https://doi.org/10.36315/2024v1end070
Education and New Developments 2024

EARLY DETECTION OF STEM SKILLS DURING SECONDARY EDUCATION. A WEAK SIGNALS APPROACH

Florentina Alina Grigorescu (Pîrvu)*, & Cezar Scarlat
FAIMA Doctoral School from National University of Science and Technology POLITEHNICA Bucharest, (Romania)

Abstract

Currently, the gap between students' professional preparation and employers' expectations is well known by both the academic and business communities. This gap could be bridged by early detection of fundamental STEM (Science, Technology, Engineering, Mathematics) skills, even before students reach university. The present study adopts a weak signals approach to identifying and analyzing a basic set of engineering skills (ES) and science and technology skills (STS). The present study started from the awareness of changes in the field of engineering and examines the difference between what universities offer and current industry requirements, emphasizing the importance of actions taken by educational institutions for the development of specific skills. This paper is composed of an extensive literature review, which addresses the topic of weak signals and early warning systems. The paper also investigates to what extent early identification of key competences can be an accurate indication of future career directions in engineering. Moreover, within this present paper, we aim to pinpoint certain tools for detecting weak signals. This study highlights the importance of fully understanding engineering roles and the skills essential for getting a job in this field. It also discusses the purpose and relevance of early detection of weak signals as a proactive strategy to adapt the curriculum to current engineering requirements. By identifying and assessing STEM skills in a comprehensive setting, the results of this study contribute to the enrichment of the literature. In addition, by highlighting the importance of integrating innovative methods such as serious games into secondary education, methods and strategies for strengthening engineering skills among students are presented. The results obtained from this study are relevant for teachers in secondary education, but also for university education, for employers and for decision-makers in the field of education, offering models and methods through which students can be educated so that they are prepared for the constantly changing requirements in the engineering field.

Keywords: *Weak signals, early detection, science and technology skills (STS), engineering skills (ES), science-technology-engineering-mathematics (STEM) skills/competences.*

1. Introduction

Undoubtedly, both academic and business communities agree that there is a gap between ‘students’ career readiness and employers’ expectations. (Doherty-Restrepo et al., 2023). There also is an agreement that sooner the career skills are identified, the students can be better educated and prepared for their future career, and better for employers as well. The better-prepared and more knowledgeable students are, the more they will succeed in driving innovation and attracting intellectual and commercial investments. (Wendler et al., 2010) In many domains of performance, early identification of talented individuals is increasingly crucial. In sports, current talent identification schemes often rely on discrete and unidimensional measurements during uncertain periods of athletes' development (Čančar & Podmenik, 2012).

With globalization and rapid technological progress, there is a consensus among researchers and employers regarding the necessity for the 21st-century engineer to possess skills such as teamwork, communication, and management, which were not prioritized in the past. Consequently, many higher education institutions have started to make adjustments to their programs to prepare engineers with a comprehensive skill set. However, there exists a disparity between the offerings of universities for engineering students and the industry requirements. Therefore, it is imperative for universities to place special emphasis on developing the skills necessary for a career in engineering (Itani & Srour, 2015).

* *Corresponding author: alina.pirvu@lrfb.ro*

It is well-established that engineers occupy a diverse range of positions within the engineering field, and the importance of professional competencies can vary depending on this aspect. However, the majority of research related to professional competencies, employability, or career counseling does not take into account this diversity of professional roles (Craps et al., 2020).

There exists a disparity between the skills required in the industry and those developed within educational institutions, creating a misalignment between job requirements and educational preparation. It is crucial to comprehend that, in the career exploration stage, individuals begin to explore thoughts and behaviors that may guide them towards a future career choice. If students in this career exploration phase are provided with the opportunity to acquire career knowledge at the right time, they can prepare more effectively for the future (Keishing & Renukadevi, 2016).

Serious games have found applications in education, and their role in educational settings has been on the rise (Squire, 2003), encompassing various disciplines, such as programming (Toukiloglou and Xinogalos, 2023). The use of educational digital games in the instructional process has significantly increased over the past decades, particularly during the COVID-19 pandemic. However, little is known about how diverse student groups interpret and evaluate serious games concerning academic and professional success. A sequential exploratory mixed-methods study, based on responses from 201 students regarding the utility of an intuitive serious game for learning engineering mechanics in civil structural design, reveals that students had distinct expectations from serious games compared to entertainment games used outside the classrooms. Some students considered the opportunity to design their own structures and observe real-time failures as a valuable advantage in understanding how beam structures react to physical loading conditions. Despite this, only a few students believed that the serious game would be beneficial for exam preparation (14/26) or job interviews (19/26). Students favored engineering games that illustrated course content and mathematical calculations used in STEM disciplines more than those that did not include these elements (Cook-Chennault et al., 2022).

2. Literature survey

Recent incidents, such as the East Palestine, Ohio train derailment, underscore the importance of weak signals. It was later discovered that a wheel had overheated, leading to the derailment of a train carrying significant quantities of hazardous chemicals. A similar incident occurred in 2009 in Viareggio, Italy, where a train transporting liquefied petroleum gas (LPG) derailed due to a malfunction in a wagon axle. In 2013, in Quebec, Canada, a train's braking system failed, resulting in a derailment. Although the source of each derailment in these situations was different, there are certain similarities regarding cause and consequences. These derailments exhibited warning signals or weak signals, but they were not understood or heeded by those responsible. These signals are present in everyday life, but we, as humans, may not perceive their true significance. A weak signal may appear isolated, without a direct connection to other information, and it can be an unexpected alarm or a hint that may be overlooked as insignificant or even a minor observation made by an employee. Although such signals may seem inconsequential, they could indicate a gradual change approaching the point of causing a significant incident (Kerin, 2023).

Initially, the early warning system was primarily adopted by military and security systems to identify threats to national security. Presently, in addition to its use within these organizations, the concept of the early warning system has been successfully applied in the context of maintaining stability in the international security environment (UN, NATO, OSCE, etc.), environmental protection, predicting natural disasters, controlling epidemics, and, more recently, in project and business management. By employing both a focused early warning and opportunity identification system, as well as a more general scenario analysis, a visionary manager can formulate scenarios for various situations and develop strategies that enable prompt responses with optimal solutions. The potential benefits of an early warning system include the identification and learning from lessons, proactive identification of opportunities and threats, and laying the foundation for strategic business simulation (business wargaming) and scenario analysis (Popescu & Scarlat, 2015).

2.1. "Gap" identification

Despite the existence of literature on weak signals (Trish, 2023) and early warning (Davis et al., 2013), there are still not many well-defined and implemented tools, methods, or programs in schools worldwide that leverage these concepts to identify students inclined toward an engineering career and provide support for them. Within the existing literature addressing emerging weak signals in science and technology, as detailed by Yang et al. (2023), a discernible gap is evident concerning the thorough investigation of fundamental engineering skills (ES), science and technology skills (STS), and/or other indispensable STEM (Science, Technology, Engineering, and Mathematics) competences. This insufficiency specifically relates to the scrutiny of these skills and competences as potential indicators for early detection and subsequent analysis as weak signals prognosticating the trajectory of a student's forthcoming engineering career. The lack of emphasis on this critical facet prompts inquiries into the current comprehension and assessment of the foundational attributes crucial for success in the field of engineering, necessitating a more nuanced exploration of the factors contributing to the identification of prospective engineers within current student cohorts.

As a result, the authors aim to identify weak signals and early warnings to efficiently prepare students for a career in engineering from a young age. Thus, this paper seeks to pinpoint useful methods and tools for detecting weak signals and early warnings in the context of fostering effective career preparation for students in the field of engineering.

2.2. A basic set of engineering skills

Recent studies emphasize the need for a broader set of skills that engineers require than ever thought before. The term "Skills" is conventionally employed to denote the proficiency in task execution. Skills are occasionally interchangeably referred to as 'Competencies'. Within the engineering context, skills are typically dichotomized into two classifications: 'technical' or 'hard' skills and 'non-technical' or 'soft' skills. Both technical and non-technical skills constitute complementary proficiencies essential for engineers. Abdulwahed et al. (2013) provide a comprehensive list of skills that an engineer should possess: Communication Skills (CS), Teamwork Skills (TWS), Problem Solving Skills (PSS), Business & Management Skills (PMS), Ethics & Responsibility (E&R), Lifelong Learning (LLL), Creative Thinking (CrT), Leadership Skills (LsS), Practical Skills (PrS), Cultural & Social Awareness (CSA), System Design Skills (SDS), Analytical Thinking (AnT), Critical Thinking (ClT), Inter/Multi-Disciplinary Skills (I/M-DS), Innovation Skills (InS), Systems Thinking Approach (STA), Professionalism (PsS), Information and computing technology skills (ICTS), Entrepreneurship Skills (EpS), Foreign Language Skills (FLS), Technical Skills (TcS), Managing Change Skills (MCS), Decision Making Skills (DMS), Numeracy Skills (NmS).

The analysis revealed that the literature places the greatest emphasis on five skills for Engineering Graduates (ENGD): 1- Business and management, 2- Communication skills, 3- Teamwork skills, 4- Problem solving, and 5- Lifelong learning. In contrast, for Generic Graduates (GEND), the highlighted skills are: 1- Communication skills, 2- ICT skills, 3- Problem solving, 4- Teamwork skills, and 5- Business and management. A notable disparity in emphasis between ENGD and GEND is evident in 12 skills. The literature places a higher emphasis on ICT skills, numeracy skills, technical knowledge, language proficiency, and decision-making skills in the context of generic required skills compared to engineering-specific skills. The gap in skills like ICT, numeracy, or technical knowledge is straightforwardly understood as engineering training and education should encompass these areas.

Modernizing the engineering curriculum is crucial to support engineers with such a broad array of skills. This modernization could involve a shift from traditional teaching methods towards more constructivist learning approaches, such as technology-enabled learning. (Abdulwahed et al., 2013)

It is well-known that secondary school students are not sufficiently equipped with adequate mathematical and scientific skills, compared to certain countries, which consequently hinders colleges from increasing the supply of engineering graduates to meet industry demand. Furthermore, other countries, such as China, are intensifying their production of engineers, supporting the notion of a general need for more engineers, although this may not be entirely accurate. However, it remains unclear what skills engineers precisely need to be productive in the current economy. In 2009, a study was conducted based on findings derived from four investigations on changes in manufacturing engineering in the United States, Germany, and Japan, on the IT industry and skills requirements, on globally distributed engineering by U.S. and European multinationals, and on the education and workforce demand in science and engineering. Over 300 individuals from more than 100 company locations participated in the interviews. While many findings regarding skills and workforce development are specific to a particular engineering field, company, or country, there are also common and consistent findings across all companies, jobs, countries, and fields. Hence, a discrepancy between the skills possessed by current engineers and those sought by employers is noticeable. Constant reports of skill deficits were identified in interviews with engineers and managers from various companies. These deficits are often associated with communication skills and the ability to operate across various "borders" – be they organizational, technological, disciplinary, or of cultural and national nature. Notably, no manager indicated that recently hired engineers in the U.S. lacked the required technical skills, and none of the interviewed managers encountered difficulties in finding engineers with strong technical abilities.

Therefore, the presented research suggests that the essential modernization of engineering education to ensure technological competitiveness in the U.S. involves less deepening of specific technical skills and more the development of new boundary-spanning skills (Lynn & Salzman, 2010).

Regarding the utilization of serious games to develop fundamental engineering skills, they have been used for decades in engineering education, but still lack widespread adoption. Learning through gaming is often seen as not rigorous enough in higher education and vocational training, leading to its exclusion from academic curricula. As a result, students miss the chance for active knowledge acquisition in lessons and face barriers to effective engagement in serious games later on.

Despite the multitude of skills associated with the engineering profession, specialized literature lacks a clear definition of a basic set of skills; instead, there are only specific sets of competencies formulated based on certain criteria (Hauge et al., 2013).

3. Methodological approach

In the current available literature, there is no clear definition of methods through which the identification, analysis, or evaluation of weak signals or early warnings regarding engineering skills can be accomplished. Despite the apparent recognition of the benefits of using early warning systems, and the existence of programs that utilize early warnings to identify students facing difficulties in certain subjects (Rumack et al., 2017), there is no clear definition or classification of early warning systems specifically for identifying, analyzing, or evaluating engineering skills.

An example of such an early warning system aimed at improving students' academic performance is proposed by Allensworth (2013). It relies on three ways in which early warning indicators are useful for improving student performance: (i) focusing conversations and efforts on actionable issues; (ii) identifying students for intervention; (iii) using indicator models to strategically address low performance. In schools where this system was implemented, changes were observed in how teachers and school staff interacted with each other, with students, and with parents to improve students' academic outcomes. Additionally, three key data tools were developed within these schools. One tool was designed for prevention – identifying students who would need support from the beginning of high school. Another tool was designed for early intervention – identifying students as they showed signs of failure or withdrawal during the year. The third tool was designed for recovery – bringing students back on track after they had failed (Allensworth, 2013).

Thus, following an analogous approach presented above, early warning systems could be used for identifying students exhibiting weak signals in the field of engineering, and various tools could be designed to support and develop students to meet the future workforce demands.

4. Further steps

Since we haven't extensively presented specific methods or tools for identifying weak signals among students in this article, the next step in our research involves developing and refining tools for the early detection of weak signals in engineering skills. Additionally, considering the significance of a comprehensive approach, we aim to explore strategies for integrating early detection and warning systems into educational institutions and industries to align the curriculum and skill development with industry requirements. This entails not only identifying weak signals but also implementing effective warning mechanisms. Continuous research and ongoing evaluation in the field of early detection and warning systems for weak signals are crucial for adapting to emerging trends in the engineering profession.

5. Conclusions

Therefore, as society as a whole evolves rapidly, and the progress that technology makes is increasingly astonishing, it is extremely important for the education and preparation of young people to start at the earliest ages. For this education to be carried out in line with the skills that students already possess, teachers and other individuals involved in the education process must be able to identify, assess, and develop each student's abilities correctly and as much as possible. In order for this to be possible and for students to become competent employees, there is a need for schools to have effective methods and tools for identifying weak signals and early warning systems.

The literature review underscores the disparity between educational offerings and industry needs, emphasizing the necessity for universities to adjust programs to adequately equip engineers. Additionally, since jobs in the field of engineering are diverse, it is important for professional requirements in education to be integrated to align with labor market demands.

In conclusion, our study provides valuable insights for educators, employers, and decision-makers, laying the groundwork for effective educational strategies in engineering. Continuous exploration of weak signals and early warning systems remains crucial for adapting to the ever-changing demands of the engineering profession.

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