PREDICTING SUCCESS IN ENGINEERING STUDIES: CHALLENGES OF EARLY DETECTION OF WEAK SIGNALS OF STEM-RELATED APTITUDES

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Abstract

The theory of signal detection, originated in the second half of the 19th century in psychophysics, has returned to life a century later when it was discovered that sensations generated by neural noise do not fall below the threshold of conscious awareness. More adequately called the theory of "weak signals" detection, the philosophy and model of this theory was conceptualized by both Gaussian and non-Gaussian models. It proved to be useful when earlier the signals are detected, then better. The applications have extended time spectre – from avoiding a negative phenomenon with rapid evolution (as a situation in medicine or catastrophic earthquakes) to predicting future evolution of a certain system, in a large range of areas: from electronics (circuit analysis) to strategic management (strategic early warning system) and economics (agriculture, market prediction). The decision is also variable as time horizon, depending on area of application, from fractions of seconds to minutes in case of catastrophic events to weeks or months in other cases (agriculture). The scope of work is an area less investigated: education. While the extant literature is rich in many areas (psychophysics, neuroscience, psychology, medicine, electronics and telecommunications, geophysics or economy), the literature related to applications of weak signals theory in education (engineering studies in particular) is rather scarce if not completely missing. Engineering skills – part of STEM (Science, Technology, Engineering, Mathematics) competencies – are trained during costly engineering studies. However, cases of engineers less talented or unhappy with their engineering jobs are sometimes met. Conversely, authors met young people with various non-engineering backgrounds landing in jobs with technical profiles. Probably, the family influence, and perfectible career orientation are blameable for such cases. Therefore, this essay aims at setting a research framework and a suitable procedure to assess and identify emergent STEM-related aptitudes (as weak signals) during pre-university education cycles to increase the chances of better matching the respective students with their future engineering education and, subsequently, with their careers as engineers. As methodology, the study is based on directly observed and/or personal experienced cases in the Romanian engineering higher education as well as pre-university education cycles, which are complemented by pilot tests designed for this purpose. Secondary research (literature survey) marks the literature gap and complement the matter under investigation. Since this is a pioneering effort, several challenges are foreseen. As a long-term endeavour by its nature, this is a risky project (false positive and false negative results might occur), which recommends a step-by-step approach. Nevertheless, the lessons learnt, and implications are important for the main stakeholders: education policy makers and administrators, students and professors alike.

Keywords: Technical higher education, engineering skills, STEM (science, technology, engineering, mathematics) competencies, STEM-related aptitudes, early detection of weak signals.

1. Introduction

In public education, early skills have become increasingly important as teachers and other educational stakeholders investigate ways to close the widening national academic achievement gap. Pathways to future academic achievement are, in most cases, shaped in the early years, when children learn essential skills that help create a foundation for later development of a set of academic skills and achievement. Research in the field has highlighted the fact that some individuals start school with certain early skills, this represents an advantage they have over others in terms of achieving academic achievements in the future (Hein, Smerdon, & Sambolt, 2013).

In order to achieve educational and professional success, early detection of skills is essential. In the field of engineering education, identifying STEM (science, technology, engineering, mathematics)

skills from pre-university education can have a positive influence on the career guidance process and help students choose careers that suit them and they bring satisfaction and fulfillment. When these early skills identification mechanisms are missing, individuals end up in unsuitable careers, leading to unfulfillment and burnout. This is supported by research of 210 professional employees working in four global high-tech companies, showing that low-performing employees are those who work in the technical field but prefer the managerial one, and employees who reported the lowest levels of burnout are those who experience a career path match (Biron & Eshed, 2017).

For the early detection of abilities, it is necessary that teachers and other educational actors are able to detect weak signals of students regarding these abilities. Weak signals are not just simple "weak evidence of future changes" but represent starting hypotheses for a lot of future-oriented knowledge processes. Rossel (2012) argues that there are several challenging research topics that lie between the deterministic belief that weak signals are easy to identify and the constructivist position that places weak signals within a complex system. However, despite the fact that weak signal detection theory has been successfully applied in fields such as medicine, economics or telecommunications and strategic management, its application in education, and especially in the field of engineering, is still unexplored territory.

The present study aims to develop a suitable research framework and methodology for the early identification and assessment of emerging STEM-related skills (seen as weak signals) during pre-university education cycles, with the aim of facilitating better correlation between students, their future engineering education and subsequently their engineering careers.

2. Literature survey

The weak signals used in the process of detecting unexpected events, such as diseases, come from the realization that these may be warning signs of accidents or other crises, identified only in retrospect. Often, weak signals are ignored if they go against general expectations about the future or if they are unusual, or if they don't agree with traditional ways of privy to things (Liff & Wikström, 2017).

In most cases, weak signals are emerging phenomena, which are the first potential signs of a major change in the future. Observing weak signals can identify the seeds of change and classify them. The "standard" theoretical base is represented by the Ansoffian perspective. This requires the weak signal watcher to identify linearly progressing problems in their early stages. In the process of formulating the premises of the theory of weak signals, the "standard" version of this theory assumes an emerging problem perceived in its rudimentary form. Weak signals represent not only the identification of a linear emergence, but also the changing positions and contexts of observers (Ahlqvist & Uotila, 2020).

In the field of medicine, the theory of weak signals is successfully used for the early detection of rapid negative phenomena, such as the evolution of diseases. The most pressing challenge facing those responsible for improving and regulating patient safety is how to identify, integrate and act on early warnings and weak signals of risk before they contribute to a catastrophic failure of care. (Macrae, 2014).

Another field in which weak signals are successfully used is that of geophysics, specifically in predicting catastrophic earthquakes. The prediction of an earthquake is challenging, with many countries conducting extensive research on this topic. Using the local cross-correlation tracking method can reflect the correlation between electromagnetic data. Even if very weak signals show anomalies, the method can sensitively detect the anomalies (Xie et al., 2022).
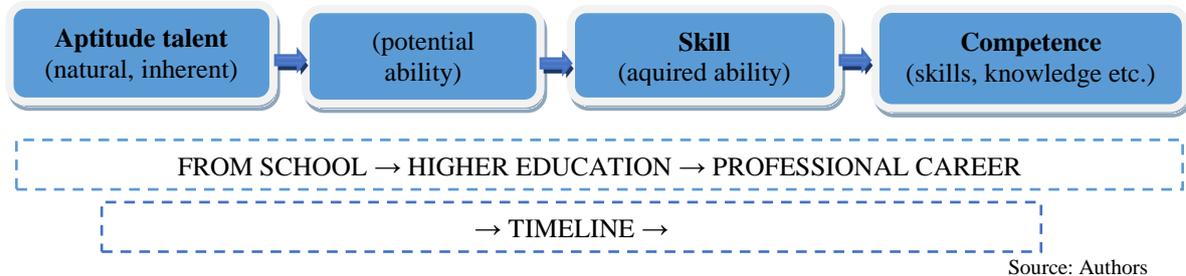
3. Methodological approach

The methodological approach of this study is a mixed one and consists of direct observations and personal experiences of the authors, accumulated in pre-university and university education in Romania. This approach is complemented by the proposal of pillar tests to identify emerging STEM skills (weak signals) among pre-university students. But also, university. Also, the study includes secondary research (specialty literature analysis) that highlights the existing gaps in the profile literature and supports the theoretical framework of the investigation. The adopted methodology is one with an exploratory character, considering the fact that the application of the theory of weak signals in education is too rare, especially in the field of engineering education.

The authors' observations are intended to optimize the orientation of students towards an appropriate engineering education, so that young people are oriented towards a career that suits them according to their potential and interests. This is a pioneering initiative and is only the first step towards a procedure and tools for identifying emerging weak STEM signals. The authors anticipate several challenges, including risks associated with false-positive or false-negative results. Therefore, the methodology proposes a gradual approach, allowing adjustments along the way and learning from

accumulated experiences. The implications of this research are relevant to several stakeholders: educational decision-makers, teachers, students and administrators of educational institutions.

This study contributes to developing a suitable research framework and methodology for the early identification and assessment of emerging STEM-related skills (*Figure 1*), aiming to facilitate *better correlation between students, their future engineering education and their future engineering careers.*

Figure 1. A scheme of research approach.

| **Aptitude talent** (natural, inherent) | → | (potential ability) | → | **Skill** (aquired ability) | → | **Competence** (skills, knowledge etc.) |

FROM SCHOOL → HIGHER EDUCATION → PROFESSIONAL CAREER

→ TIMELINE →

Source: Authors

4. Findings

A study conducted in 2016 presents a detailed analysis of seven core STEM courses, examining how resources were utilized and their correlation with final grades. Through logistic regression, researchers observed that students who extensively use exam preparation resources have higher chances of achieving good grades, whereas those who rely more on lectures have lower chances (Waddington et al., 2016).

Recent technological advancements can be effectively utilized in Early Warning Systems (EWS) to predict students who are suitable to pursue STEM disciplines further, as well as those who are at risk of not succeeding. In this way, both teachers and students can make informed decisions to support students and guide them towards the most appropriate solutions. By leveraging learning data available on online learning platforms, the use of EWS can predict students with low chances of success before the end of the semester (Yu & Wu, 2021). Such Early Warning Systems could help students remain engaged in the STEM field and ultimately secure employment opportunities within this domain. By identifying struggling students early on, educators can intervene promptly with targeted support strategies tailored to the specific needs of each student. This proactive approach not only increases the likelihood of academic success but also nurtures students' interest and confidence in STEM disciplines. In Chicago, many schools have used early warning indicators to develop strategies for improving student performance. Furthermore, teachers have been able to examine patterns in the indicators to strategically address students' low performance based on specific issues observed in the school (Allensworth, 2013).

Integrating students' behavioral signals and their entry profiles is valuable in anticipating their success in STEM courses. Behavioral signals such as the number of correct responses to in-class questions, slide and video views, can serve as stable predictors of students' success throughout the semester. By utilizing these behavioral signals along with student profiles, it becomes possible to predict students' success. Additionally, early warning systems that leverage diverse student data can aid in developing other innovative predictive features for student success and contribute to designing an enhanced early warning system (Nam, 2019).

Many recent studies advocate for the adoption of early warning systems to identify at-risk students. A study conducted in 2018 examined eight prediction methods and investigated the optimal timing for implementing such a system within a course. The study's findings indicate that the ideal time for implementing an early warning system is around weeks 5-6. (Howard et al., 2018).

To identify talented STEM students in primary school, the authors made direct observations of the students' involvement in STEM-related activities. An example of such activity was the design and 3D printing of key chains. The students worked in teams of two, at the computer, where they designed, based on predetermined models and with the help of specialists, personalized key chains. They also had the opportunity to print them using 3D printers. During the activity, there were students who demonstrated critical thinking, good logical and analytical thinking skills, but also spatial and technical thinking.

These children, if they *benefit from an educational process that supports them in developing these skills, have a high chance of achieving a successful career in engineering*. An example of an activity carried out within the primary cycle is that of building a city from recyclable materials. In this activity, students worked in teams, collected the right materials, designed and built a miniature city. They also had the task of building a bridge that would support the weight of a toy car, but also a simple circuit with batteries and light bulbs that would take the place of the street lighting in their city. The activity

stretched over several hours, and the students had limited resources at their disposal. Students who managed to find innovative solutions and solved the problems encountered during the project were noted. Through this activity, one can observe students who have the ability to solve problems, who have an increased interest in science and technology, but also spatial and technical thinking. It is an activity that can help teachers identify students' weak signals and develop them in the future.

In terms of activities observed in the university environment that can help teachers identify weak signals of students, an example of an activity is represented by problems that put students in difficulty and test their ability to solve problems, think logically and criticism, but also teamwork. One such problem is related to finding an optimal solution for street lighting in their city. The students worked in teams and had access to resources such as course materials and the internet, creating a sustainable street lighting project. In this way, students who have problem-solving, collaboration, teamwork, problem-solving, and spatial and technical thinking skills were noticed.

Participation in conferences and workshops is encouraged. Students are supported to participate in such activities by presenting scientific papers or participating in debates on current technological topics. In this way, students are motivated and can discover or develop their STEM talents or skills. Such informal activities are extremely beneficial for students and add value to the instructional-educational process. It is also in such situations that teachers can identify students who show talent in the STEM field and help them develop further to reach their full potential.

An example of a test used for primary school students consists of a cognitive test and logical thinking activities. To identify the model in numerical sequences, exercises such as: What is the next number in the sequence: 2, 4, 8, 16, …? (The answer is 32, each number being double the previous one). The next item can consist of a problem like "Maria, Ion and Michael participated in a marathon. Maria arrived before Ion, but after Michael. Who won the contest?" The Test can also contain logical association games (bread-baker boxes, clock-battery) or resource distribution problems. The list of items to test students can go on with logical transportation problems, the cube tower test, sorting problems, logic problems, or analogies tests.

As far as hands-on STEM experiments, making a volcano using baking soda and vinegar is one of the activities that get students engaged and engaged. This type of experiment gets students interested in science and technology, but also tests their collaboration, teamwork, or logical thinking skills.In the university environment, game-based activities involving STEM simulations, such as programming robots or solving virtual challenges through educational software, are effective methods of testing students on their STEM talents and abilities. During these activities teachers can gather valuable data about students' talents and how they can help them develop further. Another type of test is one that is based on logical rip-puzzle activities or reasoning problems that aim to assess students' critical and analytical thinking. These activities give teachers the freedom to customize them according to the theme of the course, while also testing the students' skills/weaknesses in the STEM field.

These tests and experiments, based on a representative sample, should provide a clearer picture of the process of identifying weak signals among pupils and students, the results being useful in drafting recommendations for teachers and educational counselors regarding the career guidance of students.

Figure 1 shows the route taken by the students, starting from primary school and ending with a professional career. The authors propose this route model that could be followed in order to identify weak signals of students early, based on the progressive development of their skills. First, it emphasizes the native aptitudes of individuals, that is, those innate traits that reflect natural talent and inclinations. The second step is the analysis from the perspective of the student's potential, evaluating his latent ability to learn and progress in certain areas. Next, the emphasis is on acquired skills, developed through education and practice, thus consolidating what the student has already learned and is able to apply in practice. The end of the path is completed by the achievement of competence, which sums up the skills, knowledge and attitudes necessary to perform successfully. The proposed model provides a clear framework for understanding and supporting student progress from potential to performance, i.e. from low signals to achievement.

5. Limitations and further steps

The present research has a number of limitations, the first one being related to the lack of longitudinal data. In addition, the lack of concrete data on the application of the tests among pupils and students is another major limitation. In addition, false positive or false negative results should be considered in terms of the application of weak signal theory in education. The authors propose the continuation of the process of carrying out a procedure to evaluate and identify emerging skills related to STEM (as weak signals) during pre-university education cycles. The previously presented pilot tests are to be applied among pupils and students, and then the results of the participants will be analyzed for

validation. The authors also propose the development of tools to be applied in pre-university education with the aim of identifying weak signals related to STEM, thus contributing to increased chances that young people who choose to study STEM disciplines in university to have higher chances to be successful while pursuing an engineering career.

6. Conclusions

In the field of education, the theory of weak signals could be successfully applied by teachers, thus helping students to develop their natural talents and thereby form skills and then competencies that will help them in their future careers. The implementation of an early warning system would help in the career guidance process, thus young people would no longer end up occupying positions or different fields that do not suit them. It is necessary that the methods currently used by teachers be adapted to identify students' talents as early as possible and to help them develop skills that will help them in the future. In this way, students will become young people who possess skills and competencies in line with their talents, achieving professional success and fulfillment and having a sense of well-being at work.

The research therefore emphasizes the importance of early identification of STEM skills among pupils and students, considering their impact on educational and professional success. The application of the theory of weak signals in the field of education, especially in engineering education, can positively contribute to the process of adequately orienting students towards careers in the technical field, highlighting the students' potential. The studies presented and the observations made by the helpers contribute to a better understanding of this complex process of identifying weak signals and using them for the benefit of students. Early identification of STEM talents can support students in choosing an appropriate educational and professional path, thus eliminating unfulfillment and burnout. Implementing early warning systems and using practical tests and experiments can help teachers use valuable tools to support the development of these skills. However, as a relatively new approach to education, the application of weak signal theory requires a flexible and adaptable framework that can be adjusted as more experiences and data accumulate.

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