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A Dashboard to Support Decision-Making Processes in Learning Ecosystems: A Metamodel Integration

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ABSTRACT

There are software solutions to solve most of the problems related to information management in any company or institutions, but still, there is a problem for transforming information into knowledge. Technological ecosystems emerge as a solution to combine existing tools and human resources to solve different problems of knowledge management. In particular, when the ecosystem is focused on learning processes associated with knowledge are named learning ecosystems. The learning ecosystem metamodel defined in previous works solves several problems related to the definition and implementation of these solutions. However, there are still challenges associated with improving the analysis and visualization of information as a way to discover knowledge and support decision making processes. On the other hand, there is a metamodel proposal to define customized dashboards for supporting decision-making processes. This proposal aims to integrate both metamodels as a way to improve the definition of learning ecosystems.

CCS Concepts

• Information systems → Open source software • Software and its engineering → Software design engineering • Software and its engineering → Software development techniques.

Keywords

Technological ecosystems; software ecosystems; MDA; metamodel; software engineering; learning ecosystem; knowledge management; decision-makers.

1. INTRODUCTION

Two main concepts are used to refer to changes in nowadays society, information society and knowledge society. The notion of the 'information society' is used above all when dealing with technological aspects and their effects on economic growth and employment [1]. On the other hand, in the knowledge society, the core element is not the technology but the ability to identify, produce, process, transform, disseminate and use the information to build and apply knowledge for human development [2]. According to [1], Heidenreich [3] associates the knowledge society to the increasing relevance of education and training processes in the initial phase as well as in the whole life course is underlined, and the increasing weight of knowledge-intensive services and communication.

Knowledge has become the backbone for development; it is a strategic factor for creating new policies, to plan new actions, and to foster innovation within organizations. Knowledge management is considered a sustainable competitive advantage [4], so the organizations expend part of their resources on building their capacity to share, create, and apply new knowledge continuously over time [5].

However, knowledge is not only present physically (i.e., in documents or books), it is also present in employees and the different processes carried out at organizations. According to [4], knowledge management processes must be able to support the transfer of implicit knowledge to tacit knowledge. This scattered nature of knowledge makes its management a complex and crucial task.

Software ecosystems emerge as a technological solution to support information and knowledge management in different contexts. According to [6, 7], institutions adopt a software ecosystem strategy to expand their organizational boundaries, share their platforms and resources with third parties, and define new business models.

Although the term software ecosystem is the most used in the literature, there are other terms that have distinctive characteristics. This is the case of the technological ecosystems, solutions that propose a decentralized configuration of software tools and nontechnological components (such as methodologies, management plans, or human resources). Technological ecosystems can be composed by several elements; elements that are connected to each other and have different functions within the ecosystem. One of the main strengths of the technological ecosystem is that when their components collaborate, they exploit all of their benefits, obtaining the most out of their functionalities to provide elaborate services.

Furthermore, when the technological ecosystem is focused on learning processes associated with knowledge are named learning ecosystems [8, 9]. The definition and development of these solutions have challenges associated with the evolution of its components and the whole ecosystem, as well as the need to adapt to the changes that constantly occur in any organization.

This work presents a holistic meta-model to support decision-making processes in learning ecosystems. This meta-model integrates two meta-models defined in previous works. First, a learning ecosystem meta-model to support the definition of learning ecosystems based on open source software [10]. On the other hand, a dashboard meta-model to support the analysis of information in order to transform implicit knowledge in tacit knowledge.

Information dashboards are powerful tools that allow the recognition of patterns and interesting data points through visual analysis [11, 12]. However, dashboards can be very diverse in terms of design, context, audience, pursued goals, supported tasks, etc., [13-18], which makes the development of these tools a complex activity.

By abstracting the common elements of information dashboards through meta-modeling it is possible to obtain a general structure of dashboards that can be instantiated and adapted to any kind of contexts, data domains or audiences.

Furthermore, as it will be detailed, the inclusion of dashboard users and their requirements as elements of the meta-model enables the integration of this meta-model as a part of technological ecosystems, specifically, learning ecosystems, providing support to discover knowledge and support decision making processes [19].

The rest of this paper is organized as follows. Section 2 outlines the methodology followed to develop the meta-models. Section 3 describes the learning ecosystem meta-model, followed by section 4, in which the dashboard meta-model is presented. Section 4 discusses the integration of both meta-models. Finally, section 5, where the conclusions derived from this work are depicted.

2. METHODOLOGY

Model-driven development (MDD) [20, 21] allows separating the data and the operations specification of the system from lower-level details, like the technical aspects related to a specific program language or platforms.

The Object Management Group (OMG) proposes the model-driven architecture (MDA) as a guideline to implement this approach. This architecture provides a framework for software development which employs models to describe and define the target system [22]. The main difference between MDD and MDA is that the OMG proposal uses a set of standards: meta-object facility (MOF), unified modeling language (UML), XML (Extensible Markup Language) metadata interchange (XMI), and query/view/transformation (QVT).

In this case, the dashboard is a part of the learning ecosystem, which is based on a meta-model defined and validated in previous works. The first version of the learning ecosystem meta-model is based on MOF, and the last validated version is an instance of Ecore [10]. Both versions are M2-models. The model has served as a map to develop and deploy the ecosystem in a real-world context.

The dashboard meta-model is also part of the four-layer meta-model architecture proposed by the OMG, in which a model at one layer is used to specify models in the layer below [23]. In particular, the dashboard meta-model is an instance of MOF (i.e., an M2-model), so it can be instantiated to obtain M1-models.

The integration of both meta-models is possible because of both are Platform Independent Models (PIM) at M2 layer, although one is instantiated from Ecore (learning ecosystem meta-model) and other from MOF (dashboard meta-model). To get the holistic meta-model, the dashboard meta-model was transformed in an instance of Ecore using Graphical Modelling for Ecore included in EMF.

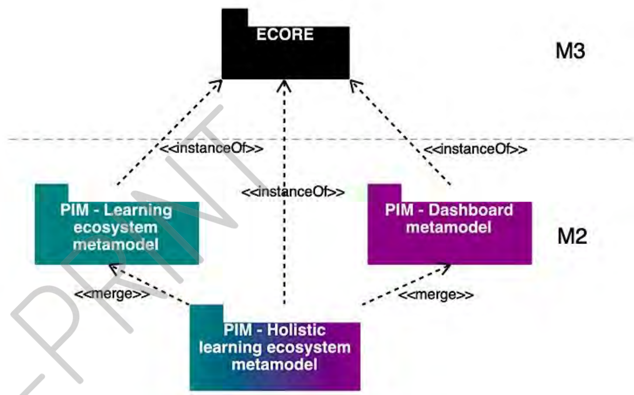

Figure 1. Meta-models organized in the four-layer metamodel architecture.

3. LEARNING ECOSYSTEM META-MODEL

There are a large number of open source tools that allow knowledge management in different ways, with particular emphasis on content managers and document repositories. On the other hand, from the point of view of learning management, there is a wide variety of learning platforms (Learning Management System, or LMS [24, 25]) and tools that allow the definition of Personal Learning Environments (PLE) [26, 27]. Technological ecosystems for learning must be able to combine some of these tools to support knowledge and learning processes in heterogeneous contexts, from institutional environments to private enterprises. Besides, they must be able to incorporate emerging tools, as well as to remove those that become obsolete or that users do not use, in such a way that the system must be in continuous evolution.

Despite the advantages offered by technological ecosystems, the development of such solutions is more complex than traditional information systems. The definition of a particular ecosystem requires knowledge and selection of appropriate systems and services to meet the needs of a particular context. Likewise, the ecosystem should be prepared to evolve and adapt to the changing needs of the environment and users; meanwhile, interoperability between the different components must ensure a high degree of integration and cohesion [9].

The learning ecosystem meta-model is proposed as a solution to improve the processes of definition and development of technological ecosystems, in order to solve the different challenges and problems identified through the analysis of a set of learning ecosystems deployed in different contexts, and with very diverse objectives.

In particular, the meta-model [28] is a Platform-Independent Model (PIM) to define learning ecosystems based on Open Source software (Figure 2). It is an instance of Ecore with a set of constraints defined with Object Constraint Language (OCL).

The meta-model represents the three main elements of a learning ecosystem.

First, the different software tools that compose the ecosystem: data repositories, monitoring tools, user management systems, indexing services, decision-making tools, etc.

Second, the proposed meta-model includes the human factor at the same level as the software because these human resources (management definition, methodologies, and users) are the key elements to ensure the evolution of the ecosystem.

Finally, the third element is the information flows used to support the interaction between the other elements in the ecosystem.

The interaction between the software tools is implemented by services and properties files. On the other hand, the interaction between software tools and users has a substantial impact on the ecosystem; for this reason, these interactions are also represented through information flows. All information flows are based on the objectives defined by management.

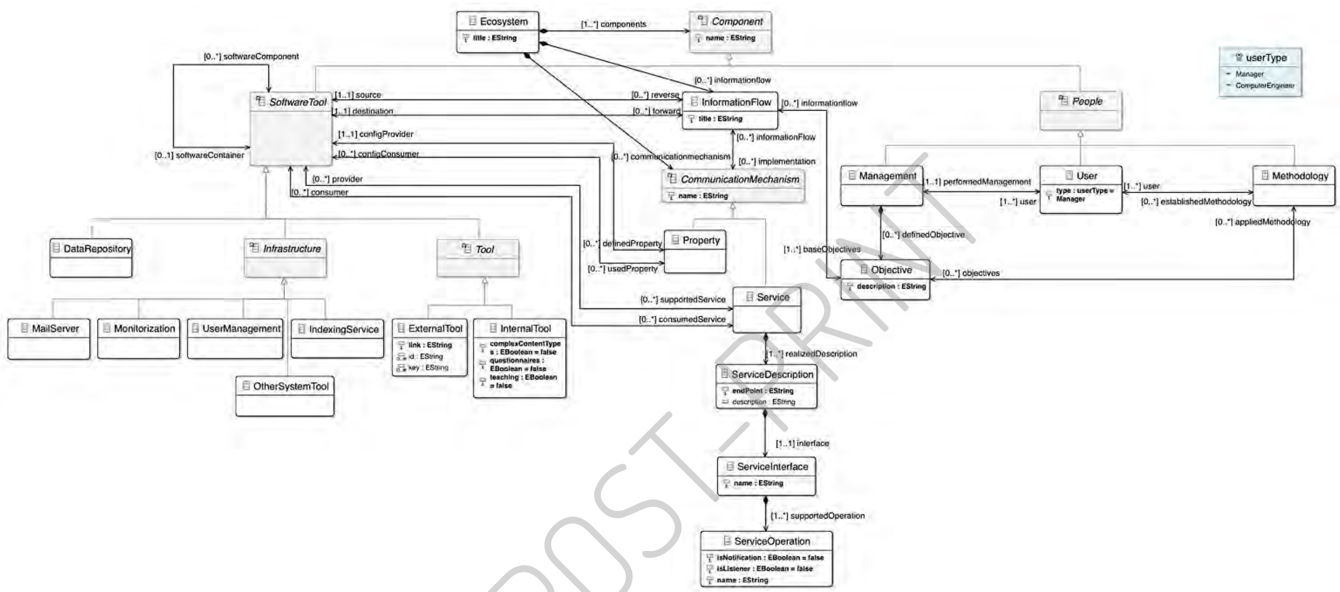

Figure 2. Learning ecosystem meta-model in Ecore. This image is available in high resolution at https://doi.org/10.5281/zenodo.1066369. Source: [9].

4. DASHBOARD ECOSYSTEM META-MODEL

The dashboard meta-model is also composed by a variety of pieces that allow the definition of different types of dashboard and information visualizations. The dashboard meta-model can be divided into three main sections: the user, the layout and the components.

Figure 3 shows an excerpt of the dashboard meta-model containing the mentioned three sections. A detailed view of the components section can be consulted in Figure 4.

The layout and the components are more technical aspects of dashboards, as they will compose the final display.

However, how many visualizations will the dashboard hold? How these views will be arranged? What type of visualizations will the dashboard display? What type of interaction patterns will the dashboard support? Will the different views be linked?

These questions cannot be answered in an arbitrary manner. These are design decisions, and they need to be driven by the final consumers of dashboards: the users.

Including the user in this meta-model is essential, because they will be using the delivered dashboards to reach insights, to support their decision-making processes or to explore certain datasets.

The user is defined in terms of significant and influential aspects to support a personalized dashboard design, i.e., the factors that influence the design process of a dashboard [29]. Given that, the user entity is decomposed in terms of his or her goals and his or her characteristics.

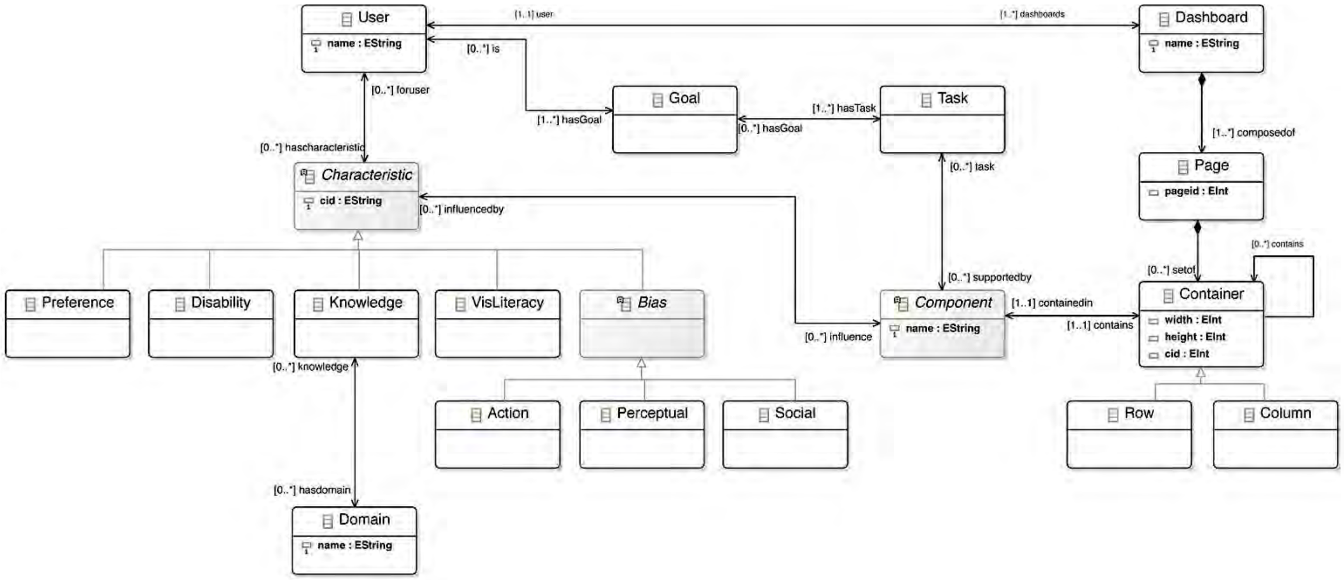

Figure 3. User, layout and components section of the dashboard meta-model proposal.

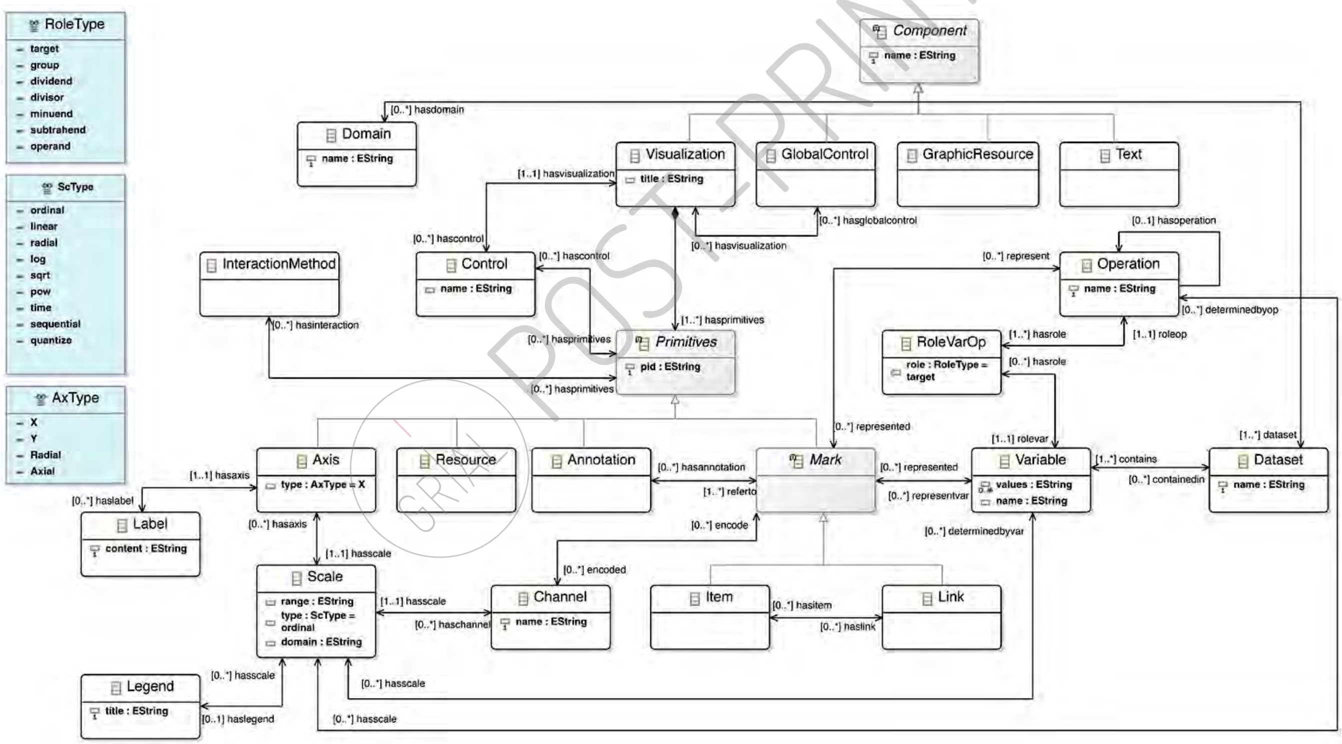

Figure 4. Detailed view of the components section of the dashboard meta-model proposal.

Firstly, a crucial concept arises; Goal. A user must have at least one goal for using a dashboard, however implicit.

Goals, in turn, can be broken down into individual and more specific, low-level tasks. Simple goals can be accomplished by performing a few tasks.

However, more elaborated goals might involve several specific and chained tasks, which could involve different data dimensions to support complex decision-making processes [15, 17, 30].

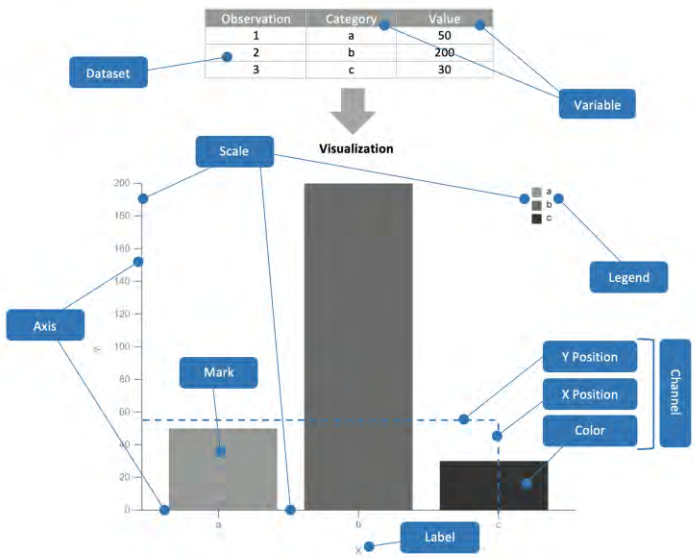

Figure 5. Example of the different elements that compose a visualization (in this case, a bar chart).

Finally, a user can have a set of identified characteristics. Characteristics can be diverse. For example, preferences, disabilities, knowledge about different domains, visualization literacy, and bias (action, perceptual, or social bias) are different kind of characteristics. These characteristics can influence the design process, thus needing to adapt the dashboard's components to match the identified user aspects.

Regarding the more technical details of the dashboards (i.e., the layout and components), the purpose of the layout section of the dashboard is to model the generic structure of a dashboard, which can be composed of different containers (rows or columns) that hold different components.

In terms of the components of the dashboard, several elements are identified. The main components of dashboards are the information visualizations that display data, but also the controls (handlers, filters, and so on), graphic resources, or text that complement these visualizations (Figure 4).

Information visualizations, in turn, are composed of primitives, which can be different visual marks that encode data variables through channels (i.e., color, size, position, etc.). These primitives are the core of information visualizations, because they are the elements that hold the actual data [12, 31].

Figure 5 shows a practical example of the identification of different parts of information visualizations through the dashboard meta-model classes.

In this example, there are two scales that represent two variables (the "Category" variable through an ordinal scale, and the "Value" variable through a linear scale). The domain of these scales are the set of values from the variables. For instance, the domain of the scale that encode the X position of the visual marks is the set of values retrieved from the "Category" variable (i.e., 'a', 'b', and 'c'). Axes, on the other hand, support the visualization of the scales' domains.

The visual marks of this visualization are bars with a specific position along both X and Y axes and a specific color based on a color scale that encodes the "Category" variable. Scales map the data values to another specific range of values in order to encode the information, that is why these entities are related both to the dataset variables' values (to obtain the domain) and to the visual channels or encodings (to encode these values using another specific range of values, like color codes or screen positions).

The dashboard metamodel was an instance of MOF, but it was transformed into an instance of Ecore using Graphical Modelling for Ecore to enable its the connection to the learning ecosystem meta-model, as mentioned in the methodology section.

During the transformation, some changes were introduced to compile with the Ecore rules, so the dashboard meta-model described in this section differs in some details from the previous version [32, 33].

These changes only address modeling issues to enable the instantiation of Ecore. These are the modified aspects of the meta-model:

- Renaming some classes to remove white spaces and introducing CamelCase notation: *VisLiteracy*, *GlobalControl*, *GraphicResource*, and *InteractionMethod*.
- Introduction of id attributes in each class in order to allow the instantiation of the meta-model in a M1-model.
- Introduction of enumeration classes to enclose the values for some attributes: *RoleType*, *AxType*, and *ScType*.
- Review of the associations' navigability because in Ecore the navigability is always represented.
- Introduction of names for each relationship.
- Translation of the *RoleVarOp* association class into binary associations (association class is not supported by Ecore).
- Transformation of the reflexive composition association of the *Container* class into a reflexive binary association.
- Transformation of the aggregations into binary associations (aggregation is not supported by Ecore).

The mentioned modifications are crucial for the next steps. The introduction of identifiers and the explicit navigability of the relationships are necessary to instantiate the metamodel and to introduce constraints through OCL, for example.

5. A HOLISTIC ECOSYSTEM METAMODEL

As introduced at the beginning, ecosystems are composed by different elements with different functions and goals. However, these elements are more powerful when connected and when they collaborate with each other through information flows.

That is why a holistic solution is proposed, in which each part of it is strengthened when collaborating among them. The ecosystem is seen as a whole, and not only as individual parts with no relationships between one another.

Although the learning ecosystem meta-model proposed solve most of the problems associated to the definition and development of theses technological solutions, there are some issues related to the analysis of the information flows and the support to decision-making processes that should be improved.

The dashboard meta-model presented in Figures 3 and 4 is connected to the ecosystem meta-model (available at https://doi.org/10.5281/zenodo.3561320 [34]).

The ecosystem meta-model represents each software component as a black box, to provide a high-level abstraction of its structure. The dashboard meta-model provides detail to model these tools as a part of the ecosystem. The complexity of dashboards requires an in-depth analysis of the domain to identify their main commonalities and features, and how these features relate with each other.

Although the dashboard meta-model includes more details regarding these tools' structure and elements, the meta-model is still at a M2-level in terms of the OMG's four-layer architecture. The presented dashboard meta-model is an instance of Ecore, as well as the learning ecosystem meta-model.

These two M2-level meta-models are connected by some elements present both in the dashboard meta-model and the ecosystem meta-model. On the one hand, it has been justified the necessity of including users in the dashboard meta-model because they are the drivers and consumers of the displayed data.

The human factor also plays a crucial role in the learning ecosystem meta-model because the technology is defined and evolved to support the users' needs.

On the other hand, there are two relevant elements shared in both meta-models too. The dashboard *Goals* (within the dashboard meta-model) are represented as *Objectives* within the learning ecosystem meta-model.

These elements are represented by a set of *Tasks*, and *Information Flows*, respectively. The relevance of these entities is that they are the core of the meta-model, because they frame the required components to achieve the goals or objectives set.

Figure 6 shows the connection between both meta-models. The dashboard *Goal* is merged with *Objective. T*he connection between *Goal* and *User* in the dashboard meta-model is replaced by the association between *User* and *Objective* through the *Management*. In this sense, all the goals that support the definition of the dashboard are connected to the management decisions in the ecosystem.

Regarding the *Dashboard*, the main class to instantiate the dashboard meta-model is connected with the learning ecosystem as a *Tool*. Besides, the connection between *User* and *Dashboard*, which has a particular impact on the dashboard meta-model, is included in the proposal.

The information flows and tasks are different concepts, so it is not possible to merge them. For this reason, the dashboard *Task* is included in Figure 6.

On the other hand, a new communication mechanism is included to implement the information flows, the *Dataset*, as a way to represent the integration between the dashboard and other software tools in the learning ecosystem.

Regarding the dashboard *Component*, it is renamed as *DashboardComponent* to distinguish it from the learning ecosystem *Component*.

Finally, the connection between dashboard *Characteristic* and *User* appears in the new proposal. Tasks are supported by the dashboard's elements, that are also influenced by the user characteristics to match his or her information requirements.

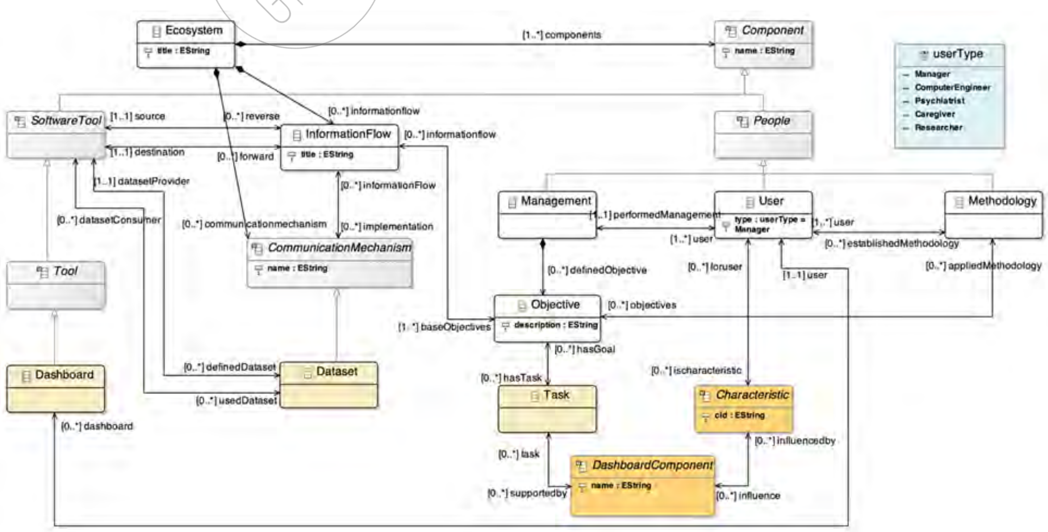

Figure 6. Connection between both meta-models.

6. CONCLUSIONS

An integration of two meta-models has been proposed. Specifically, a dashboard meta-model has been included within a learning ecosystem meta-model to solve some issues related to knowledge discovery and decision-making processes in the learning ecosystems.

The dashboard meta-model provides a skeleton that can be adapted to instantiate concrete dashboard solutions. The role of the dashboard is to support decision-making processes through visual analysis.

Including the user within the meta-model is crucial, as their goals and data requirements are the drivers of the dashboard configuration process.

On the other hand, the learning ecosystem meta-model solves several problems related to the definition and implementation of learning ecosystems. Learning ecosystems combine tools to support knowledge management. Including an information dashboard within the learning ecosystem address the improvement of knowledge discovery within the ecosystem, by providing a tool to visually analyze information flows.

However, although the learning ecosystem is validated and its quality was checked through the framework defined by López-Fernández et al. [35]. it is necessary to validate and apply the same framework to the meta-model proposed due to the dashboard meta-model is not fully validated in previous works.

Furthermore, future research lines will involve the refinement of the meta-model through the addition of constraints, rules, and design guidelines, in addition to the testing of products instantiated from these meta-models. The goal is to obtain a tool to automatically generate information dashboards based on the context of application using, for example, machine learning algorithms [36-38].

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