "cooperate", we can add their values as they are disjoint or orthogonal.

3. Virtual production line

The concept of the virtual production line was introduced by Walukiewicz in 2006 as a model for analysing creative processes. To describe our idea, we need general information about its predecessor a (classical) assembly/production line, which we would like to explain with an example from the automotive industry.

Fig. 2. Production circle

Before 1913 cars were manufactured in so-called production circles (Fig. 2), where a few highly skilled craftsmen produced a car from beginning to end using parts and raw materials. The division of labor in such a production process was very flexible. In fact, craftsmen could easily substitute one another, and an obvious limit on productivity was the number of highly skilled craftsmen in a given society.

Henry Ford was the first who put into practice the following observation: if we partition the complex process of manufacturing a car into a fixed number of simple operations (jobs) done by unskilled workers (blue collars) on a line (belt) (Fig. 3), then its productivity will increase and the problem of the limited number of highly skilled craftsmen should be solved. This is one of the greatest achievements in management science and economics, which completely changed our world. The idea of the assembly line was then applied in many production and service processes. If we have many production/service lines manned by people or robots, then for the purpose of our analysis, we combine them into one production/service line, which we will call the classical production line (CPL). A similar approach is used by Tang et al. [5].

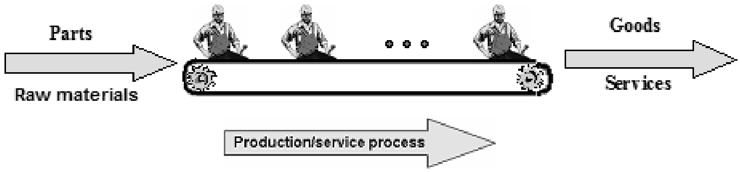

Fig. 3. Classical production line (CPL)

Let us assume that a given worker has increased his/her skills (his/her human capital) and now can do the job assigned in half the previous time. Does it have any impact on the organization/productivity of the production process concerned? The answer is: no, it does not. His/her extra skills may be used in the design and implementation of another production process on another CPL, but not in the one in hand as its organization is fixed. We conclude that a CPL does not allow any self-organization and workers (blue collars) are to work on it, not think.

Definition 1. A classical production/service line (CPL) is a partition of a complex production/service process into a fixed number of simple operations (jobs) described in the smallest detail. Such a partition is fixed over a period of time and does not allow any self-organization (Fig. 4).

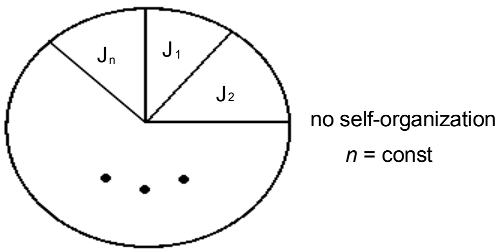

Fig. 4. CPL as a rigid partition of labor

A bit exaggeratedly, we can now say that highly-skilled craftsmen are not needed in the automotive industry, where organization is a priority. Due to excellent organization, very unskilled workers can produce very sophisticated cars.

Let us consider a VPL shown in Fig. 5, where a number of experts (teams of experts), scientists, specialists, etc., backed by data processing and computing machines – in Fig. 5 we show their keypads and monitors – get together *via* the Internet or any

ICT networks to solve, using some creative process, a more or less accurately defined problem of our firm *F*. Since there is no material representation of a VPL (our experts can be located in different parts of the world), we denote it in Fig. 5 with a dotted line.

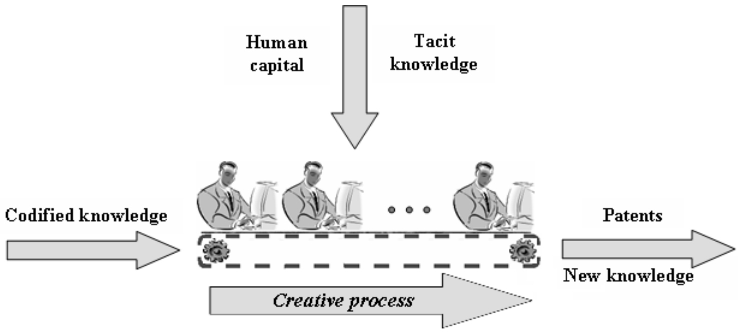

Fig. 5. The concept of a virtual production line (VPL)

As shown above, on a VPL experts combine their human capital – mostly their tacit knowledge – with codified knowledge to solve a problem in a creative process. At the beginning, the problem may be murky or poorly defined, but due to their efforts (self organization), it will become more and more explicit and definable. This is so, because experts on a VPL not only work but – mostly – think.

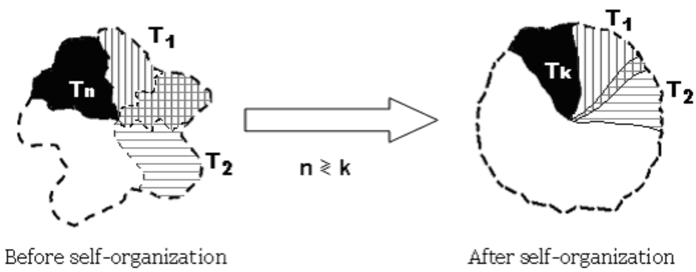

Fig. 6. A VPL as a flexible division of labor and self-organization

In Figure, 6 we see that at the beginning of a creative process, the problem is usually not well defined – we denote this with a dotted line along the perimeter. Tasks often overlap and their boundaries are not well delineated – we denote this with a wavy line. After self-organization, the problem is much better defined (it is almost a circle), and the overlapping of tasks is substantially smaller and their boundaries almost straight lines. If the problem is initially divided into *n* tasks $T_1, T_2, \ldots, T_n$, then, after self-organization, there are *k* tasks $T_1, T_2, \ldots, T_k$, where *k* can be equal to, bigger or smaller than *n*. We conclude that a VPL allows a flexible division of labor, while a CPL is based on a rigid (stiff) partition of labor (see Fig. 4), where the production/servicing process is well defined – see the circle in Fig. 4 – jobs $J_1, J_2, \ldots, J_n$ do not overlap and the boundaries between them are straight lines. Obviously, we do not claim that any problem on a VPL can be solved – transformed to a perfect circle after self-organization in Fig. 6.

Definition 2. A virtual production line (VPL) is generally a division, not a partition, of a complex creative process into more or less precisely described tasks (jobs), with the use of modern ICT being paramount. The division of the creative process into tasks, and the number of tasks itself may be changed throughout the process by actions of experts involved in it. Such modifications shall be called the self-organization of a virtual production line and may recur over the course of the process.

We note that unlike a CPL, a VPL is not a simple division of labor but a more complex structure composed of three elements: division of labor, self-organization and modern ICT. We realize that social capital only made its way into the spotlight in the 90's and at the same time humans began to be able to send information electronically, now reaching virtually every corner of the world at almost zero cost.

To sum up, we may say that a VPL is an instrument (a virtual conveyor belt) that experts use to combine codified knowledge with their tacit knowledge, competence, experience, etc. to introduce improvements in products, services, technology and management, and contribute to the world's stock of knowledge, both codified and tacit (Fig. 5). In other words, it is a device from which the social capital of firm F makes money (financial capital) in a creative process using the human capital of its experts and physical capital of its assets (computers with software, data bases, communication networks, patents, licenses, books, buildings, furniture, etc.). Thus Figure 5 expresses the fundamental equation (1). In the next section we show how a VPL is used to "produce" new human capital.

Nowadays the word "virtual" is used in many different contexts. For instance, Tang et al. [5] used the term "virtual production line" as a dummy line accommodating different real CPLs in semiconductor manufacturing. So in that paper, both dummy and real CPLs are used in a routine process producing millions of chips. Above, we showed that a VPL can be used to model a creative, not routine, type of cooperation between at least two experts, who use their brain power to solve a given problem. A full comparison of VPL and CPL is given by Walukiewicz in [14, p. 157].

4. VPL in education

In this Section, we will see a school (our firm F) as a system where a number of creative educational processes are employed. Using the example of P1 (teaching knowledge) and P2 (teaching skills) in a secondary school (SS), we will demonstrate how useful the concept of a VPL is in modeling and analyzing such processes (Fig. 7). It should be stressed that on a VPL, students will never be treated as parts or components of a CPL but on the other hand, using the concept of human capital, absolutely all the characteristics of a student as a human being can be tracked and measured (his/her knowledge: codified or tacit, experiences, talent, health, etc.). Below we show how the self-organization and social capital (cooperation between teachers) of a given VPL can be used in modeling and analyzing such complex components of the human capital represented by a single student, as well as a group of students, e.g. a given class or a school.

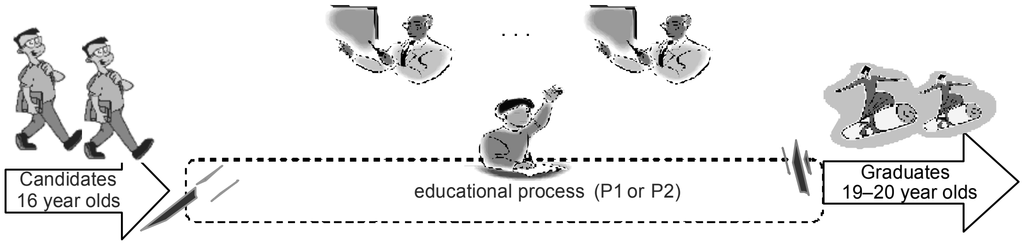

Fig. 7. A VPL in education

At the input are 16 year old candidates (SS entry age), with their knowledge, physical and mental levels of competency, health and other components of human capital (*HC*). By $v(HC, s_i, t)$ we denote the value of the human capital represented by a given student s_i at time t of the (school) year, in most cases the end of the year. When we gauge the human capital represented by e.g. all students in a class or a school instead of a single individual, we skip s_i which leaves us with $v(HC, t)$. Human capital has a lot of similarities to financial capital and, in general, should be measured in monetary units [13–15]. Also, it has a cumulative property: the knowledge, experience, etc. of a student accumulate and build up as their schooling progresses, though, realistically, we never assume that $v(HC, t)$ is always increasing. We understand that it does not always work that way. We assume that the value $v(HC, t)$ on entering school F equals the exit value $v(HC, t_0)$ on leaving the previous level of schooling. Presently, in Poland, $v(HC, t_0)$ is determined by the standard (all-Poland) middle school exit examination.

At the output of our VPL (school F) are graduates who have taken their high school examinations (in Poland – the matriculation examination) after k years of education (in Poland k = 3 or 4). The value of human capital represented by a given student is denoted as $v(HC, s_i, t_k)$. Over k years of study in the P1 process, students are taught a given set of courses (tasks) in a prescribed sequence and the teaching load and methodology are carefully selected. In contrast to a CPL, teachers on a VPL mostly use brainpower, e.g. to divide the teaching process into a sequence of tasks with the inclusion of the human and social capital of students. This is what we call self-organization (of the P1 process) on a VPL. So, a VPL is a virtual belt which transforms a given student s_i with his/her human capital $v(HC, s_i, t_0)$ to graduate level at which his/her human capital is $v(HC, s_i, t_k)$.

Obviously, a process as the one above never happens in isolation. To give due credit to the impact of the community (parents, school administration etc.), we assume that since they all take their concerns to teachers and exert pressure on them, they affect the self-organization of the teachers' VPL. We also note that there is an obvious asymmetry in volume between information going from teachers to students and that going the other direction. Note the various arrows in Fig. 7.

Before concluding, let us emphasize two points. First, unlike a CPL, a VPL in education is normally nonlinear – a teacher can teach, e.g. physics one year and in the next year chemistry. Thus the concept of human capital in education is much, much wider than a mere measure of student achievement, like with the value added score [2, 3], grade equivalent method [3] and the vertical scales method [6]. The difference will be seen once ICT is fully implemented, particularly in school administration (electronic class register, data bases, etc.). Clearly, a large number of practical and legal problems have to be discussed and solved before this happens and this goes beyond the scope and ambit of this paper. In the next Section, based mostly on the PhD dissertation of Wiktorzak [15], we demonstrate how the concept of human capital can be applied to the value added score method.

5. Process P1

The value of the human capital represented by a given student s_i in year t, denoted as $v(HC, s_i, t)$, can be regarded as statistical data which represents a population of n students from a class/school/region/country. So we can determine certain population parameters, e.g. the mean value of social capital (for that population)

$$\bar{v}_t = \frac{1}{n}\sum_{i=1}^{n} v\left(HC, s_i, t\right) \tag{2}$$

or the standard deviation defined as

$$\sigma_t = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left[v\left(HC, s_i, t\right) - \bar{v}_t\right]^2} \tag{3}$$

We define the efficiency of school F in the completion of the P1 process, or the efficiency of P1, as the difference between the output and input values for the relevant

VPL. From the perspective of student (s_i) the efficiency of a given VPL equals the difference

$$v\left(HC, s_i, t_k\right) - v\left(HC, s_i, t_0\right) \tag{4}$$

In Poland, different methodologies are applied in the examinations at times t_0 and t_k, different subjects are chosen and the results are measured on different scales. Wiktorzak [15] suggests a way out: use (linear) regression analysis to calculate the difference in question. To do so, we first work out Pearson's correlation coefficient for the input and output results on a VPL of the population of n students (class, school, region or country), defined as

$$r = \frac{\sum_{i=1}^{n}\left[v\left(HC, s_i, t_k\right) - \overline{v}_k\right]\left[v\left(HC, s_i, t_0\right) - \overline{v}_0\right]}{\sqrt{\sum_{i=1}^{n}\left[v\left(HC, s_i, t_k\right) - \overline{v}_k\right]^2}\sqrt{\sum_{i=1}^{n}\left[v\left(HC, s_i, t_0\right) - \overline{v}_0\right]^2}} \tag{5}$$

Next, we calculate the value of human capital represented by a given student s_i at the final exam stage, denoted as $v(HC, s_i, t_k)$, taking into account his/her exam results in year t_0, defined as

$$v(HC,\ s_i,\ t_k) - \overline{v}_k = r\left[v\left(HC,\ s_i,\ t_0\right) - \overline{v}_0\right] + V(F,\ t_k) \tag{6}$$

where $V(F, t_k)$ is the so called value added score or the contribution of school F (to the growth of human capital in the population concerned).

We can consider linear regression analysis as a linear transformation of the input results x into output ones y. If we denote $x = v\left(HC, s_i, t_0\right) - \overline{v}_0$ and $y = v\left(HC, s_i, t_k\right) - \overline{v}_k$, we arrive at a formula for the regression line

$$y = V\left(F, t_k\right) + rx \tag{7}$$

The idea of linear regression analysis for input/output exam scores scaled on the standard nine scale is given in Fig. 8.

Thus we can consider linear regression analysis as a linear transformation of the input results into those of the output stage. Extensive secondary education results obtained using this approach are given in [15]. In Figure 9, we present the Polish education system as a chain of VPLs starting from primary school and finishing at secondary school level. In fact, the system includes kindergarten at its beginning and university at its end but we do not include them at this early stage of our study. Rather than that, we focus on how the system affects the value of human capital represented by students as they progress from six year old beginners at primary school to high school graduates. As a measure of human capital, we use the marks obtained in exams at a given level of education. Thus we combine all the VPLs into one virtual production line, which reflects the Polish system of education and transforms a six-year child into a 19–20 year old graduate (Fig. 9).

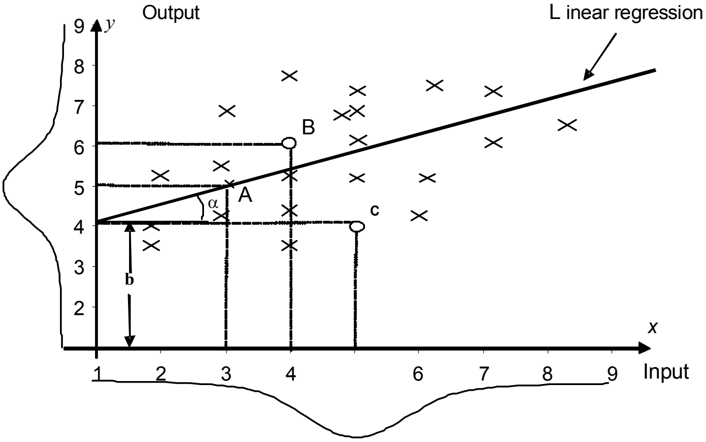

Fig. 8. The idea of linear regression analysis

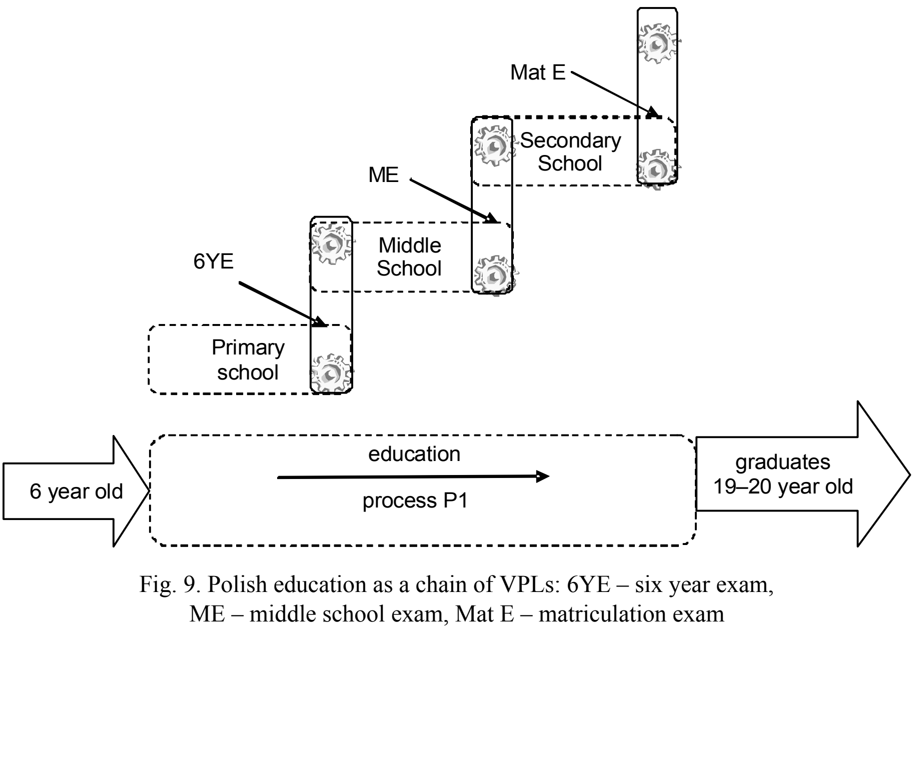

Fig. 9. Polish education as a chain of VPLs: 6YE – six year exam, ME – middle school exam, Mat E – matriculation exam

In Poland, the exams occurring between consecutive levels of education, shown in Fig. 9, differ in methodology, the subjects taken and the scales results are measured on. To control this, we propose to measure a student's achievement as the percentage of the maximum mark obtainable in a given exam. In Figure 10, we compare the results of Janek Kowalski (JK) with the expected results for the population of 156 students in north-east Poland obtained by linear regression.

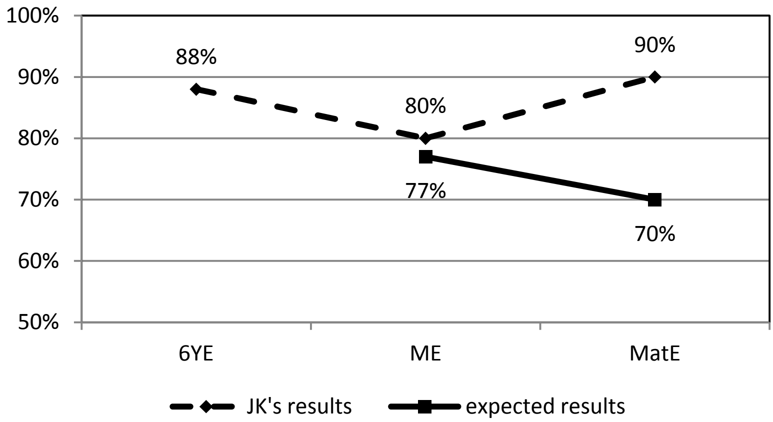

Fig. 10. Comparison of JK's achievement with the results of linear regression for n = 156

In Figures 11 and 12 we present the results of regression analyses for two consecutive exams. JK's scores are denoted as a big dot. Although the population is small, we easily note that the regression lines become more and more horizontal as the level of education increases. This may mean that insufficient care is given by teachers to good and outstanding students.

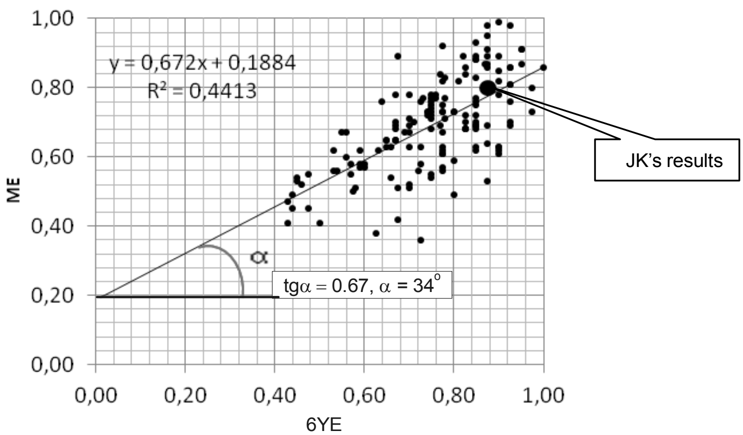

Fig. 11. Regression of ME scores on 6 YE scores. Source: [15]

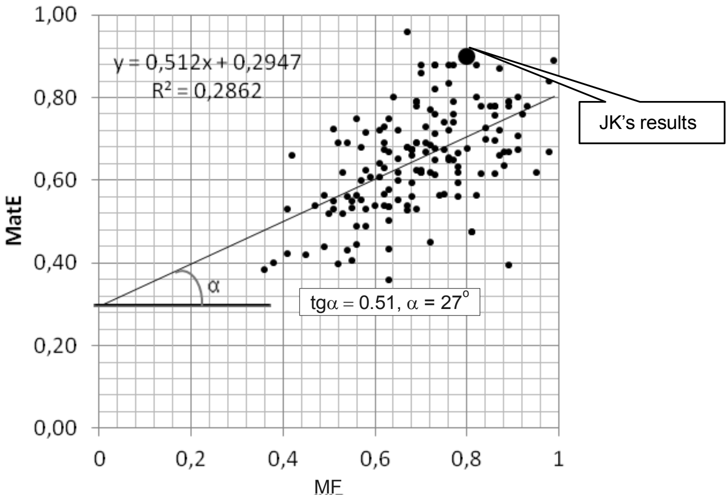

Fig. 12. Regression of MatE scores on ME scores. Source: [15]

6. Recommendations and conclusions

Although the build-up of human capital is a lifelong process, it is school education, from kindergarten to PhD for many, that plays a key role in it. A bit exaggeratedly perhaps, we could say that in a knowledge-based economy each community member is a capitalist with his/her own human capital and the communities/regions/countries where such "human capitalists" unite will be the most successful in the global economy. Given this, we suggest considering education as one, logical and consistent system aimed at the development of the human and social capital represented by individual students and groups of them. Let us put some light on what our goals are by giving a handful of recommendations (R1–R3):

- **R1. Consistency.** Exams at each level of education should be delivered using the same methodology (the same subjects/skills, the same form, external evaluators, etc.). This allows reliable and rapid assessment of the development of human capital for each student or group of students and the contribution of each school/university/institute to the process.
- **R2. Accuracy of measurement.** For obvious reasons, the results of exams at each level of education should be assessed/evaluated on the same scale [6].
- **R3. From P1 to P2.** We recognize the fact that the transformation from teaching more or less loosely connected courses (P1) to teaching skills (P2) requires time, money and extra effort. Schools need more ICT, fewer students per class, a lot of changes in curricula and teachers should be better assigned to tasks. Granted that it needs

a step-by-step approach, it needs to start right now. P2 promotes the growth of human capital much better than P1.

The Internet is dramatically changing education worldwide. A teacher is becoming a tutor-captain helping students navigate in a practically unlimited ocean of knowledge. We are confident that a VPL with its self-organization and social and human capital will stand in good stead in such a transformation. Self-organization matters a lot in education and with a VPL, teachers can make a difference and schools "produce geniuses".

This paper should be considered as an application of systems research in education. We hope that the orthogonality principle, as well as the concepts of human and social capital and VPL will form a firm base for further studies.

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