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COMPETENCY CENTERED CURRICULA MAPPING SUPPORT: THE FORESTED VISUALIZATION TOOL

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ABSTRACT

Curriculum Design in competency-based education often lacks means to capture relationships between competencies and courses intended to develop them. In this paper, we present ForestED an interactive visualization tool which addresses this issue. Applied to curricula, ForestED displays visualizations of the curricula that render explicit the links between competencies and courses. While the visualization reflects the static curriculum definition, it also allows inference of competency development over time through the course timeline.

KEYWORDS

Curriculum Visualization, Competency-Based Curricula

1. THE WHY AND HOW OF CURRICULUM VISUALIZATION

Curriculum design approaches vary considerably. The most common is the *course-centered curriculum* which focuses on individual courses and their content. Other approaches include to name but a few the *competency-based curriculum* (focusing on the development of specific competencies or learning outcomes - LOs), *program-based curriculum* (ensures coherence and alignment between courses, LOs and assessments), *learner-centered curriculum* (focuses on student needs, interests and learning styles). Regardless of the approach used in their design, curricula are carefully crafted complex systems (Aldrich, 2015), designed by highly qualified groups of experts in particular fields. A curriculum definition most often takes the form of a detailed document presenting the constituent elements and the interplay between them. As with any complex system represented textually, understanding the curriculum is challenging, even for those involved in its design. Visual representations of complex systems aid understanding by engaging the visual cortex in addition to the prefrontal cortex.

Learning Analytics is defined as the measurement, collection, analysis, and reporting of data about learners and their contexts, with the goal of understanding and optimizing learning and the environments in which it occurs (Siemens, 2013). One of the most common applications in learning analytics is the design of student dashboards entailing visualizations created using instructional data. These dashboards are intended to assist learners and enhance the learning experience (Susnjak et *al.*, 2022). The study of curricula with the aim of improving their quality, coherence, and design is the focus of the academic field of Curriculum Analytics (Barthakur et *al.*, 2024). We are interested in a particular part of this academic field - Curricula Visualization. More precisely, we investigate how visualization favors new insights on competency-based curriculum.

Before going deeper into curricula visualization, we acknowledge that there is a variety of approaches, or levels of detail when defining competencies-based curricula. We illustrate this in Figure 1 by showing steps or stages between a classic knowledge-based curriculum design (stage 1) to a competency-based curriculum one (stage 4).

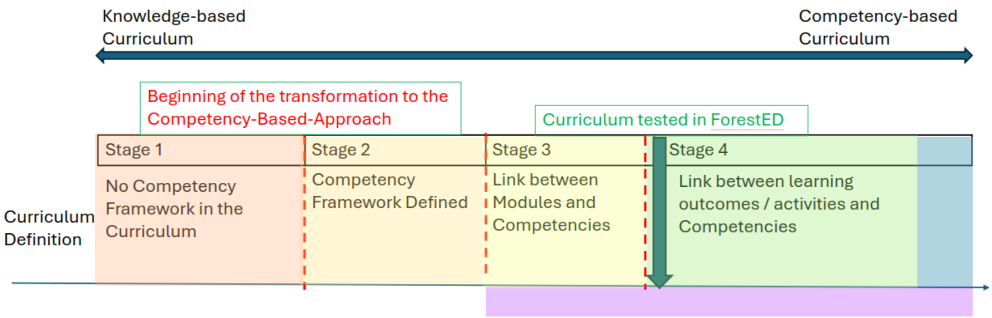

Figure 1. Stages in the curricula design transformation from a Knowledge-based Curriculum to a Competency-based Curriculum

The development is structured into four stage: no competency framework at all which corresponds either to the very beginning or the absence of a transformation. Stage two occurs when a competency framework has been defined, presenting the intended competency to be developed by the students. At stage 3 an explicit link is made between the content proposed (modules) and competencies. At the last stage, the link is refined at the level of learning outcomes and activities – each one being related to specific sub-competencies. The progression illustrates the transition between a knowledge-based curriculum towards a competency-based curriculum. The visualization approach we propose targets stage 4 curriculum designs.

While in some cases curricula definitions include graphic representations, comprehensive curriculum visualizations remain relatively rare. The purpose of curriculum visualization is to enhance the understanding of educational offerings. Depending on the curriculum design approach, visualizations may focus on different aspects. For content-based curricula, visual representations often highlight relationships between curricular elements. One common approach involves using heat maps (Joyner, 2016; Plaza et *al.*, 2007; Siirtola et *al.*, 2013; Vuong et *al.*, 2011) which visually represent correlation matrices. In these matrices, both the rows and columns correspond to courses, and the cell at position *(i, j)* indicates the existence or the degree of a relationship between *course i* and *course j*.

The relationship can take various forms, most often the one pre-requisites between modules. In some cases, prerequisites are not defined between modules but rather among LO (Auvinen, 2011; Auvinen et *al.,* 2014). The relationship values may be binary (*i.e.*, in the set *{0,1}*), as is common in prerequisite structures, where a value of *1* indicates that *course i* is a prerequisite for *course j*. Alternatively, the values can range continuously between *0* and *1* to represent degrees of similarity, calculated using various methods—such as the proportion of shared topics between courses (Siirtola *et al.,* 2013).

The same information presented in correlation matrices is sometimes visualized as a graph, where nodes represent courses and edges (or arcs) indicate the identified relationships between them (Akbaş *et al*., 2015; Aldrich, 2014; Gestwicki, 2008; Kabicher & Motschnig-Pitrik, 2009; Kriglstein, 2008; Zucker, 2009). The graph-based representation not only offers a different visual perspective on course relationships but also enables further curriculum analysis through graph theory. For instance, courses (as graph nodes) can be characterized by their incoming and outgoing degrees, providing insights into their roles within the curriculum structure.

As with correlation matrices, the values used in these graphs are not limited to prerequisite relationships. They can also represent various forms of similarity between courses, calculated using different approaches. Such similarity may relate to shared topics—derived from course content or from connections to the same competencies (Blasco Soplon et *al*., 2014). When interpreted this way, the graph structure supports advanced analyses, such as cluster detection, to reveal groups of closely related courses.

In the case of competency-based curricula, the link between competencies and content can materialize in different forms. In the design of such curricula the targeted competencies are associated to each of the courses, in a declarative manner, like "*course A is related with competency X and Y*". The heat maps are the most common form of rendering visual these relations. Such representations allow analysis like coverage of competencies in the curriculum, as one can easily spot a competency column that has few or no courses associated to it. Some approaches provide visualizations for understanding the link between competencies and content by also constructing graphs where nodes are courses, an arc between two nodes indicates that the courses are related to the same competency.

At university Savoie Mont-Blanc (France) some curricula designs are competencies-based. Correspondence matrices are the common way of visualizing the relations between modules and competencies (stage 3 curricula design cf. Figure 1). An example of such a correspondence matrix is presented in Figure 2. Columns correspond to competencies whilst rows correspond to related module groups, or learning units (Unités d'Enseignement - *UE*). If the competency *c* is related to at least one of the modules in a learning unit *lu*, then the corresponding matrix value (c*, lu)* is 1 *(*green check in the visual representation). This visualization facilitates the comprehension of the curriculum as it enables a global vision of how competencies are linked with groups of modules, allowing for analysis such as overall coverage of the competence referential by the curriculum. However, as this description of the curricula only addresses clusters of modules (not always grouped by addressed competencies), it doesn't enable a precise comprehension how each module in the cluster is related to the competency.

Semestre	UE	IDU-1			IDU-2			IDU-3		IDU-4		TC-1					TC-2			TC-3				TC-4			
		1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	4.1	4.2	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4
S5	UE1-S5-TC											✓	✓		✓	✓	✓		✓	✓		✓	✓			✓	
	UE2-S5-TC	✓	✓			✓	✓		✓			✓		✓					✓			✓	✓				
	UE3-S5-IDU	✓	✓				✓	✓		✓		✓			✓	✓	✓	✓			✓						
S6	UE1-S6-TC																✓	✓	✓		✓	✓					
	UE2-S6-IDU	✓	✓		✓		✓			✓														✓	✓		
	UE3-S6-IDU	✓				✓	✓			✓																	
	UE4-S6-IDU	✓			✓		✓			✓		✓															
S7	UE1-S7-TC																✓	✓	✓		✓	✓	✓			✓	✓
	UE2-S7-IDU	✓			✓	✓	✓			✓	✓																
	UE3-S7-IDU	✓	✓	✓			✓			✓	✓			✓							✓						
	UE4-S7-IDU	✓			✓		✓		✓		✓		✓	✓							✓						
	UE4-S7-TC																										
S8	UE1-S8-TC											✓					✓		✓	✓	✓	✓					
	UE2-S8-TC											✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	UE3-S8-IDU	✓		✓	✓	✓	✓	✓					✓								✓						
	UE4-S8-IDU	✓	✓	✓			✓			✓	✓		✓							✓	✓						
	UE4-S8-TC																										

Figure 2. Example of curriculum design visualization as orrelation matrix between sub-competencies (columns) and learning units (clusters of modules, rows)

This paper focuses on the support of competencies-based curricula design and understanding and presents ForestED – an interactive curriculum visualization tool. We explore how visualizing curricula as a set of trees can help to understand the interplay between the competencies targeted by the curriculum, and the content of curriculum (courses, projects, *etc.*). As presented in the following section, we use trees to highlight the relations between courses and competencies but also exploit these relations to show how competencies (or rather resources related to them) develop over the curricula.

2. FORESTED – A VISUAL LINK BETWEEN CURRICULUM AND COMPETENCIES

We developed ForestED in the context of an engineering school in France, in which the curriculum design is competency-based. The definition of the competency referential follows the model proposed by Tardif (Tardif, 2003) and defines a competency as a *"complex ability to act within a family of situations relying on the effective mobilization and combination of a set of internal and external resources"*.

A competency referential has been defined for each engineering diploma, comprising 4 transversal and 4 specific competencies. As the goal of the paper is to present the visualization technique (and not the referential), we will refer to these competences by their identifier only. Thus, the transversal competencies, shared by all diplomas in the engineering school are labeled as *TC-1* to *TC-4* in our visualizations, whilst the 4 specific competencies are labeled from *IDU-1* to *IDU-4*. Each competence has several core-components, or sub-competencies intuitively labeled *IDU-1.1, IDU-1.2* and so on. In the curriculum design, the link between modules and competencies is made by attaching each course learning outcome to one or several sub-competencies. A correlation matrix renders visual these links, an extract of which is presented in Figure 3 presenting one course with two LO. The first learning outcome is attached to 5 sub-competencies, while the second one is attached to two sub-competencies. Each learning outcome has a complexity level declared, the possible values being *Notion(N)*, *Advanced(A)*, *Mastered(M)* and *Expert(E)*. These levels are inspired by hierarchical model of development such as Bloom's Revised Taxonomy (Anderson et *al*., 2001), which organizes learning objectives according to levels of complexity and mastery.

UE	EC	Acquis attendu de l'apprentissage Cette unité d'enseignement (UE) vise à rendre l'étudiant apte à :	Niveau	IDU-1			IDU-2			IDU-3		IDU-4		TC-1					TC-2			TC-3				TC-4			
				1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	4.1	4.2	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4
	ISOC731 - Économie et gouvernance de la donnée	Understand principles of data governance	M						✓		✓		✓			✓							✓						
		Understand principle of data economics	M												✓								✓						

Figure 3. The curriculum design makes the link between courses LO and sub-competencies

ForestED visualizes the correlation matrix as a set of trees (hence the name of the tool, ED standing for education). Each tree in the forest corresponds to a course, the branches are the LO, and the leaves are the competencies. Once a diploma is selected, ForestED displays the curriculum trees, as presented in Figure 4, as well as some additional graphics: a set of spark-lines for competencies, and more-detailed visualizations for each competency, as well as the color scheme. The visualization is interactive, giving the possibility to focus on specific competencies or sub-competencies.

The main component – the forest - provides an overall visualization of the curriculum, as a set of trees structures, presented in columns (see Figure 5). Each column from left to right represents a semester. In our case study the semesters go from 5 to 10. The number of trees in a column corresponds to the number of courses in that semester. Each tree structure represents a course and has three levels of depth. The roots represent the subjects, the intermediate nodes are the LO, and the leaves are the sub-competencies. We deliberately made the choice not to display any analytic data on this visualization, keeping it purely structural, the curriculum being displayed entirely, with the colors chosen to help the overall understanding.

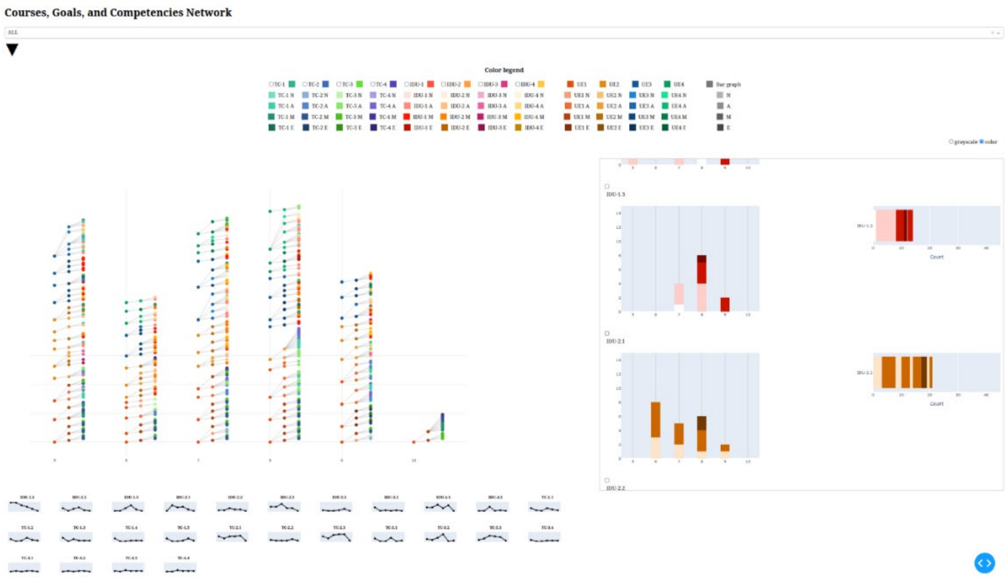

Figure 4. Overview of ForestED main display, with one curriculum selected

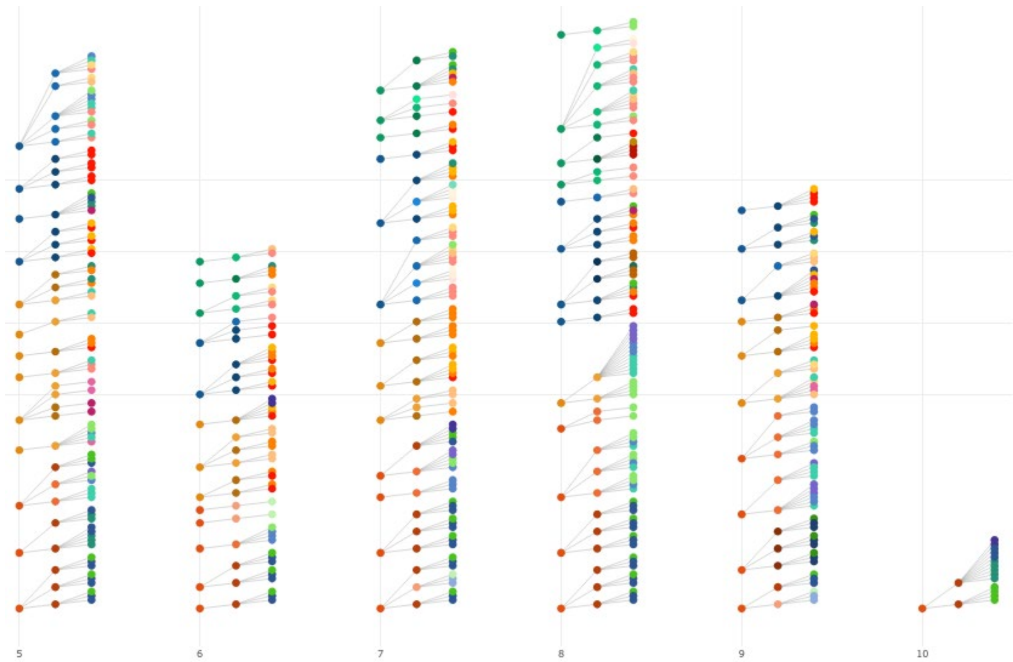

Figure 5. A curriculum forest: visualization using tree-like structures, where trunks are modules, branches are learning outcomes, and leaves are targeted sub-competencies

Each competency has a color attached to it, with warm colors for the specific competencies (*IDU*) and cold colors for the transversal competencies (*TC*). This global view of the forest allows us to make some analysis. In the example presented in Figure 5, the different columns, corresponding to the different semesters, vary in size. Nevertheless, semesters have the same length and weight in the diploma. The case of the last semester (10) is special, because there is just one module, corresponding to the internship. But the other columns still considerable vary in size. On closer inspection, we notice that the trees are of different shapes. In semester 6 (second column) the trees are smaller, which indicates that there were less learning objectives identified for the corresponding courses, with fewer competencies attached. This is normal as the designers (teachers) were not given specific directions as to the number of LO and competencies they should consider for the courses they oversaw, but it surprises, and it begs for further enquiry (undergoing).

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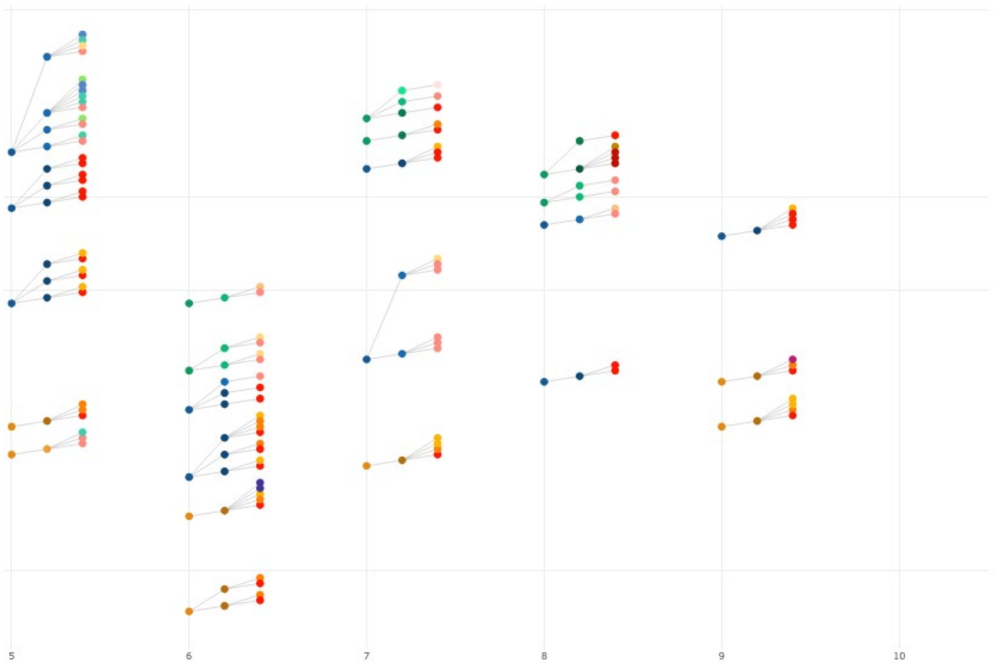

Figure 6. Trees (courses) associated to a specific sub-competency (IDU-1.1)
The courses are entirely represented, allowing for spotting the competences developed simultaneously with the selected one competency

As mentioned, the tool is interactive. When choosing one sub-competency, the forest displays only the modules related to the select sub-competency. Figure 6 presents the courses (trees) in the curriculum (forest) that are related to the sub-competency *IDU-1.1*. The trees are entirely displayed, and we can spot which other competencies are addressed jointly with *IDU-1.1.* Hoovering over the nodes displays their label (sub-competency). Note that there is no course displayed in the last semester, as the only course in that semester did not address sub-competency *IDU-1.1*

The color palette is chosen carefully as it supports better comprehension (cf. Figure 7). A sufficient color distance between hues is ensured to avoid confusion due to similarity. The same color scheme is reused constantly across the different graphics. The different levels of acquisition are represented through shades of the same color, enhancing visual coherence. Recall that the root nodes of trees correspond to courses. The color of these nodes is given by the learning unit to which they belong, allowing to pre-attentively identify courses belonging to the same unit. For the nodes corresponding to the *LO* of a course, the hue is the one of that course, but the shade corresponds to their maturity or difficulty level. As the visualization is interactive, a simple selection in the forest allows to zoom on specific modules, such as presented in Figure 7, where we show examples of two modules. The first tree has warm colored leaves. This indicates it is a specialized course, but some transversal competencies are also addressed, as there are green leaves. The second example tree has blue and green leaves, so it is related to transversal competencies. Also, as the root nodes for the two trees are of different colors, this indicates the fact that the courses belong to different learning units.

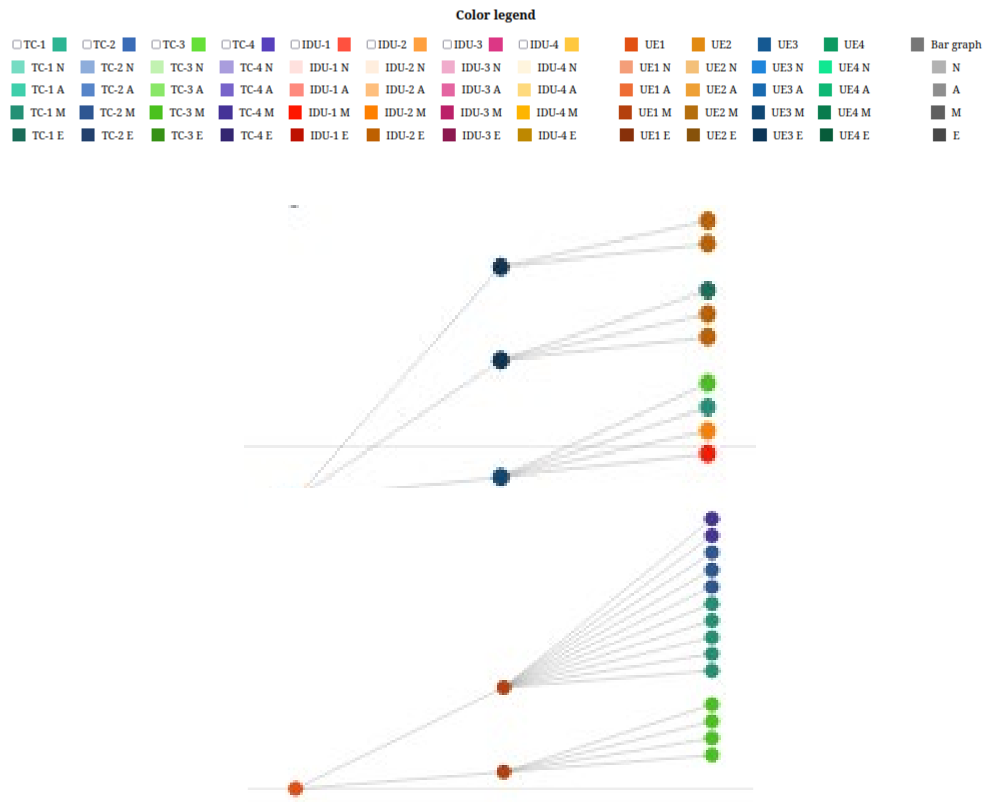

Figure 7. Zoom on color palette and two different modules on the curriculum overview

An alternative visualization that provides an overview of correlation between content and competencies is an interactive heat-map (cf. Figure 8), where the level of granularity can be adjusted. Three levels of granularity are available, corresponding to three possible views. The *global view* (presented in Figure 6) focuses on the link between competencies (columns) and semesters (rows). The *semester view* focuses on a specific semester, showing in a similar manner the link between modules and competencies. The *module view* gives the correlation between the learning outcomes and the competencies.

The color intensity at each intersection (x, y) represents different information depending on the granularity and the choice made by the user. For the global view, the user can choose to associate the color intensity to the number of modules in which the competency is assessed during a semester, or to the average level at which the competency is assessed. For the semester view, the intensity can be associated to the number of learning outcomes in which the competency is tested in a module, or to the average level at which the competency is assessed. For the module view, the color intensity can only be associated to the level at which the competency is assessed.

These visualizations propose an extension of the competency's correspondence matrix presented in Figure 2. They allow the possibility to move from more general to more detailed representations easily. As always, the colors are exploited to convey additional information on the curriculum.

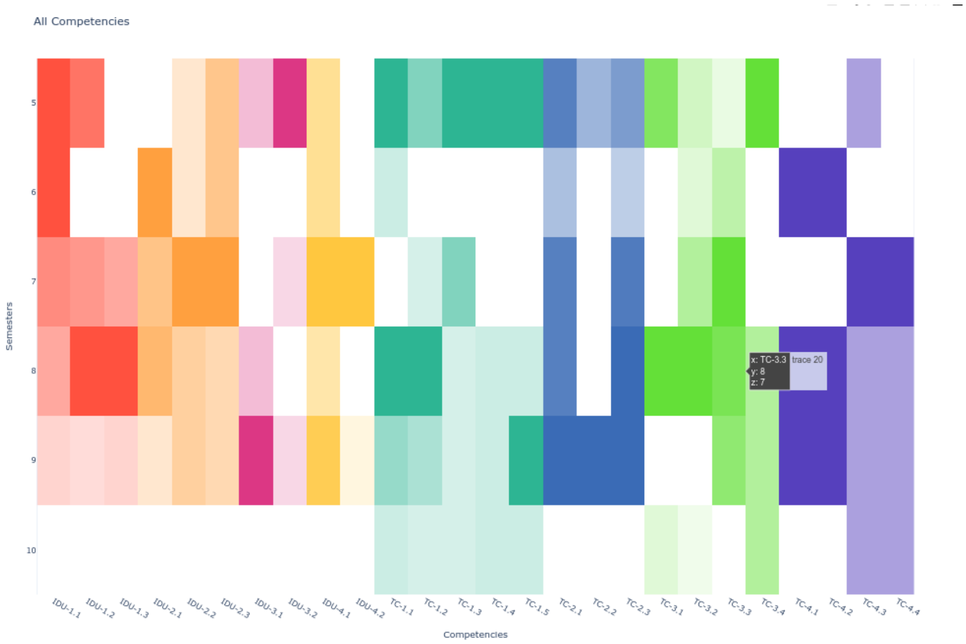

Figure 8. Heatmaps showing the competencies developed per semester

The interactive heatmap is a more familiar representation, but the user must choose (and switch) between overview (semester to competency link) and detail (LO and competency link). The forest has the advantage of giving the overview (entire curriculum) and the detail (associated competencies at LO level). These two representations are complementary.

Two of the remaining graphics are displayed on the right side of the interactive tool (cf. Figure 4). They focus on sub-competencies, and present two displays for each one of them.

Figure 9 presents these graphs for 4 different sub-competencies. The stacked bar-chart on the left displays how many times the sub-competency appears in the LO per semester, using color to display the complexity level of each learning outcome (the darker the shade, the higher the complexity). The horizontal bar-chart consists of counting the total number of LO helping to the acquisition of the core competency during the overall duration of the whole curriculum - this chart essentially sums up the values from the semester-based bar charts. Although the information may seem redundant, as our goal is to rely as much as possible on visual perception, the second graph (horizontally stacked chart) allows for quick comparison among competencies. It allows us to compare visually how many *LO* each competency has attached to it. Looking at the different competencies presented in Figure 9, we easily see which is specific (left hand side, warm colors), which is transversal (right hand side, cold colors). Also, we can easily see that *IDU-1.2* has less coverage in the curriculum than the others, we can detect that pre-attentively – by comparing the size of the bars. We can also attentively see that *IDU-1.2* has around 13 LOs attached to it whereas *TC-2.1* has around 35. Looking at the shades used, we can see that specific competencies (*IDU*) have fewer LOs that address high complexity levels attached to them (the very dark shades of red and yellow) than the transversal competencies.

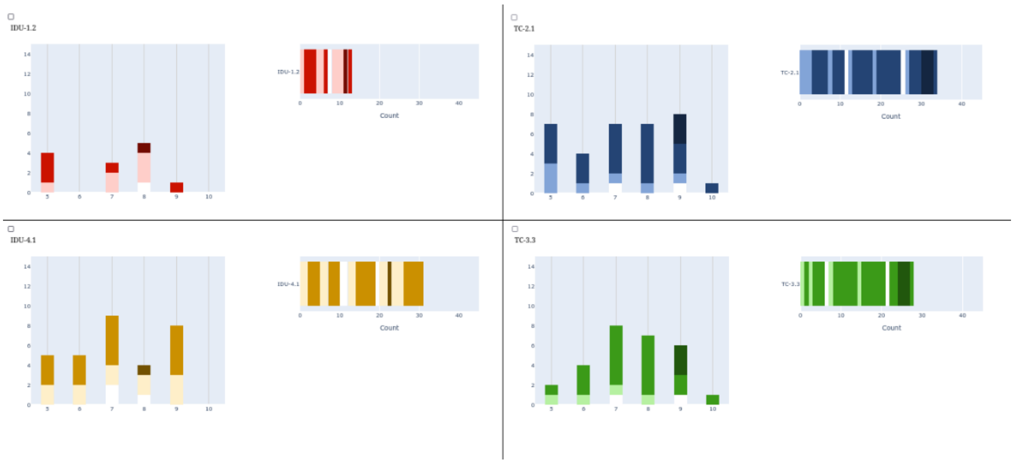

Figure 9. Competency-specific views: per semester development and overall coverage

Another set of visualizations, consisting of spark-lines positioned side by side is intended to further ease the comparison between sub-competencies (see Figure 10). The sparklines are minimalist versions of the stacked bar-charts from the previously presented. They are intended for facilitating the comparison of sub-competencies, as the bar-charts already give detailed information about every sub-competency. Using this graphic, it is easy to see that the way competencies develop over time is different. Note that each dot in a spark line corresponds to how many LOs are attached to this sub-competency in a particular semester. Each spark line provides thus a chronological view on how the curriculum addresses it. The shapes are different, indicating that the way competencies are covered in time varies from one competency to another.

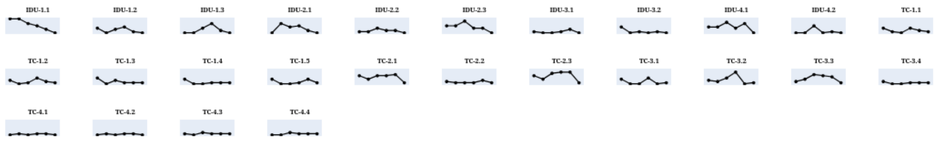

Figure 10. Spark-lines showing competencies temporal development

This kind of comparative analysis is easy to make using this visualization, but it will require immense effort without it. As mentioned, the ForestED is an interactive tool. If one competency is selected, the curriculum overview only displays the courses (trees) that are related to that competency.

An additional visualization displays side by side the heatmaps of the semester view. The heatmaps are basically the same as described earlier, but without the possibility of zooming in. They are displayed in a similar manner to the sparklines displayed to allow quick comparisons but between semesters instead of competencies. It corresponds to more global temporal comparisons, as the principal point of focus is directly the number of occurrences or the average level – depending on the option chosen - the competencies have in a semester.

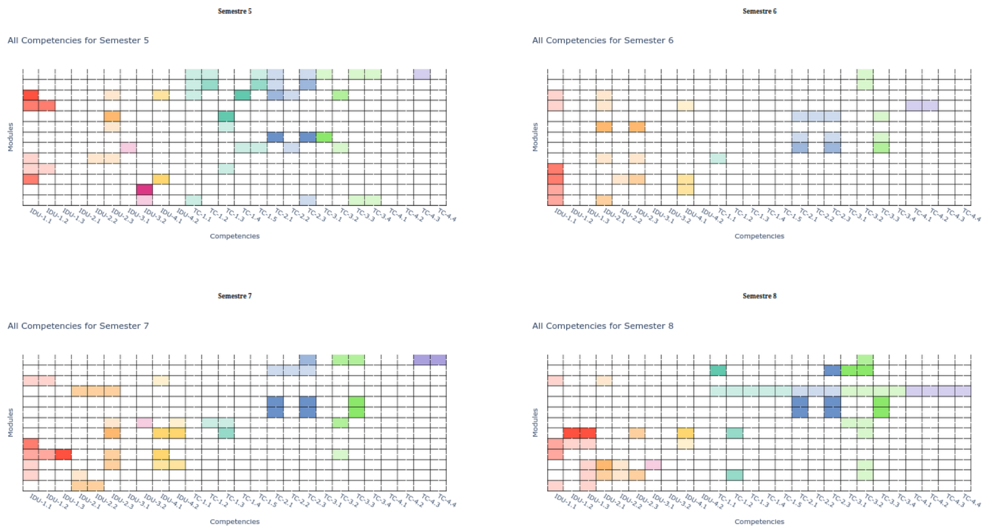

Figure 11. Heatmaps of comparison of distribution of competencies

3. CONCLUSION

ForestED showcases the relevance of visualization as a means for understanding educational offers. Different diplomas in our engineering school have been visualized, as their curriculum design is based on the same model. In terms of architecture, ForestED relies on a CVS file where the curriculum and its relations to competencies have been stored. Further experimentation with diplomas outside our engineering school is envisaged and will allow us to test its genericity.

ForestED was presented to the teachers involved in designing and delivering the curriculum and the feedback was very positive. The teacher panel included the head of department– and the tool appears to be of help for curriculum maintenance.

ForestED focuses on the interplay between the targeted competencies and the curriculum content (such as defined in the curriculum design). At the current time, most of the evaluation of students enrolled in the curriculum is done traditionally, at the level of each course. The competencies are evaluated only in some specific modules - mostly transversal projects in each semester, but even these modules must deliver grades. So, the curriculum, although designed using this competency-based approach, delivers the diplomas on grades-based evaluation, related to each module. Thus, the two models - competency based (design) and content based (delivery and certification) co-exist. This is the case in most of the higher education institutions in France. The link made by the curriculum design between the content (course LO) and competencies corresponds to the development of resources (internal and external) that hopefully will be effectively mobilized by the learners when the corresponding competency is needed.

ForestED is part of a toolkit that aims supporting the competency-based approaches at different levels. Whilst we focus here on the curriculum visualization, other tools in the kit include the student's dashboard focused on the actual competency development.

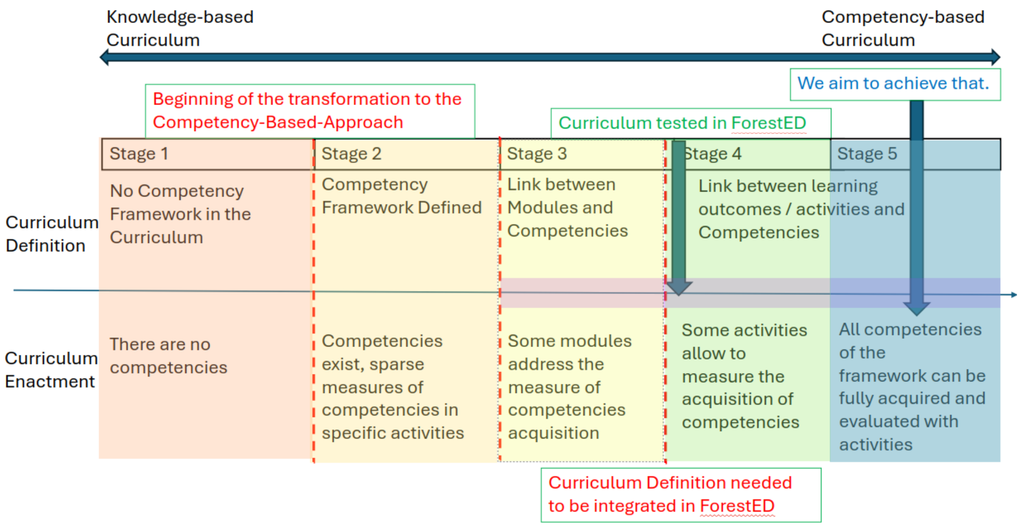

Figure 12. Heatmaps of comparison of distribution of competencies

Figure 12 extends Figure 1 by adding the curriculum enactment features corresponding to the transformation stages/steps from content based to competency-based curricula. The curricula tested on ForestED takes usually place after step four is achieved. It needs to have this level of curriculum definition and have the links between learning outcomes or activities and competencies to be done. As for curriculum enactment, the steps usually mirror those of curriculum definition. It starts with the fact that there is no competency to measure as the Competency Framework hasn't been defined yet. Then after defining the competencies within the Competency Framework, those are measured but only sparsely and in specific activities.

Those steps mean that the measure of competencies has no or a very few importance. Once the links between learning outcomes or activities and competencies are done, it becomes possible to address the assessment of competencies in some or all modules. However, the level of enactment aimed to be achieved is that the measure of all activities is fully acquired.

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