Computer-aided curriculum analysis and design: existing challenges and open research directions

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***Abstract*—This Research-to-Practice Full Paper investigates the emerging perspectives for the 21st engineering curriculum, and discusses the crucial role that digital technologies will have in facilitating the management, evaluation, and development of such a curriculum. First, a vision for future engineering curricula is distilled from modern curricular perspectives and trends of future engineering professions, where the integration of non-cognitive competences and the increased individualization of study paths are central. Core requirements for future curricula are outlined, which pose significant barriers to curricular changes. Then, the role of technology in mitigating these barriers is discussed, by outlining key aspects of a data-driven digital approach to the management of future curricula. To illustrate the proposed approach, the paper presents a case example of a digital tool that analyzes curriculum coherency at the content level. The paper concludes with a discussion of future research directions regarding the conceptualization and management of future engineering curricula through digital technologies.**

***Index Terms*—future curriculum, curriculum theory, curriculum management, digitization**

I. Introduction

The demand on competences in engineering is in constant change, and the demands for change seems to grow rather than diminish. To adjust engineering education to this rapid change, there is the need to adapt the evaluation of curricula, study plans and courses. The World Economic Forum (WEF) reports that 65% of schooling age students will end up working in job types that don't yet exist, and that most in-demand occupations did not exist 10 or even five years ago [1]. The new generation of citizens does not only require strong academic skills (in the sense of disciplinary knowledge), but also entrepreneurship, imagination, curiosity, empathy and resilience [2]. Indeed global industries are no longer just companies with physical products like cars and oil products: the digitization era and the explosion in computer-based products currently dominates the world scene. Therefore, today's (and future's) engineers are demanded to own both traditional engineering skills and competences firmly dependent on traditional disciplinary knowledge, and the seemingly endless set of skills and competences required by the new workflows induced by IT and communication media. Examples on the fast technological innovation are big data analytics, app- and web-enabled markets, internet of things, machine learning, cloud computing, digital trade, augmented and virtual reality, encryption and new materials.

As recognized by the Nordic council of ministries and other international bodies (e.g., NordForsk and OECD), specialized education and training is the key for the development of the competences of the future. As an example, educating engineers for the complexity of the future requires education towards: (i) a more holistic human engineer; (ii) promoting independence and consciousness about their own learning; (iii) increasing the curriculum flexibility by enabling students to co-construct the curriculum and learning [3]. In meeting these challenges, Higher Education Institutions (HEIs) should revise their current paradigms and practices on what and how to educate for the future in engineering, with a focus on the knowledge and competences that fit into new curriculum models that enable personalized study paths.

This manuscript focuses thus on how HEIs may update our workflows around the design and curation of engineering program's (EPs) curricula with the specific goal of adding more flexibility and capabilities in creating personalized study paths. In particular, this paper addresses the conceptualization and operationalization of future curricula, and identifies needs of future curricula that can only be effectively met through the integration of pedagogical theories, data-driven modeling and analysis, and digital technologies. More precisely, we consider how to do curriculum analysis and design by means of computer-aided tools, what are the existing challenges, and how we may resolve them.

We thus start with reviewing the relevant literature in Section II, to continue with our vision of future curricula and their design in Section III. We then describe how this vision induces the need for solving some technical issues, and how those may be addressed by means of opportune data driven

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IT-based artifacts and associated workflows in Section IV, plus present how part of these concepts have been applied in a real-life use case in Section V. We then continue with a discussion about the results in Section VI, and finish the manuscript by adding some concluding remarks and future research & development directions in Section VII.

II. Engineering trends versus the current status of higher education

We briefly review literature on the future of engineering, also known in the literature as *engineering 2030 trends*, and their implications for engineering education. More precisely, in this review we address the questioning of traditional paradigms and *praxis* in educational institutions, leading, for example, to the revision of existent qualification frameworks, the reformulation of learning outcomes, the re-design of curriculum and courses towards more student-centered learning and digitization, and the emergence of learning analytics to evaluate students and teachers behaviors in educational settings.

A. Future of engineering

The fast technological innovation and mass use of technologies is expected to touch every aspect of everyday life, disrupt jobs and allow creation of new business models [2], [4]–[6]. The disruption and transformation caused by this wave of technologies will significantly affect the skills required to perform in most of the jobs. Several work organizations refer to learning abilities such as self-directed and lifelong learning, proficiency in technology (namely design and programming), creativity, complex problem solving, systems thinking, adaptability and flexibility, sustainable mind-set, citizenship and responsibility, as the trending skills for 2030 [2], [7]. Undoubtedly, the qualification profile of employable engineers will not only include mastery of technical subjects, but also interdisciplinary knowledge, communication and collaboration and other non-cognitive skills. Note that the term *non-cognitive skill* is "used to contrast a variety of behaviors, personality characteristics, and attitudes with academic skills, aptitudes, and attainment". Additionally, they "*are considered to be distinct from the cognitive and academic skills usually measured by tests*" [8]. From a practice perspective, the need to integrate them in engineering curriculum leads to challenges on how to define, develop and assess them in the formal curriculum [8]. In this context, the need is for engineering educators and engineering education (EE) research communities to collaborate with external stakeholders to create subject-specific typologies (i.e., define skills that are specific of a given domain) and transversal typologies (i.e. that are general in engineering sciences).

B. The European Qualification Framework

The European Qualification Framework (EQF) aims to "*make qualifications more readable and understandable across different countries and systems*", and in this way support lifelong learning, work, and cross-border mobility of learners & workers. Considering the needs of the labor market, the EQF aims to bridge different European qualifications systems by enabling countries to develop their national qualification frameworks (NQF) while using a common overarching framework. The EQF is characterized by eight consecutive levels of increasing complexity and difficulty across three domains usable to define learning outcomes: knowledge, skills, and competences [11]–[14]. The EQF and the Bologna process enabled to create a learning outcome-based higher education across Europe based on three fundamental principles: international transparency, recognition, and mobility [11], [12]. The EQF provides also descriptors for the different levels, and contextual definitions of the domains that compose the learning outcomes [13]. However, a few inconsistencies can be found in the characterization and definition of learning outcomes domains in the last 10 years.

Furthermore, it is questionable if the European countries have updated their national qualification frameworks accordingly, and to which extent the local educational systems provide their teachers the support and resources needed to adjust their teaching practices to these changes.

C. Digitization and Learning Analytics

Digitization can play a dual role in supporting higher education institutions that educate for the future. The large number of platforms, digital tools, learning resources, and educational research reports led to a widespread perception that 'digitization of higher education' is a synonymous of 'modernization'. On the one hand, the widespread integration of virtual learning environment (VLEs), learning management systems (LMSs), and courseware management systems (CMSs) enable many teachers to create blended / hybrid / distance learning, flipped learning, plus asynchronous and synchronous activities [16], [17]. On the other hand, creating engaging and effective e-learning requires learning designs that redefine (see also [17]): teachers and students' roles; the planned learning experiences; the interaction spaces; and the learning workflows.

In summary, e-learning settings are self-directed, student-centered, flexible, and cooperative. A very important point is though that effective e-learning settings call for curriculum alignment in their design [17]. To the best of our knowledge, in the current typical practices teachers still lack guidance and support in designing learning experiences that are aligned with learning outcomes. Therefore, there is the need for digital tools and resources that specifically help the teachers in making informed decisions about how to design learning experiences.

This point is tightly connected to Learning analytics (LA) in the following sense: LA aims to evaluate students and teachers' behaviors in educational settings, and performs such a task by using statistical analysis techniques to mine large data sets generated by and about *students*. LA is renown for its potential to address institutional problems such as students' retention by using predictive modeling and developing intervention strategies (e.g., see [18]–[20]).

Seeing teaching as a design activity that is, as in [19], "potentially collaborative, iterative, and learner and learning-centred", LA has the potential to identify and collect evidence about where and when students do not grasp the intended material. In this sense, LA can inform teaching practice, and holds an indirect potential to be used by teachers to better organize their teaching and learning activities for an education of quality and to address the challenges of 2030.

At the same time, though, to the best of our knowledge the existing LA literature does not explicitly focus on aiding or assisting the organization of the teaching and learning activities. In a sense, the current 'learning analytics' tools are not directly exportable into opportune 'teaching analytics' tools that help boards, teachers and industries to collaborate to create more aligned and compelling HE programs to achieve the specific goal of adding more flexibility and allowing for personalized study paths.

In summary, digitization and LA create opportunities to develop new learning settings, tools and resources that can contribute to a more student-centered, flexible and personalized curriculum management which inform decision making using large set of data generated by and for the students and teachers. However, we perceive a lack of works that focus on helping HE teachers and boards to organize and coordinate the teaching activities on a program-wide horizon.

III. A Vision for Future Curricula

The literature review above summarized important challenges and trends that are likely to arise, or are already under way, in the future of EE. In this section, we investigate the connections between these trends and curricular perspectives and practices in HE. As a start, we here present a brief overview of recent curricular perspectives, followed by a summary of the recognized main difficulties in designing and implementing curricular changes. Based on these discussions, we then make a case for the need of a paradigm shift concerning the curriculum of engineering studies. To support our case, we distill a set of important requirements for future curricula in engineering education, based on the scenarios and trends described in Section II.

A. Current curriculum perspectives and practices

In the context of HE, the term *curriculum* has a broad set of definitions (see [22] for different perspectives). Within the scope of this paper, we focus mainly on the view of *curriculum as the set of activities and processes related to the structure, organization, and management of teaching and learning*. In other words, this paper lays within the field of design and management of curricula. Nonetheless, curriculum design and management is tightly related to the implementation and delivery of curricula, and the two perspectives must be harmonized and aligned with each other to facilitate high-quality education. Therefore, it comes without surprise that both aspects of curriculum are often intertwined in our discussions within this section. Having clarified our angle with respect to the term *curriculum*, we now turn to the different perspectives around this term, which are naturally and fundamentally related to different theories of knowledge and learning.

Different curricula conceptualizations within the context of curriculum co-creation between students and staff are discussed in [23]. A subset of them is reviewed below.

Conceptualization 1: The model of constructive alignment by Biggs [24], predominant in European HEIs, promotes a student-centered approach and argues the need to ensure coherency within three core dimensions of curriculum: intended learning outcomes, teaching and learning activities, and assessment. The constructive alignment model naturally accommodates an outcome-based learning that is typically the focus of qualification and accreditation frameworks. At the same time, it has been criticized for its focus on the product and subsequent neglect of the process of learning. Moreover, although Biggs' model promotes a student-centered approach, it does not accommodate the role of the student in the design of the curriculum, where the teacher is still at the center [23].

Conceptualization 2: Another perspective, based on [25], contains four different curricular understandings that interpret the curriculum as, respectively, (A) the structure and content of a unit, (B) the structure and content of a study program, (C) the students' experience of learning, and (D) a dynamic and interactive process of teaching and learning. Clearly, and as argued by [23], the perspectives A and B are more related to the product of learning (the learning outcomes), whereas C and D are aligned with the view of "learning as a process".

Conceptualization 3: The final perspective we mention is that of [26], which builds a model of curriculum based on the notions of *knowing*, *acting* and *being*. The first part, *knowing*, refers to the cognitive dimension of knowledge, thus being related to the views A and B in [25] and the ILOs of Biggs' model [24], respectively. The notion of *acting* refers to non-cognitive learning outcomes, related to ways of thinking and practicing (see [23]). Finally, the idea of *being* relates to the growth and development of the student as an individual, which resonates with holistic learning perspectives [29] and the recent work on the development of professional identify in HE studies [30].

Comparing the different conceptualizations above, one may observe a certain form of ordering and inclusion among them. More precisely, the constructive alignment model is surely applicable to the parts of [25] and [26] that address the aspects of knowledge, or "learning product". On the other hand, the perspectives C and D from [25] may be understood as parts of and mediums needed to reach the notions of *acting* and *being* in the framework proposed by [26].

Having these conceptualizations of curricula in mind, we move into the changes in curriculum and the requirements for the curricula of the 21st century.

B. Future Curricula: requirements towards a systemic change

Arguments and calls for revising the contemporary curricula paradigms are naturally reoccurring throughout the years. Already in 2000, [27] reflected on the recent changes in HE, and discussed new challenges that would soon need to be addressed. Interestingly, many of these issues are still up to date even after 20 years have passed, such as the tension between flexibility and quality assurance. More recently, [23], [26] have argued the need for more fluid curricula that focus on educational processes and the development of students, and that are negotiated and co-created between staff and students.

But if visions for future curricula are abundant, how can we proceed to change curriculum in engineering? Precisely this question is investigated by analyzing and discussing different strategies for curriculum change in [28]. Reflecting on the framework in [28], our manuscript may be seen as a promoter for a *systemic change* of curriculum, embedded within a strategy for *re-building* the curriculum. In particular, this section contributes to a vision of *how* the future curricula may be conceptualized, and of *what* are the key requirements needed to implement and facilitate such curricula, while facing the uncertainty and complexity of the engineering of the future.

The following summarizes some of the key requirement and features that future engineering curricula must possess, in order to prepare engineers for the complex future that awaits them as described in Section II. While discussing the core requirements of future curricula, we make references to the different curricula conceptualizations from Section III-A, as to distill a unified perspective of the curricula.

1) Balancing cognitive and non-cognitive learning outcomes: As summarized in Section II-A, in addition to the common *cognitive competences* related to the mastery of technical subjects, engineering jobs are increasingly demanding *non-cognitive competences* that relate to desired values, attitudes, and mind-sets [2]. Examples include perseverance, critical thinking, and sustainable mind-sets, among others. Additionally, there is also the need to educate students in the engineer ethos and *professional identity* [30], and to facilitate their own development as professionals.

On the one hand, cognitive competences are deeply integrated in engineering curricula and international qualification frameworks, that are often outcome-based. On the other hand, non-cognitive competences and professional identity are seldom formally considered in curricula, given their subjective and elusive definitions [10]. Furthermore, as formulated in [23] regarding the position of [26], "*current views of curriculum that focus on content and skills development are insufficient to meet the complex needs of the twenty-first century.*"

Future curricula must thus be able to balance and integrate these different aspects, both for planning and implementation.

2) Guaranteeing coherency and alignment with standards across learning contexts and practices: One of our standpoints is that a prerequisite to align with standards is that of being able to measure and evaluate the role of education. This need for measurement is to a large extent what promotes the outcome-based perspective of the EQF (see Section II-B), and hence the focus on the *learning product* of current curricula. However, we also recognize that there exists an increasing weight given by society to competences that are difficult to define and measure (i.e., non-cognitive competences and identity), and this indicates a need for change in both curriculum and in standardization and qualification frameworks.

Reflecting on the curricula conceptualizations summarized in Section III-A, a more holistic view as that of [26] may be a natural perspective to take in future curricula, as it integrates cognitive learning outcomes through *knowing*, non-cognitive competences through *acting*, and identity development through *being*. Additionally, the alignment perspective of Biggs [24] is certainly crucial to keep in regards to *knowing*, and to extend towards *acting* and *being*.

The latter two curricular dimensions, *acting* and *being*, take the perspective of "learning as a process", and thus value more the process of learning through teaching and learning activities than assessing the actual outcome. Therefore, as an extension of Biggs' model to these curricular dimensions, we envision an alignment model more focused on the intended development of the student and the dynamic co-designed teaching and learning process, rather than on the assessment of the outcomes. This view is further supported by the understandings of curriculum C and D outlined by [25], that focus on the experiences of the students and the teaching and learning processes, as well as by [26], where the authors state that "*curricula in higher education in the twenty-rst century can be understood as intended educational processes*".

3) Promoting active participation and co-construction of curricula between students and other stakeholders: The need for a student-centered approach to teaching and learning is not recent, and it is by now well-accepted within HE. The notion of co-construction of curriculum,however, has been more recently advocated as a necessary feature of future curricula and is subject to intensive research recently [23], [31]. The active participation and involvement of students in the design and implementation of the curriculum is indeed considered crucial to promote the acquisition and development of the non-cognitive competences referred in Section II-A, such as responsibility, self-directness, and lifelong learning.

Moreover, bringing in the students as participants in the co-creation of curriculum empowers them in deciding and designing their own education and development. Aside from the potential pedagogical gain of curriculum co-creation, it also results in a more fluid and dynamic curriculum as called for by [26], which possesses increased adaptability that can timely act on the emergence of new technologies and challenges.

4) Facilitating the emergence of individualized study paths: As the curriculum departs from a product- or outcome-centered perspective to acquire a more balanced view that includes dimensions such as *acting* and *being*, the focus of teaching and learning activities naturally shifts more towards the development of the student as a person and a professional. A question immediately arises, then: does one curriculum, even if co-created with the students, address the specific educational and developmental needs of all individual students? We believe that the answer is most likely no, and that in turn there exists the following implication: being able to shift towards the inclusion of the *acting* and *being* dimensions necessarily requires to be capable of adapting, at least to some extent, the curriculum to the context of each individual student.

Note that, on the one hand, the capability of adjusting a given set of teaching and learning activities to individual students is already under development through the field of LA. On the other hand, as argued in Section II-C, the adaptations are performed for individual subject modules and restricted to outcome-focused subjects focused on the *knowing* dimension.

As opposed to the perspective taken by LA, we argue for the need of *individualized study paths*, by which we mean the possibility of: *a)* negotiating curricula at an individual level, *b)* adapting educational processes to the needs of each student, and *c)* designing the progression of modules individually.

Summarizing, the emergence of individualized study paths can, in a sense, be seen as an extreme case of co-creation of curricula where individual students negotiate their own educational processes and trajectories based on their needs and goals. We expect this capability, in a future where most engineering jobs will demand unique sets of competences and skills that are not fully captured in the existing EP, to be essential to empower students to construct themselves into the professionals they desire to be. Furthermore, individualized study paths are crucial for enabling lifelong learning and re-skilling and up-skilling to be seamlessly incorporated in the context of EE, where professionals can devise their own study path with their own personal development as a starting point.

5) Ensuring transparency and interpretability to all stakeholders: The previous requirements of future curricula investigated above, addressed the need to promote the co-creation of curriculum among students and staff. However, as stated in [23], "*students may not understand what the curriculum is (or the particular version of curriculum envisaged by the teacher)*", which endangers the efforts for co-creating the curriculum. Hence, another prerequisite for curriculum co-creation is the formulation of intended learning outcomes in an intelligible way, transparent to all stakeholders.

Guaranteeing intelligibility and transparency, though, is not an easy task: future curricula need to balance cognitive and non-cognitive learning outcomes. Given that non-cognitive learning outcomes are more suitably treated through a focus on educational processes, rather than as a learning product, the educational processes themselves also need to be transparent and clear in regards to their aims and context.

Transparency and interpretability of the intended outcomes and educational processes is therefore essential in future curricula. In addition to the aforementioned aspects, a closer engagements of other stakeholders such as employers and society will also benefit from interpretable curricula. Moreover, in the pursuit of transparency and interpretability, the EE community may also discover ways to incorporate the dimensions of *acting* and *being* and their process-focus in the qualification and accreditation frameworks.

6) Enabling in-time evaluation and adaptation of curricula: The fast pace at which future engineering trends are evolving requires the associated curricula to adapt at an equally fast pace. New disruptive technologies may appear, which in turn need new study programs or directions within. Alas, skills and competences demanded by industry and society may change fast as well. The capability of co-creation of curricula by students, teachers and society shall then be complemented by a capability of dynamically coping with the changes.

These needs would then push towards strategies for dynamic co-creation of fluid and individualized curricula which may substantially depart from the originally planned ones as a student transverses her/his study path [23]. On the other hand, engineering curricula must be approved by accreditation agencies and qualification frameworks (e.g., the EQF), which requires the compliance with formal learning outcomes.

To solve this clash there is thus a need for strategies and tools that enable the timely evaluation of both the formal and the executed curricula, as well as solutions that assist the in-time development and co-creation of the curricula so that they comply with the accreditation requirements.

C. Barriers and Challenges: the Role of Technology

Any systemic change faces numerous barriers and challenges, and curricular changes are no different. This section concludes with a brief reflection of which main barriers and challenges prevent the realization of the previously outlined future curricula, and with a possible way forward.

As outlined in [27], numerous challenges prevent increasing the flexibility of the curriculum: the need to fulfill the requirements of qualification and accreditation frameworks; the desire to have a sense of progression in the study program, with prerequisite courses for more advanced subject studies; the desire of management to secure funding related to teaching, and therefore the incentive of limiting the students' choice and study flexibility; the expansion of EP and the increasing number of students, study programs, and courses.

Additionally, there are barriers arising in curricular changes in general, as investigated in [32]: the inherent complexity to context, development, implementation, and evaluation of curriculum; lack of incentives, knowledge and expertise; and lack of time and resources.

There are surely many other relevant barriers that are not mentioned here, and we make no claim to have an exhaustive overview of the challenges ahead of a systemic curricular change. Nonetheless, to the best of our experience, the barriers highlighted here are ubiquitous across HEIs. Our viewpoint is that it is currently crucial to address them; and, as explained in more detail in the next section, we argue that digitization of curriculum management and development, supported through a data-driven approach, is a meaningful way forward.

IV. A DATA-DRIVEN DIGITAL APPROACH TO THE MANAGEMENT OF FUTURE CURRICULA

Summarizing Section III, the goal is to develop methodologies for managing curricula that ensure being able to perform several actions, e.g., balance cognitive and non-cognitive learning outcomes, and all the other paragraphs' titles.

Our experience suggests that any EP-oriented program design and curation tool (and the associated workflows) that meets the requirements above will necessarily be based on *digital computing technologies* and will be *data-driven* (i.e., using all the quantitative and qualitative data that is available in different formats as in the examples below). More precisely, and keeping the same structure as in Section III:

• *Balancing cognitive and non-cognitive learning outcomes:* Stakeholders need help in interpreting the curriculum in various different formats, and getting a deep awareness of how the learning outcomes balance. We foresee digital approaches that label learning outcomes in terms of the format in [25] (so to visualize the relations of the learning outcomes with the structure and content of the various subjects, with the structure and content of the program of study, with the students' experience of learning, and with the teaching and learning activities), and in terms of the format in [26] (so to interpret the outcomes as promoting knowing, acting, being, and their combinations). In other words, we foresee a digital tool that shows the stakeholders how the outcomes are connected, similar to the case shown in Section V.

• *Guaranteeing coherency and alignment with standards across learning contexts and practices:* The overarching need is for tools assessing the planned teaching and learning activities (and potentially the related actual outcomes). More precisely, in addition to LA, we envision the need for *teaching analytics* tools that start from quantitative indications on the planned activities & practices (and potentially students' performance), together with information on the contexts, and transcend this information into an assessment of alignment with opportunely coded standards.

• *Promoting active participation and co-construction of curricula between students and other stakeholders:* As for the overarching accessibility by everybody, we envision digital tools that democratize the process, in the sense of easing the processes of collecting and synthesizing opinions about the structure and contents of the curricula. Importantly, the digital tools should *empower*. Our current intuition is that this would be best promoted through pushing openness also in the workflows surrounding the tools, i.e., by make public and available to critics / suggestions / modifications also the strategies about collecting, storing and synthesizing the opinions from the stakeholders.

• *Facilitate the emergence of individualized study paths:* The need is to enable students to indicate their learning career goals, and stakeholders from the working life sector to express opinions / suggestions on the program contents. We note that the tools shall also enable creating custom plans for each individual student on *how and how fast to traverse the syllabus* given her/his current status and history, the planned lecture plans, the student's goals, and potentially the indications from the stakeholders from the working life about which skills and competences may be appreciated when the student seeks a job. We thus stress the need for platforms that can collect a variegated set of information.

• *Ensure transparency and interpretability to all stakeholders:* As for the transparency part, there is again the need for openness in both accessing the platform, the data, and the workflows surrounding these components. As for the interpretability, there is the need for an attention to the graphical user interfaces, and to how the reports are compiled. Moreover, there is the need of clear explanatory additional material that can guide persons that are not used to be exposed to pedagogy-related ideas in interpreting the various concepts involved in the usage of the platform.

• *Enable in-time evaluation and adaptation of curricula:* as for this, there is again the need for *teaching and learning analytics* algorithms that can use quantitative indications on the planned activities & practices and information about both students' performance and societal trends to detect curricular inefficiencies (e.g., the need for including / excluding / changing the emphasis on certain types of skills, as time passes). What we advocate for is, in other words, tools for a computer-assisted approach to the evaluation and adaptation of curricula.

This requirement shall include the capability of doing continuous progress reporting, where both teachers and students can create at any time anonymized and statistical reports of how individual or groups of students are performing, in comparison to the nominal expectation of progress.

Finally, we envision also the capability of predicting how future teaching and learning activities may help diminishing the discrepancies "actual vs expected status", so to enable implementing predictive intervention approaches in the on-the-fly adaptations mentioned above.

V. A CASE EXAMPLE: GRAPH-BASED CURRICULUM ANALYSIS

As argued in the previous sections, digital technologies are essential to manage and operationalize future curricula in HEIs. In fact, the benefits to digital technologies has long since been recognized in the literature, and there exist multiple reports of approaches to map and visualize curricula through digital tools.

For instance, [33] discusses an approach on quantitative analysis of curriculum structure where four distinct graphs create individual study plans for students within a study program. Another paper [34] connects learning goals, topics and courses within a program, labeled as nodes, with prerequisite dependencies modeled as edges. The relation between courses and topics are then represented as edges. In [35], the authors analyze connections between courses and their coherence within a University program to understand what role courses have and can differ in a curriculum. Further, [36] suggests graph-oriented approaches on where to focus the assessments, corrective actions and data collection within the curriculum.

The above-mentioned approaches are restricted to a macro-perspective that solely gives a program-wide view of how courses interface each other. Albeit useful, such a perspective does not accommodate several important aspects discussed in Section III, such as: *1) Balancing cognitive and non-cognitive learning outcomes*, where teaching and learning activities play a crucial role; *3) Promoting active participation and co-construction of curricula*, which requires a student-centered perspective within each course; and *6) Enabling in-time evaluation and adaptation of curricula*, which needs to occur also at the course-level.

Moreover, the focus of curriculum mapping and visualization techniques is to describe the current situation. In contrast, in Section IV we have argued that future curricula require data-driven tools that facilitate in-time adaptation of curricula, and provide detailed student- and course-centered information to different stakeholders. Thus, there is a need for a different, more holistic approach to the digitization of curriculum development and management.

As one step towards the goal of reaching the vision proposed in Section III, we summarize our past activities about enabling alignment and coherence between courses based on data driven approaches, whose results may also be used to create personalized study plans. More specifically, we refer to the digital tool "COnCUR, see [37], developed to collect, merge and visualize information about individual courses and how they connect within a program. The tools contains detailed information about each course, and can thus facilitate curriculum adaptation at various levels. In particular, for each course the tool enables inserting the following information:

- teaching period, i.e., start date and duration of the course;
- required prerequisites for the course, as list of knowledge components (KC) (see explanation below) together with their taxonomy level for a chosen, suitable taxonomy, such as Blooms revised taxonomy [38], SOLO taxonomy [39] or Feisel-Schmitz technical taxonomy [40];
- intended learning goals and their taxonomy levels;
- interconnections within and between courses, i.e., which prerequisites are specifically required for each of the developed earning goals; and
- the Teaching and Learning Activities (TLAs) associated to the course and how they connect to individual KCs.

In this tool, each KC describes an acquirable and testable unit of cognitive knowledge, which may be facts, concepts, procedures, etc., such as "understanding evolution", or "design a beam" [41]. Note that summarizing a course by its planned KCs implies taking a constructivist interpretation of knowledge, and focusing thus on cognitive outcomes. In our experience, this perspective is rather convenient for teachers in STEM disciplines, where KCs are easily identifiable, often corresponding to which cognitive knowledge can be tested.

Importantly, COnCUR enables collecting the information for each course in a decentralized, asynchronous manner, plus it simplifies the work that the teachers need to do in case there is the need to update a course (in terms of its contents, structures or difficulties). Additionally, COnCUR enables listing which prerequisite cognitive knowledge students should know from their secondary education, and which intended learning outcomes students should have reached at the end of the various courses / program.

COnCUR then analyses all the information above by combining the data collected for the individual courses. Most importantly, taking into account the temporal order and required and taught KCs of each course, as well as the program's prerequisites and learning goals, COnCUR detects temporal and structural inconsistencies and redundancies (i.e., overlaps between courses). Logical inconsistencies on the structure of the program may indeed arise in case:

- a KC is required for a certain course but only taught in a later course or not at all in the program;
- a KC is required at a certain taxonomy level for a course, but the actual connections to the developed KCs within the course require a different taxonomy level;
- a KC is required with a certain taxonomy level for a certain course but only taught at a lower level at a previous course; or
- a KC X is required to learn Y, while Y is required for learning X.

Redundancies, in turn, may arise in case:

- a KC is taught in several courses at the same level;
- a KC is taught in a course without being needed for learning another KC within the same course, in a following course, or as program learning goal; or
- a KC is listed as a prerequisite for a certain course, but not used within the course.

All the inconsistencies and redundancies above are typically undesirable, as they reveal mismatches between courses or expectations of teachers. Sometimes, these mismatches are a result of poor communication between teachers. Some other times they arise due to small, gradual changes over time, often also related to teachers' replacement or course development. Such inconsistencies understandably might lead to frustration among students and teachers and hence may also hinder learning. Redundancies might in some cases be desired as teachers might want to repeat important KCs or refresh students' memory in case the requisites have been taught in a course much before. However, a high amount of redundancies might also hint on inefficiencies in the program, which might not only waste valuable time but also lead to bored students.

COnCUR illustrates and visualizes the program, its contents, the connections between them, and possible inconsistencies using two distinct visualizations: *a)* displays of the courses as nodes in their temporal order and edges of different width connecting the courses according to the quantity of connecting KCs, and *b)* displays of the KCs listed in all courses as a network where KCs taught earlier in the program are placed more towards the left and KCs developed later in the program tend to be displayed more towards the right. These two possibilities enable the inspection of how courses and KCs interconnect, and how taught contents flow in time and in taxonomy level complexity through opportune color shifts. Inconsistencies are also shown by highlighting the corresponding interconnections in the graph.

It is however important to stress that COnCUR cannot solve the structural problems within a program, but only detect, analyze and visualize them. Based on this, teachers and program coordinators then need to discuss the problems and find solutions by appropriate adaptations of the program structure or the courses. COnCUR might in fact also be used to inspect the effects of planned or desired changes within a program or a course, in the sense that by adjusting the course as planned in the future, for instance as a result of course development or in response to students' feedback, teachers and program boards may understand how the program structure would change and how potential mismatches may arise, disappear or change as an effect.

An important *caveat* is that COnCUR might find inconsistencies due to differences in understanding and interpretation of taxonomies and the corresponding taxonomy levels between teachers. This may be thought as a "false alarm"; however if this eventuality triggers a discussion of the case, it may then help teachers to better align themselves.

Finally, we note that while COnCUR was originally designed and conceptualized as a tool to enable better alignment within a program, it may as well be used to create individualized study plans: indeed students may enter their current knowledge status in terms of reached KCs as "prerequisites" and select which courses they aim to take in the future. In this way COnCUR allows to understand whether the proposed study plan needs adjustments in case the prerequisites are not met, the courses are not aligned well, the temporal order should be changed, or the courses are in fact not instrumental to reach the desired overall learning goals.

VI. A BRIEF DISCUSSION ON FUTURE DIRECTIONS

The transformation of the job market is evident and the associated rate of transformation is increasing rather that diminishing. Despite this calls for re-design of curriculum and consider more interdisciplinary knowledge and student-centered learning activities and environments, digitization in teaching and learning is only in its initial phase. As claimed above, non-cognitive skills and competencies need to be integrated in the curriculum, and the workflow surrounding this integration must be easily implementable and adaptable.

Moreover, importantly: what are the skills and competences to be included? What typologies are for the future engineer of 2030? Discussing and answering these questions efficiently needs yet an other methodology, and our experience suggests that there is the need for iterative communications between the agents outside the academia, the industry and the society, the decision makers, plus boards and teachers in EE. Tools for aiding these discussions must also be easy to use and adapt.

Finally, to provide for effective e-learning, the curriculum needs to be constantly aligned with new ways of teaching and learning that are currently unforeseen. What methods are there to facilitate the evaluation and development of the curriculum for tomorrows engineers? There is a need for digital tools and resources to deliver statistical data, both quantitative and qualitative, on the learning activities and outcome of the curriculum and consequences of changes. We are convinced that COnCUR is one step in the right direction, and that upcoming field tests on complete programs during 2020 will result in a IT artifact that gives valuable and necessary data, not just on the content, but also on coherence and progression. Important not to forget, such information provides the freshmen students with a clearer overview of the content and how choices of different courses and study directions effect their final knowledge profile, which increases motivation and inspiration to co-create teaching and learning activities over a wider span than of today, and definitely steps towards more student-centered learning.

VII. CONCLUSIONS

In this paper, we discussed the crucial role that digital technologies can have in facilitating the management, evaluation, and development of future curriculum in engineering education. We started by looking into the future of engineering and what are the demands to educate qualified and employable engineers for the future. Industry 4.0 and sustainable development goals (SDGs) are two examples of engineering trends 2030, where mass use of ICT and other emergent technologies not only shape the future of engineering profession but also contribute to sustainable solutions. For certain, other trends will emerge in the future. In 2005, the National Academy of Engineering [42] questioned how can engineering education and educators be proactive instead of reactive towards emergent trends and challenges? The reactive nature of engineering education is due to the gaps between the fast and continuous emergence of technological trends, their professional and social impacts, and the slow pace of educational systems in changing, adapting and responding to societal and professional demands imposed by such trends.

Given these discussions, we argue that the 21st century engineering education must become more flexible, integrate non-cognitive competences through a larger focus on learning processes rather than products, and should empower students to co-create their own individual study paths. Nonetheless, the future engineering education needs also to comply with the European Qualification Framework and accreditation agencies.

To tackle the barriers to curricular changes, it is crucial that HEIs take the opportunities that digitization and learning analytics provide to redesign engineering education for the future. It is unquestionable that digitization plays a central role in 'day-to-day life' of higher education institutions, namely research, teaching and administration activities, by providing support, enable trans-national and continental collaborations and partnerships, access and dissemination of knowledge, etc. The most recent example is the outbreak of COVID-19 pandemic, where teachers and students saw their learning spaces, and teaching and learning activities, abruptly move to virtual and online platforms.

We thus strongly advocate for a data-driven digital approach to manage future curriculum: as shown in our case-example in Section V, it is possible to find concrete approaches using digitization as the main vehicle to transform engineering education and curriculum for the future and to take a more proactive role in addressing its trends. Finally, the development of digital tools should go beyond online collaboration platforms, learning management systems, or learning analytics engines to predict and model students' progression. Digitization shall indeed be used to support also teachers, managers, quality assurance personnel, and the industrial world to co-construct, manage and develop the curriculum.

References

[1] World Economic Forum, "The Future of Jobs: Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution." 2016

[2] OECD, "OECD Skills Outlook 2017: Skills and global value chains." 2017.

[3] Crawley, E. F., Hosoi, A., Long, G. L., Kassis, T., Dickson, W., & Mitra, A. Babi. "Moving Forward with the New Engineering Education Transformation (NEET) program at MIT-Building Community, Developing Projects, and Connecting with Industry." 2019 ASEE Annual Conference & Exposition.

[4] L. Sander, "In the workplace of the future, these are the skills employers want," Conversat. + World Econ. Forum, pp. 225251, 2017.

[5] A. T. Leopold, V. S. Ratcheva, and S. Zahidi, The Future of Jobs Report 2018 Insight Report Centre for the New Economy and Society. 2018.

[6] T. Wrahatnolo and Munoto, 21st centuries skill implication on educational system, in IOP Conference Series: Materials Science and Engineering, 2018, vol. 296, no. 1.

[7] K. Schwab, The Future of Jobs Report, vol. 5, no. January. 2018.

[8] L. Gutman and I. Schoon, The impact of non-cognitive skills on outcomes for young people. A literature review., London, 2013.

[9] K. Zhou. Non-cognitive skills: definitions, measurement and malleability, UNESCO - UNESDOC Digital Library. Available at: https://unesdoc.unesco.org/ark:/48223/pf0000245576 (Accessed: 9 April 2020). 2016

[10] A. Guerra and B. Nrgaard, Sustainable Industry 4.0. SEFI: European Association for Engineering Education, pp. 501510, 16-Sep-2019.

[11] European Centre for the Development of Vocational Training - CEDEFOP, European qualifications framework (EQF), European qualifications framework (EQF) Project info, 2020. [Online]. Available: https://www.cedefop.europa.eu/en/events-and-projects/projects/european-qualifications-framework-eqf. [Accessed: 09-Apr-2020].

[12] Bologna Working Group, Framework for Qualifications of the European Higher Education Area, Copenhagen, 2015.

[13] European Commission, The European Qualifications Framework: supporting learning, work and cross-border mobility 10 th Anniversary Social Europe, Luxembourg, Feb. 2018.

[14] European Commission, Descriptors defining levels in the European Qualifications Framework (EQF) — Learning Opportunities and Qualifications in Europe, Descriptors defining levels in European Qualification Frameworks (EQF), 2020. [Online]. Available: https://ec.europa.eu/ploteus/content/descriptors-page. [Accessed: 09-Apr-2020].

[15] European Commission, The European Qualifications Framework for Lifelong Learning (EQF), Off. Off. Publ. Eur. , pp. 14, 2008.

[16] H. Hutchins, Instructional immediacy and the seven principles: Strategies for facilitating online courses, Online J. Distance Learn., vol. VI, no. III, 2003.

[17] R. Oliver, B. Harper, S. Wills, S. Agostinho, and J. Hedberg, Describing ICT-based learning designs that promote quality learning outcomes, in Rethinking Pedagogy for a Digital Age: Designing and Delivering E-Learning, H. Beetham and R. Sharpe, Eds. 2007, pp. 6480.

[18] S. Hartman-Caverly, Human nature is not a machine: On liberty, attention engineering, and learning analytics, Libr. Trends, vol. 68, no. 1, pp. 2453, Jun. 2019.

[19] S. S. J. Alhadad, K. Thompson, S. Knight, M. Lewis, and J. M. Lodge, Analytics-Enabled teaching as design: Reconceptualisation and call for research, in ACM International Conference Proceeding Series, 2018, pp. 427435.

[20] A. Pea-Ayala, Learning Analytics: Fundaments, Applications, and Trends. A View of the Current State of the Art to Enhance e-Learning, vol. 94. Springer, 2017.

[21] R. Ferguson et al., Research Evidence on the Use of Learning Analytics - Implications for Education Policy, 2016.

[22] W. E. Toombs and W. G. Tierne, "Curriculum Definitions and Reference Points", in Journal of Curriculum and Supervision, vol. 8, no.3, pp. 175-195, 1993.

[23] C. Bovill and C. Woolmer, "How conceptualisations of curriculum in higher education influence student-staff co-creation in and of the curriculum", in Higher Education, vol. 78, pp. 407422, 2019.

[24] J. Biggs, "Enhancing teaching through constructive alignment", in Higher Education, vol.32, no. 3, pp. 347364, 1996.

[25] S. Fraser and A. Bosanquet, "The curriculum? Thats just a unit outline, isnt it?", in Studies in Higher Education, vol. 31, no. 3, pp. 269284, 2006.

[26] R. Barnett and K. Coate, "Engaging the curriculum in higher education". Maidenhead: Open University Press, 2005.

[27] D. Bridges, "Back to the Future: The higher education curriculum in the 21st century", in Cambridge Journal of Education, vol. 30, no. 1, pp. 37-55, 2000.

[28] A. Kolmos, R.G. Hadgraft and J.E. Holgaard, "Response strategies for curriculum change in engineering", in Int J Technol Des Educ, vol. 26, pp. 391411, 2016.

[29] B. Yang, "Toward a holistic theory of knowledge and adult learning", in Human Resource Dev. Review, vol. 2, no. 2, pp. 106–129, 2003.

[30] F. Trede , R. Macklin and D. Bridges, "Professional identity development: a review of the higher education literature", in Studies in Higher Education, vol. 37, no. 3, pp. 365-384, 2012.

[31] L. Ollis and K. Gravett, "The Emerging Landscape of StudentStaff Partnerships in Higher Education". In: K. Gravett, N. Yakovchuk, I. Kinchin (eds), Enhancing Student-Centred Teaching in Higher Education. Palgrave Macmillan, Cham, 2020.

[32] H. Hubball and M.L. Pearson, "Grappling with the complexity of undergraduate degree program reform: Critical barriers and emergent strategies", in Transformative Dialogues: Teaching and Learning Journal, vol. 3, no. 3, pp. 1-17, 2010.

[33] Rollande, R., "Research and Implementation of Personalized Study Planning as a Component of Pedagogical Module" (Doctoral dissertation, Doctoral Thesis. Riga: RTU), 2015

[34] Pavlich-Mariscal, J. A., Curiel, M., & Chavarro, G., "CDIO Curriculum Design for Computing: A Graph-based Approach." In Proceedings of the 15th International CDIO Conference, Aarhus, Denmark. 2019.

[35] Aldrich, P. R., "The curriculum prerequisite network: a tool for visualizing and analyzing academic curricula." arXiv preprint arXiv:1408.5340. 2014

[36] Lightfoot, J. M., "A graph-theoretic approach to improved curriculum structure and assessment placement." Communications of the IIMA, 10(2), 5. 2010

[37] Wengle, E, Knorn, S. & Varagnolo, D. "COnCUR - COherence in CURricula: A tool to assess, analyze and visualize coherence in higher education curricula." In Proceedings of the IFAC World Congress, Berlin, Germany. 2020.

[38] Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J., & Wittrock, M. C., "A taxonomy for learning, teaching, and assessing: A revision of Blooms taxonomy of educational objectives", abridged edition. White Plains, NY: Longman, 2001.

[39] Brabrand, C., & Dahl, B., "Using the SOLO taxonomy to analyze competence progression of university science curricula" Higher Education, 58(4), 531-549, 2009.

[40] Feisel, L. D. "Teaching students to continue their education", Proceedings of the Frontiers in Education Conference (pp. 12-15), 1986.

[41] Koedinger, K. R., Corbett, A. T., & Perfetti, C., "The knowledge-learning-instruction framework: Bridging the science-practice chasm to enhance robust student learning". Cognitive science, 36(5), 2012.

[42] National Academy of Engineering, Educating the Engineer of 2020: Adapting Engineering Education to the New Century. Washington, D.C.: National Academies Press, 2005