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Modeling Academic Education Processes by Dynamic Storyboarding

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ABSTRACT

In high-level education such as university studies, there is a flexible but complicated system of subject offerings and registration rules such as prerequisite subjects. Those offerings, connected with registration rules, should be matched to the students' learning needs and desires, which change dynamically. Students need assistance in such a maze of dynamically changing opportunities and limitations. To cope with this problem, a new storyboard concept for academic education, called "dynamic storyboarding" is proposed to assist university students. Dynamic storyboarding is based on the idea of semi-formally representing, processing, evaluating, and refining didactic knowledge. This storyboarding is more appropriate in managing high-level education than is general artificial intelligence knowledge representations such as frames. This is because the structure of dynamic storyboarding is driven by the semi-formal and multilayered nature of didactic knowledge in university education. A feasibility study showed that storyboarding can be used to supplement an academic educational system, such as the dynamic learning need reflection system (DLNRS) of Tokyo Denki University (TDU) in Japan. Concretely speaking, didactic knowledge in the university curricula was proven to be easily and clearly represented by dynamic storyboarding. This contributed to the students' dynamic learning activities by supporting features that help students review and adapt their own individual curricula.

Keywords

Process modeling, Learning processes, Storyboarding, Dynamic learning need reflection system, Knowledge engineering

Introduction

University studies are characterized by a high degree of flexibility with respect to the subjects to be included in a student's curriculum. On the other hand, there are complex and dynamic rules of subject registration that can constrain the student's selections. Some of these rules are as follows:

➤ when subject registration can be made
➤ how to register (in-person, online, via post)
➤ department permission for particular subjects or courses
➤ limitations due to class capacity and time conflicts among classes
➤ particular subject or course combinations necessary for graduation
➤ prerequisites

Each of those subjects and their registration rules should be matched with students' learning needs and desires, which change dynamically depending on factors such as the learning status attained in the previous semester. Under these circumstances, it is not easy to finish a study plan or curriculum in time for registration.

The flexibility and complexity of regulations increase students' burden in planning their university studies. The authors' experiences with Japanese, German, and US universities indicate that this may be a world-wide problem.

Generally, university students suffer from a lack of clarity due to the above-mentioned complex situation. A significantly high number of students do not succeed in their desired subjects or courses because they cannot comply with some of these regulations or do not even know about them. Therefore, students sometimes cannot finish their studies in the designated time. Avoiding the resulting frustration is one objective of introducing the new approach of storyboarding as a means to keep track of the big picture in the maze of dynamically changing opportunities and restrictions mentioned above. University students need assistance in this maze.

Flexibility has both advantages and disadvantages. Being flexible helps students in their learning and, as long as the flexibility doesn't threaten their success, increases students' motivation. Increasing student motivation is the other

goal of using storyboards. But, this advantage can turn out to be a problem when students are unable to meet the requirements because they violated the complex and dynamic rules/constraints mentioned above. Helping students meet the requirements without such violation is the other objective of the proposed storyboard application.

In contrast to basic-level education, such as in primary and secondary schools, higher education is characterized by
- ➢ a large variety of opportunities for creating the academic curricula and timelines, and
- ➢ teachers (professors and tutors) who are experts in their subjects but do not necessarily have the didactic skills to teach.

Particularly due to the first point, at the School of Information Environment (SIE) of Tokyo Denki University (TDU), students can be more flexible than students of other schools or universities in designing their studies according to their needs, wishes, interests, and talents. Thus, students at SIE of TDU need more qualified assistance or guidance in the maze of dynamically changing opportunities.

To address the above-mentioned problems, an education system, which we currently call dynamic learning need reflection system (DLNR system or DLNRS), was developed and introduced at SIE of TDU (Dohi & Nakamura, 2003; Dohi, Nakamura, Sakurai, Tsuruta, & Knauf, 2006a). Its objective is to maintain or increase the students' motivation by clarifying and dynamically reflecting students' individual learning needs. The system is characterized by
- ➢ the abolition of the traditional rigid academic year
- ➢ the introduction of prerequisite conditions instead of a fixed, pre-determined subject sequence
- ➢ the replacement of fixed yearly tuition by a subject-based payment system
- ➢ a grade point average (GPA) system that evaluates the learning results and helps create or modify the upcoming class schedule, namely, the next semester's curriculum, in deriving appropriate results or consequences.

As shown in Dohi & Nakamura (2003), the introduction was revolutionary and a remarkable success. In a questionnaire that was filled out by 203 students, almost 90 percent said that the DLNRS is very understandable and useful for both creating each semester's schedule and making a long-term graduation plan. However, the level of understanding of the prerequisite conditions was about 60 percent. Thus, the method of displaying the prerequisite conditions needs to be improved, according to Dohi and Nakamura (2003).

Qualified guidance for factors such as the prerequisite conditions mentioned above needs adaptation with respect to varying learning needs, context conditions (the students' performance in the previous stages of the study), and the students' educational history. Such adaptation, however, presumes an anticipation of various structurally complicated alternatives and their explicit representation. Didactic variants have to be subject to discussion and, more systematically, subject to quality assurance. For this purpose, an appropriate didactic design methodology and tool needs to be established.

The current state of affairs in learning in general and in e-learning in particular shows some obvious reluctance to such didactic design. Scientists discuss and learners complain about the insufficient learning adaptability offered to the learners' needs (Schulmeister, 2003).

The employment of dramaturgy and storyboarding seems promising in moving toward qualified guidance for the above didactic design. This is because storyboarding is considered to express the process flow through structured diagrams and, therefore, seems to simplify the representation of structurally complicated alternatives.

However, the current employment of such representations is characterized by misunderstandings. The so-called storyboard concepts in use (Meissner, 2003) are mostly substitutes for technological documents of high-level design, but are not specific to the instructional design process (Gagne, Briggs, & Wager, 1992; Rothwell & Kazanas, 2004). Didactic concepts (Flechsig, 1996; Jank & Meyer, 2002) are not made explicit and, therefore, modeling, evaluating, and refining such didactic issues are not sufficiently enforced. Even quite recent approaches (Schewe & Thalheim, 2004) could not go beyond IT systems. That is, they could not sufficiently consider handling educational contents such as didactics or educational knowledge.

There are contrasting approaches (Forsha, 1994) that are conceptually very useful, but syntactically too different from a workflow directed to technology-enhanced learning implementations. Forsha's storyboards stick to the classic

booklet form of storyboards. They are a linear sequence of pages (called "panels" in Forsha, 1994). Although each page is quite flexible in terms of its content, there is no way to clearly represent and anticipate alternative paths and to use a hierarchical structuring in Forsha's storyboards to support the user's overview of the general structure of the plan of study and alternative choices in it. Purely software-driven concepts avoid such drawbacks. However, they do not provide an opportunity to represent and discuss details of more informal human learning (Bransford, Brown, & Cocking, 2000; Damasio, 1999). Learning is much more than logically formalized memorizing. "Learning imposes new patterns of organization on the brain, and this phenomenon has been confirmed by electro-physiological recordings of the activity of nerve cells" (Bransford et al., 2000, p. 121).

Learning is reasonably understood as an interactive knowledge construction process. Illustrative case studies are discussed in much detail in Davis, Sumara, and Luce-Kapler (2000). Chapter 3B, "Organizing Shapes," for instance, nicely reports a lengthy process of conversation and co-operation between a teacher and his/her students in which a variety of media types, forms of interaction, and learners' activities are dovetailed.

Didactic design implies the anticipation of those teacher-learner communication processes (Flechsig, 1996), and storyboards may provide the expressive power suitable to the didactic design and implementation in the learning processes. This, however, needs to go beyond the limits of software systems specification — the crucial question for innovations in didactic design.

The new storyboarding approach adopted here (Jantke & Knauf, 2005; Knauf, Sakurai, & Tsuruta, 2007) avoids the drawbacks and enjoys the advantages of both kinds of approaches (Forsha-like [1994] and technologically driven approaches). Such storyboarding, as introduced in Jantke & Knauf (2005) and Knauf et al. (2007), is a very general concept. In the context of DLNRS, this storyboarding is expected to complement the currently existing system such as the dynamic syllabus (DS) system or tool.

To illustrate the dependence between the subjects (courses) as well as to propose useful and efficient timetables with respect to the students' needs, this storyboard concept is appropriate.

There is a maze due to dynamically changing opportunities, restrictions, and constraints. These opportunities, restrictions, and constraints are difficult to meet and their changes are difficult to predict. At some point of complexity, humans are not able to understand the rules as characterized above, which are driven by various factors, such as

➢ topical prerequisites, i.e., subjects to complete before taking new ones
➢ mental prerequisites, such as the student's maintaining concentration throughout the class or at certain times of the day
➢ performance requirements, such as a high GPA,
➢ personal aspects (needs, wishes, talents, aims)
➢ organizational aspects (schedules without conflicts in time or location, and without undesired time gaps)
➢ resource management, including money, time, necessary equipment, and textbooks.

However, many explanations of such factors (on a web page, in a textbook, in the schedule) are quite informal and do not really help students to manage a program of study in a way that meets all regulations and the students' learning needs.

In the authors' universities (in Japan and Germany), students often study very ineffectively (too many semesters, few related subjects, and so on) or sometimes even fail in their desired academic career because of not keeping an accurate plan of study and/or not respecting regulations. To make choices in a legal and optimal way is difficult without a method such as this newly proposed storyboarding.

Although this storyboarding application was originally created to introduce e-learning systems, its reach goes far beyond the limits of current e-learning systems. The concept is simple as well as general and allows for modeling the didactics of any learning activities. New storyboards model the didactics behind learning in general and provide appropriate paths in a system of nested graphs, depending on the students' needs. Dynamic storyboarding presented in this paper is expected to contribute to the learning in a wider context than to just a particular subject. This is because it can help students to keep track of both their program of study and the constantly changing opportunities and limitations in university education.

In general, learning activities need to be composed and designed at different levels of detail. For example, a lower level is the design of each lesson or, even lower, the discussion about a particular problem. On the other hand, the storyboard introduced here is of a higher level of detail and covers a complete/whole study in university education.

The larger the scope of learning, the more involved human activities are in the field of management. In other words, by enlarging the scope, the subject modeled by storyboards is extended from just didactics to didactics and management. For example, shifting from a difficult theory to a small example for its explanation is a tactic called didactic decision that can be easily made by the teacher without worrying about resources or about the cooperation of other individuals outside the current situation. On the other hand, inserting an additional subject in a curriculum can have a greater impact on resources such as time and cost. The latter adds strategic or management issues to the tactical or purely didactic (low-level or detail-level) ones in composing or modifying a detailed storyboard.

By adopting the new storyboard concept for a complete university study, even the management of the study becomes accessible for evaluation and refinement, that is, quality assurance.

As a deeper benefit of this work, some data mining can be performed on the paths of particular students after they have completed their studies at Tokyo Denki University. This will answer questions such as: What do the successful students' paths have in common? How do the paths of successful students differ from those of less successful students? This will also allow future students to create curricula with an optimal chance of success.

Before showing how to adapt the new storyboarding concept for the intended application, we provide a short introduction to the DLNR system.

The paper is organized as follows: The next section describes the DLNRS as successfully introduced at SIE of TDU. This is followed by a section on the new storyboard concept as developed so far. After that, we introduce the enhancement of the storyboard concept to support the development of curricula and long-term graduation timetables for effective and target-oriented university studies at TDU. Finally, the suggested approach is summarized, conclusions are derived, and benefits are illustrated.

Dynamic learning need reflection system

Dynamic learning need reflection system (DLNRS) (Dohi & Nakamura, 2003) primarily aims at encouraging the students' motivation by allowing students to create or modify their own class schedule each semester as well as their own graduation timelines. This develops a spirit of independence and keeps up with globalization. Key features of DLNRS are as follows:

➢ **Elimination of the traditional rigid academic year.** There is no academic year with fixed courses (here, a course is an ordered combination of subjects) and a fixed fee. Instead, there is a semester-based system where students can take their preferable subjects or change their course each semester, without restriction by rigid academic year, and pay the fee for each subject. The only restrictions to taking a particular subject in a particular semester are the prerequisites. Thus, the students are able to study at their own adaptive pace.

➢ **Elimination of compulsory subjects.** Compulsory subjects are replaced by the concept of prerequisite conditions. These conditions are expressed in two levels of recommendation: subjects that must be taken beforehand (prerequisites) and subjects recommended to be taken beforehand. The grades given to students in the prerequisite subjects are formally checked.

➢ **Replacement of a fixed charge per year by a subject-based payment system.** Students pay a subject-based fee in proportion to the number of units in each subject. Therefore, they carefully check their learning needs to pick the right subjects to achieve their academic goal at a minimum cost. Furthermore, a subject-based fee motivates them to make the maximum effort in order to pass the subject so that they don't waste money.

➢ **Class length.** The usual length of a class is reduced from 90 minutes to 50 or 75 minutes. Typically, a subject is taught in three units, either as 3×50 minutes or as 2×75 minutes a week. The intended effect is that students will be able to concentrate the entire length of a class. This results in greater learning benefit from the subjects and, thus, more learning for the amount of money spent on a subject.

➢ **Grade Point Average (GPA).** This is a system to rate the learning results, especially to measure the learning quality that students attained. The GPA is calculated by equation 1, with g_i being the points earned for a

particular subject, u being the number of units of the subject, and n being the number of subjects in the semester.

$$(1) \quad GPA = \frac{\sum_{i=1}^{n} u_i g_i}{\sum_{i=1}^{n} u_i}$$

According to equation 2, the number of grade points (*GP*) per subject ranges from 4 (> 80%) to 0 (< 40%).

$$(2) \quad GP = \begin{cases} 4 & , \ if \quad performance = \ [80\%, 100\%] \\ 3 & , \ if \quad performance = \ [70\%, 80\%) \\ 2 & , \ if \quad performance = \ [60\%, 70\%) \\ 1 & , \ if \quad performance = \ [40\%, 60\%) \\ 0 & , \ if \quad performance = \ [0\%, 40\%) \end{cases}$$

The intention of this measure is that the maximum number (n_{max}) of units for which a student can register is controlled by the GPA of the previous semester as shown in equation (3).

$$(3) \quad n_{max} = \begin{cases} 25 & , \ if \quad GPA \geq 3.0 \\ 21 & , \ if \quad 1.0 < GPA < 3.0 \\ 12 & , \ if \quad GPA \leq 1.0 \end{cases}$$

The regulation demonstrated by equation 3 is a result of the experience with students who are not able to self-estimate their capacity. In the trade-off between a high learning quality, indicated by a high GPA, and a high learning quantity, indicated by a high number of units, some students tend to promote the latter at the expense of the former.

Obviously, this is not only a typically Japanese phenomenon, but is also apparent in German universities, judging from the experience of the German author, who reports of students who tend to just pass examinations but do not care about the learning quality.

This extrinsic motivation for examination results usually reveals itself when students feel that they will not necessarily need the subject's topical content in their future career. Therefore, the DLNR contributes to avoiding this phenomenon by either making students open to recognizing the potential future need of the subject's content or encouraging them to refrain from choosing this subject.

The introduction of the DLNRS at the SIE, is supported by a curriculum planning class, which aims to teach the student to develop an individual curriculum that meets his/her needs and desires by him/herself and a workshop that aims to develop an ambience of mutual trust between a professor and his/her students.

Table 1. Unit composition for graduation

Field of the subjects	Units
Introduction to SIE, computer literacy	2
Liberal arts subjects	40
Major subjects	60
Any subjects other than free subjects	22
Σ	124

The relationship among prerequisite conditions GPA and GP, the quantitative unit composition requirement for graduation as shown in Table 1, and other aspects are difficult to obtain and to keep track of Instead of compulsory subjects, there are prerequisite subjects whose GP should not be E level (the lowest rating) for students to register in the related subject. Instead of the traditional rigid academic year, there is a unit composition regulation for graduation as shown in Table 1, where the total number of units that students can register in each semester is regulated based on their GPA of the previous semester, whether the number of units that students can get differs in each subject, and whether or not some subjects have prerequisites.

Furthermore, free subjects, such as those for qualifications to teach in high schools, don't count for the 22 units in the last row of Table 1 because they don't directly contribute to the career itself established by SIE but contribute to other qualifications instead.

To sum up, the development of class schedules and long-term graduation timetables is a quite challenging task.

Indeed, the GPA is a means to control the quantity (the total number of units) of subjects, but it doesn't help the students to select appropriate subjects to achieve their individual goals under the terms of the complicated rules mentioned in the introduction.

On the one hand, there is a combinatorial explosion of opportunities for selecting subjects (e.g., 10 out of 100 possible ones for each class period or each semester). Yet there is a system of constraints that is driven by both topical and quantitative reasons.

Depending on the student's individual academic history (subjects previously taken), the opportunities for a student's academic future (the subjects in the upcoming semester) are narrowed. Here, as shown in Figure 2, the DS can indicate only a direct part of prerequisite subjects for which the prerequisite conditions are not directly met (constraint violation). Meanwhile, the storyboard application (presented later as "dynamic storyboarding") helps keep track of the student's program of study by marking all prerequisite subjects hierarchically, including consecutive prerequisite relations in which the prerequisite conditions are met in multiple stages. For example, prerequisite subjects for each of the subjects of a certain area of study are shown in a multistage hierarchy.

However, practice shows that there still remains a number of possible combinations even after masking the non-options, due to the prerequisite conditions. Fortunately, some combinations require a certain number of units beyond the number allowed by the GPA restriction. Here, again, the storyboard application helps by also masking the non-options resulting from the GPA regulations.

It is really difficult to keep track of the remaining choices in a huge catalogue of subjects after considering the individual combination of topical and quantitative restrictions. Therefore, a dynamic syllabus system has been developed, which supports the students in this complex task by way of the following four-step process:
(1) acquisition of student data (model course, field after graduation, career goal, individual preferences)
(2) selection of subjects
(3) simulation of the schedule
(4) registration for the subjects

Steps 2 and 3 form a repeated process until a satisfactory solution, one that meets all requirements and regulations, is found.

Figure 1. Information on a subject

For each subject, the dynamic syllabus system provides the number of units (the number in brackets, see Figure 1), the particular syllabus of this subject (in a separate window, accessed by clicking on the book icon), and information about the prerequisites, accessed by clicking on the star icon (see Figure 2).

The creation or modification of a class schedule is a complex process of repeated prototyping and simulation with the dynamic syllabus system. Using the system, students can interactively check the syllabus of each semester or, more correctly, just one semester, to verify if prerequisites are met and if there is a time or location conflict or an undesired time gap between classes.

However, the system does not provide an overview of the complete interdependencies nor a long-term schedule that meets the individual students' desires and needs regarding the unit composition rules for graduation shown in Table 1. In fact, the storyboard concept is a way to add this feature to DLNRS. We propose to illustrate the interdependencies among subjects in a dynamic storyboard and thus help the students see and understand these interdependencies. This way, students will have an overview of the prerequisites for each subject. With a view to

future trends, this approach might become consistent with the representation of each student's personal curriculum, including the didactics of its creation. Thus, a storyboard presentation here forms nested storyboards for a complete overview of the academic process toward graduation.

The effects of the DLNRS were investigated through a questionnaire at the end of the curriculum planning course, which was administered to 203 students. The rate of understanding the prerequisite conditions was about 60 percent, which means the method of displaying the prerequisite conditions needs to be improved. The rate of understanding class schedules for a current semester and until graduation was greater than 80 percent. Thus, using the DS tool to compose curricula seems to be effective and will become even more effective if the method for displaying prerequisite conditions is improved. The significantly decreased time frame in which students create their timetable supports this thesis about the DS. More than 50 percent of the students were able to create their class schedules in two hours or less. About 50 percent of the students were not able to complete their class schedule in the curriculum planning class. Those students were given a week to complete it as homework. A total of 162 out of 173 students (96.3 %) were finally able to submit their class schedules.
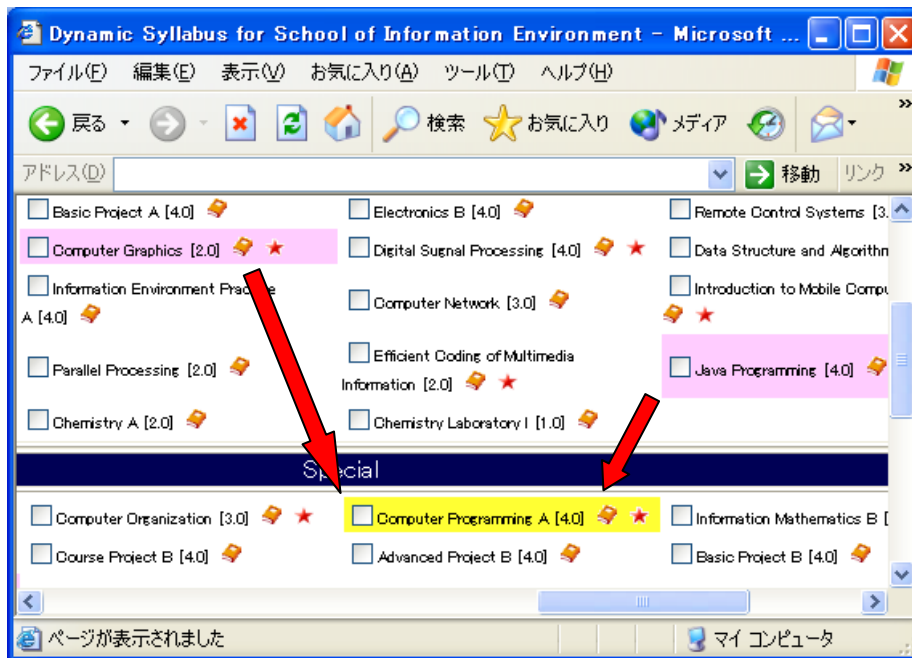

Figure 2. Prerequisite conditions

Two classes under the same conditions, except for GPA and the credit system, were compared: an undergraduate class taught in the new system (DLNRS) and a postgraduate class taught in the old system. The class taught by the new system had no drop-outs, but in the other class, 50 percent of all students had dropped out by mid-semester. Students in both classes had much homework. In the conventional system, students did not need to pay for the class and they were not considered formally registered in the class until they had taken the class examination. Their GPA did not change even if they did not take the examination, that is, if they had dropped the subject. As a consequence, we introduced the GPA and credit mechanisms, which provide a harsh yet not unfair assessment of the students' performance. Students should clarify their learning needs and be moderately controlled so that they can overcome difficulties such as too much homework. Thirty percent of the remaining students in the old system could not pass. Meanwhile, fewer than five percent in the new system failed. This suggests that a shorter class period (50 minutes vs. 150 minutes), a higher frequency (three times per week vs. once a week), and a significant amount of homework for review is effective for learning. However, because of the increased number of shorter classes, students' class schedules became very complicated.

Thus, we suggest supplementing the DLNRS concept with the concept of storyboarding, which we describe in greater detail in the following section. After that, a separate section tells how to adapt this concept to supplement DLNRS (Dohi et al., 2006a; Dohi, Sakurai, Tsuruta, & Knauf, 2006b).

Storyboarding

Roots and related work

Storyboarding as a means to model information and learning processes was introduced around 1998 (Feyer, Schewe, & Thalheim, 1998; Feyer & Thalheim, 1999). One of the first storyboarding languages called SiteLang (Thalheim & Dusterhoft, 2001) was introduced in 2001. However, this language, created to model web information systems (WIS) had related but limited expressivity and suffered from non usability by non-IT experts.

The latter, however, was not a drawback for the application described by Thalheim and Dusterhoft (2001). Chang, Lin, Shih, and Yang (2005) attempted to apply SiteLang for learning processes. However, this application was limited to e-learning only. An application to use that language for the reverse purpose, that is, not to describe WIS but to represent stories or data contents in WIS, was presented by Kaschek, Matthews, Schewe, and Wallace (2003a).

In fact, this work inspired the authors of the present paper to investigate successful didactic patterns with the more general storyboarding approach presented here. However, in the limited application field WIS and e-learning, there was a need to formally distinguish media types (Feyer, Kao, Schewe, & Thalheim, 2000) and to integrate context (Kaschek, Schewe, Thalheim & Zhang, 2003b). A first approach in distinguishing various abstraction layers in storyboards was introduced by Kaschek et al. in 2003a. In Kaschek's publication, a limited number of different layers were modeled by different means. Again, all the mentioned approaches suffer from a lack of generality and from an intended application (e.g., WIS are different from e-learning, which is limited to electronic material or the data in internet sites of WIS).

The new storyboard concept

The storyboard concept newly developed and adopted here (Jantke & Knauf, 2005; Dohi et al., 2006a; Knauf & Jantke, 2006) is built upon standard concepts which enjoy the following:
➢ clarity by providing a high-level modeling approach
➢ simplicity, which enables everybody to become a storyboard author
➢ visual elements such as graphs

With respect to a better formal composition, processing, verification, validation, and refinement, the concept as introduced so far (in Dohi et al., 2006a; Jantke & Knauf, 2005; Jantke, Knauf, & Gonzalez, 2006; Knauf & Jantke, 2006; Knauf et al., 2007) has been refined by Sauerstein (2006), who introduced some modifications aimed at improving the formal verification of knowledge represented by storyboards and the machine support of its usage in practice. In particular, Sauerstein introduced a distinct start node and end node for each graph and bi-colored edges to express, in a graphic way, conditional interdependencies between incoming and outgoing edges of a node.

Here, we adopt above-mentioned modifications. This new storyboard concept is as follows:
➢ A storyboard is a nested hierarchy of directed graphs with annotated nodes and annotated edges.
➢ Nodes are scenes or episodes.
➢ Scenes denote no further structured elements (elements with no sub-graph behind it) of the nesting hierarchy and represent a basic learning activity, which cannot be broken down and can be implemented in any way. The storyboard can be the presentation of a media document, the opening of any other software tool that supports learning, such as a URL and/or an e-learning system or an informal description of the activity. There is no formal representation at or below the scene level.
➢ Episodes denote a sub-graph.
➢ Graphs are interpreted by the paths on which the graphs can be traversed.
➢ There is a start node and an end node for each graph. The start node of a graph defines the starting point of a legal graph traversing. The end node of a graph defines the final point of a legal graph traversing.
➢ Edges denote transitions between nodes. The outgoing edge from a node must have the same color as the incoming edge by which the node was reached; and if there is a condition specified as the edge's key attribute, this condition has to be met for leaving the node by this edge.
➢ Nodes and edges can carry key attributes and/or free attributes (annotations). Key attributes of nodes specify application-driven information that is necessary for all nodes of the same type, such as actors and locations. Key

attributes of edges specify conditions that must be true for continuing traversing on this edge. Free attributes may specify whatever informal information the storyboard author wants the user to know: didactic intentions, useful methods, necessary equipment, and so on.

The interpretations of these terms are described after presenting a small example. Figure 3 shows a top-level storyboard representing the anticipation of the diverse ways to study this paper according to the reader's individual goals. The sections of the paper that are currently under the reader's (your) consideration appear as the storyboard's episodes if the reader has a substructure, and as its scenes if the reader doesn't.
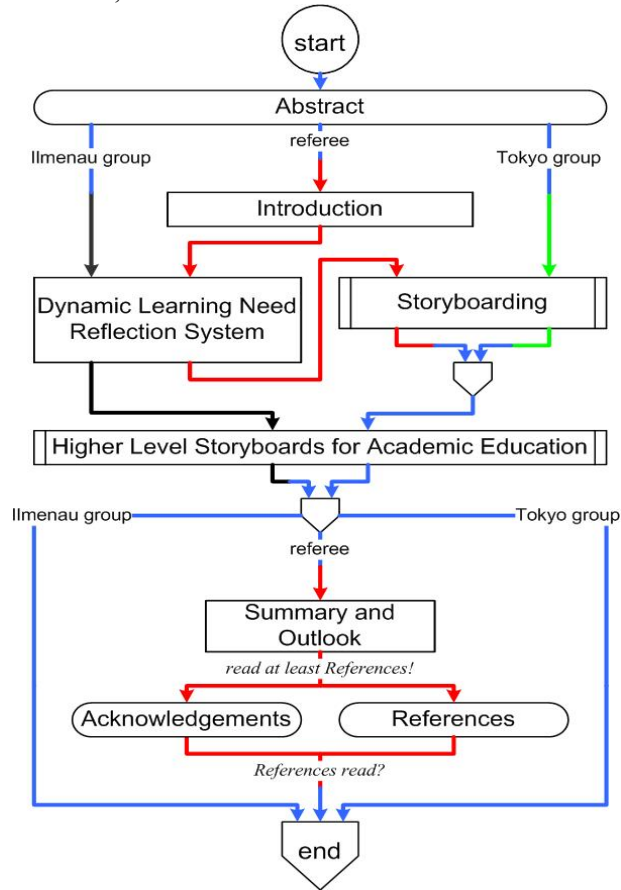
Figure 3. A sample storyboard

Further structured sections are episodes (with subsections). Episodes need to be implemented by constructing a related sub-graph. Episodes are represented by a rectangular with double vertical lines. Each episode is followed by a pentagonal reference node, which is the episode's re-entry point into the graph after the episode has reached the end node of the sub-graph. Sections with no further structure are scenes without subsections and are represented as rectangles. If a scene does not introduce new topical content (such as the reference list), it is represented by an ellipsis.

The representation as a graph (as opposed to a linear sequence of sections) reflects the fact that different readers trace the paper in different ways, according to their particular interests, prerequisites, a current situation (e.g., being under time pressure), and other situations.

The alternative paths may be driven by the reader's role as follows:
➢ Members of the Ilmenau research group may skip the introduction, summary, and outlook sections, as well as the section on the storyboarding concept, because they are familiar with it.
➢ Members of the Tokyo research group may also skip the introduction, summary, and outlook sections as well as the section on the dynamic learning need reflection system, because they are familiar with it.

➢ Referees, on the other hand, may want to read all sections. After reading the summary and outlook sections, they can read the acknowledgements and references independently from each other. Although they don't have to read the acknowledgements, they should read the references at least.

A storyboard can be traversed in different ways, based on users' interests, objectives, and desires; didactic preferences (such as the need for examples or illustrations for better understanding); the sequence of nodes and other storyboards visited before, the availability of resources such as time, money, equipment to present material; and other application-driven situations.

Free attributes were introduced after practical experimental usage showed that much of the information necessary by a user to execute a storyboard cannot be formalized well. However, such informal information is essential for the proper implementation of the storyboard.

The new storyboard is a semi-formal knowledge representation for the didactics of a teaching subject. Informal knowledge represented as free attributes and scenes can be integrated in a formal structure. Because of the formal graph hierarchy above scene level, the storyboard is effective as a firm base for processing, evaluating, and refining this knowledge. The vision of the further effect of these ideas is to gain didactic knowledge by analyzing storyboard paths by means of data mining methods.

Implementation details of the new storyboard concept

The following are supplements to the implementation of the new concept. Some of the features might not be applicable to particular implementation of the storyboards. Many of them are implicit in the general concept. Those details are described only to show implementation feasibility in order for readers to become a little more familiar with our ideas, aims, and intuition.
➢ The nodes called episodes may be expanded into sub-graphs on double click, since storyboards are hierarchically structured graphs by their nature. A double click on the end node of a graph will result in a return to the related reference-node in the related super-graph.
➢ Comments in nodes and edges are intended to carry information about didactics. Comments express goals and variants.
➢ Educational meta-data, such as a degree of difficulty (e.g., basic or advanced) or a style of presentation (e.g., theory-based or illustrated) may be added as key attributes.
➢ Edges may carry conditions as key attributes.
➢ Edges may carry other information about conditions or recommendations.
➢ Certain scenes may represent documents of different media types, such as pictures, videos, PDF files, Power Point slides, Excel tables, and so on.

Clearly, the sophistication of our storyboards can go further. The concept allows for deeply nested structures, comprising different learning knowledge (forms of learning), getting many factors involved (actors, locations, materials) and permitting a large variety of alternatives.

This is intentionally different from all the modeling approaches so far, which are driven by software technology.

In Microsoft Visio (Walker & Eaton, 2004), so-called hyperlinks can be defined on any graphic object either to open a local file of any media type with the appropriate tool or to open the standard browser with a specified URL or mail tool, if it is an e-mail address. These hyperlinks appear as a symbol when the mouse passes over a related node. With a left mouse-key click, the list of hyperlinks shows up. We make use of this opportunity for the scenes and episodes. In this way, the off-line and on-line teaching materials and tools (such as e-learning systems) are collected and structured according to individual paths of users through the storyboard.

Nodes and edges

The nodes types, their visual appearance, their behavior when double-clicked, and their behavior when following a hyperlink, are as specified in Tables 2 through 6.

<div align="center">*Table 2.* Scene</div>

Symbol	
Behavior when double-clicked	• opening a document (*.doc, *.pdf, *.wav, *.vsd, *.ppt, *.xls, etc.) • nothing, if just a verbally described scene
Behavior when following a hyperlink	• opening a document (*.doc, *.pdf, *.wav, *.vsd, *.ppt, *.xls, etc.) • visiting a website with the standard browser, if it is a URL • opening the standard mail tool, if it is an e-mail address

<div align="center">*Table 3.* Episode</div>

Symbol	
Behavior when double clicked	• opening the sub-graph that specifies the episode
Behavior when following a hyperlink	• opening a document (***.doc, *.pdf, *.wav, *.vsd, *.ppt, *.xls , …***) • visiting a website with the standard browser, if it is an URL • opening the standard mail tool, if it is an e-mail address

<div align="center">*Table 4.* Start node</div>

Symbol	**start**
Behavior when double-clicked	jumping to the start node of the related graph
Behavior when following a hyperlink	not applicable

<div align="center">*Table 5.* End node</div>

Symbol	**End**
Behavior when double-clicked	jumping to the reference node that succeeds the associated episode node in the related graph
Behavior when following a hyperlink	not applicable

<div align="center">*Table 6.* Reference node</div>

Symbol	
Behavior when double-clicked	jumping to the end node of the sub-graph that is associated with the preceding episode node
Behavior when following a hyperlink	not applicable

For edges, it is not meaningful to define double-click actions or hyperlinks. The edges are not intended to carry subject content, but are intended to carry didactics of a mandatory, conditioned, or recommended switch between the nodes of the graph. However, the way that the sequence of nodes is defined by edges needs to be defined, particularly in the case of alternatives and forks. As introduced above, there is a rule that an outgoing edge of a node should have the same starting color as the incoming edge of the node. This serves to express conditions for leaving a node that refers to the incoming edge. The sequence of node traversing is defined as specified in Table 7 through Table 10.
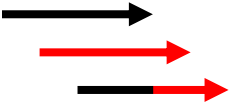
Table 7. Simple edge

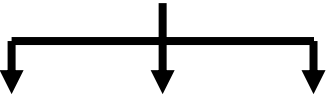| Symbols	
Interpretation	Defines a unique successor node

Table 8. Fork

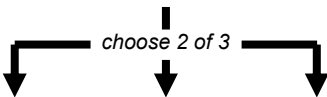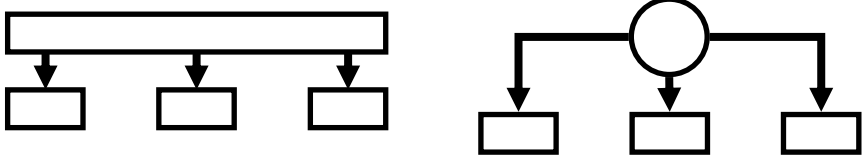| Symbol	
Interpretation	Defines several successor nodes, which have to be traversed independently from each other, i.e., in any sequence or parallel

Table 9. Fork with conditions

Symbol	choose 2 of 3
Interpretation	Defines several successor nodes, which have to be traversed independently from each other, i.e., in any sequence or parallel according to the specified condition, e.g., *take* n *out of* m *specified paths*

Table 10. Alternatives

Symbol	
Interpretation	Defines alternative successor nodes, i.e., one of them has to be traversed

Characteristics of the new storyboard concept

Generally, the basic but important approach behind the new storyboarding is that teaching consists of activity sequences, which can be described by a hierarchy of nested directed graphs.

On the first view, the purpose of our storyboards is similar to the purpose of traditional storyboards that are produced for plays or movies. The materials and tools of the storyboard learning activities such as textbooks, scripts, slides, hardware and software models, e-learning systems, and others are comparable to the props of a play or movie.

However, there are basic differences between the storyboards proposed here and the traditional storyboards used to depict a play or movie. The differences are as follows:
➢ primary purpose (learning vs. entertainment)
➢ degree of formalization
➢ the constraint of everything above the level of scenes, which is not (and should not be) applied to traditional storyboards in performing arts, since the director has some freedom of individual interpretation (which is good for arts, but bad for our purpose)
➢ opportunities to formally represent, process, evaluate, and refine new storyboards, which do not apply at all to storyboards in performing arts

In fact, the last two differences are due to the degree of formalization.

Also, the newly proposed storyboard concept has features in common with the following:

- classic artificial intelligence (AI) knowledge representations such as semantic networks and frames
- process modeling languages
- state diagrams such as Petri nets (see Chang et al., 2005, for examples of their use in learning processes
- workflow diagrams (see Lin, Ho, Orlowska & Sadiq, 2002, for examples of their use in learning processes
- flow charts (see Sykes & Franek, 2003, for examples of their use in learning processes)
- the educational modeling language (EML) (Koper, Hermans, Vogten, Brouns et al., 2000)
- IMS learning design specification (IMS Global Learning Consortium, Inc., 2003)

However, items that make the storyboard concept more expressive for didactic knowledge than do the conventional representations mentioned above are as follows:
- the potentially unlimited nesting of graphs
- the opportunity to express "conditioned" edges by using the colors or respective key annotations to edges
- the opportunity to use two kinds of fork-edges
- the potential of nodes to carry many different teaching materials and tools as hyperlinks,
- the fact that a scene can be implemented in any way, i.e., a scene is not restricted to something electronically available or even formally structured, such as any knowledge representations in AI, and any material that may be included in process models
- free attributes are not restricted to formal information

A good example of the usefulness of hyperlinks is a storyboard by Knauf (Knauf & Jantke, 2006) for an AI course at a US university, which included hyperlinks to material from his own AI course in Germany. Now, this storyboard serves both Knauf's university and the US university for which the storyboard was originally developed, and is also a common platform for internationally sharing teaching materials.

Furthermore, at a first glance, storyboards are quite similar to modeling approaches that are usual in software engineering, such as Petri nets and other process modeling languages. However, these languages are completely formal. There is no room to represent informal parts of didactics knowledge.

Clearly, the scenes of our storyboards define this level. A scene can be anything (media content, an informal activity description, etc.). There is no formalism at or below this level.

In the application that this paper focuses on, there is still a chance to refine the granularity through storyboarding the topics of the study. At some point, we can't go deeper. There is no way to formalize a movie or a song, for example. However, such media content needs to be involved in the learning processes. Consequently, a hybrid knowledge/media representation through storyboarding needs to be used for (semi-)formalizing the didactics of learning processes.

Dynamic storyboarding for modeling academic education

High-level dynamic usage of new storyboards for modeling academic education

The above-mentioned new storyboards can be used to represent the didactics or tutorial knowledge of academic education, especially of DLNR. Through this, learning plans have several advantages. Examples are students' curriculum plans for their academic career. Besides being visual in nature, these curriculum plans are formally created and can also be dynamically verified and modified each semester.

In order to optimize the new storyboard concept for an academic graduation path, we propose a new method of storyboard use: a high-level use that we call dynamic storyboarding. The results of a feasibility study are shown here.

In dynamic storyboarding, subjects to be taught are represented as scenes. In the original storyboarding, subjects are represented as top-level episodes.

In learning plans, namely curriculum plans, some high-level structure (i.e., episodes) lies above the subject level.
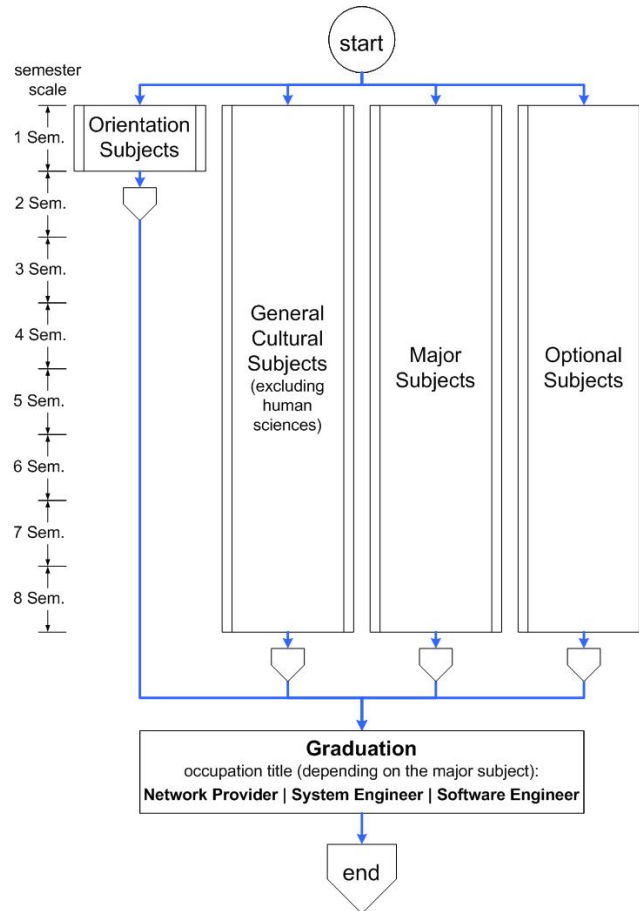
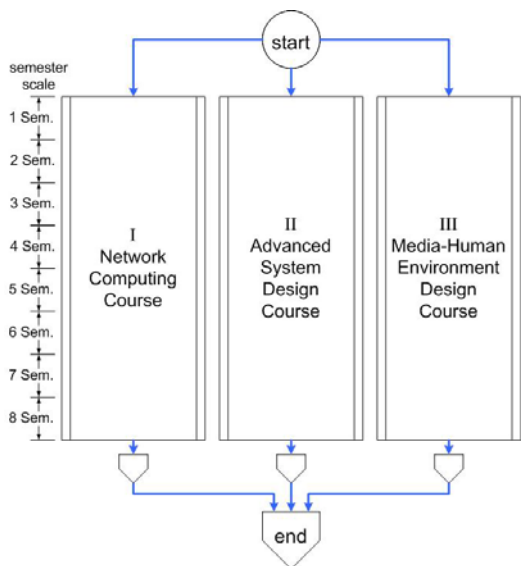*Figure 4*. Top-level storyboard for graduation ("Sem." means "semester")

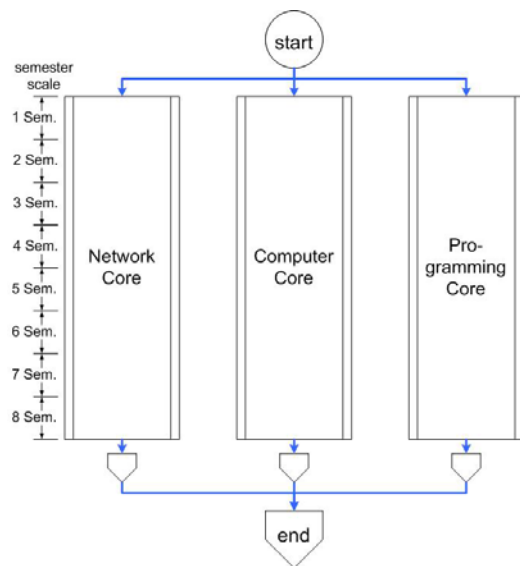*Figure 5*. Alternative major subjects

Figure 6. Network computing course

As shown in Figures 4 through 8, dynamic storyboarding provides a chance to make explicit the high-level complex and dynamic education structure of university study. This makes a complex and dynamic education structure more understandable to students.

Yet, if necessary, this storyboard can also be refined later through exchanging a scene representing a subject for an episode and through storyboarding (expanding the episode hierarchically into sub-episodes, sub-sub-episodes, etc. and/or scenes representing content or syllabi). Here, each episode representing a subject is defined as sub-graphs by the professor or tutor in charge of the subject.

This paper is expected to lead us towards multilayered, high-level, and dynamic storyboarding, which is useful for university study. As shown in Figure 4 at the top-level and in Figures 5 through 7 at the lower level, it is easier to get an overview by nesting the storyboard graphs using episodes throughout all levels except for the lowest. This overview cannot be provided by any printed document commonly used.

In some dynamic storyboards, as shown in Figures 4 through 7, there is a semester scale at the left-hand side of each graph. This shows a time sequence of semesters. The group of subjects at the right side of each semester in the scale should be taken as the curriculum of a semester.

At SIE of TDU, the education based on the DLNR concept is very adaptable to students' needs, but the cost of this feature is a complex system of conditions to meet. The regulations on composing a curriculum for studying subjects at SIE are as follows:

➢ The subjects to study are grouped into four subject blocks (as explained in the section describing DLNR and summarized in Table 1): major subjects (specialized subjects most related to one's graduation path); general cultural subjects (liberal arts related subjects); optional subjects (less related but specialized subjects, cultural subjects, or free subjects); and orientation subjects (which introduce students to the new study system DLNRS and to computer operation).

➢ This is storyboarded quite simply, as shown in Figure 4. Of course, at this level all nodes but graduation ceremony are episodes that are further storyboarded or structurally expanded.

➢ As illustrated in the storyboard graph shown in Figure 5, the study of major subjects can be performed in one of three subject groups called courses, namely network computing, advanced system design, and media human environment design.

➢ Each course is composed of several cores. For example, the network computing course consists of the following three cores (see Figure 6), namely the network core, the computer core, and the programming core.

➢ With regard to nesting, each core contains about 60 units of recommended major or specialized subjects. Some of the subjects belong to more than one core.

➢ For the other two general cores, (a) at least two units of orientation subjects and (b) 40 units of general cultural subjects (liberal arts and related subjects) are indispensable for graduation.

➢ Twenty-two other units of any subjects less related to the selected course or career are recommended for graduation. Optional subjects can be taken but not counted as any unit or credit.

This situation calls for a representation in nested structures. To show the complexity for requesting the nested structure, Figure 7 illustrates the subjects and their relationship within the network core. It shows only the precondition prerequisite edges that are relevant for a particular student. The introduction of the dummy node "summing-up" is an idea for a mechanism to process the information of all nodes in this sub-graph and to avoid too many edges from every node in the figure. The processing is, for example, to add units of all succeeded subjects in the sub-graph and to check if the graduation conditions for these subjects are met. As described later, such results are passed on to the super-graph (i.e., network core, network computing course) of the sub-graph. This introduction also helps students see the big picture.

Meanwhile, Figure 8 shows the general dynamic storyboard on learning English with fewer semester restrictions or with a loosely fixed sequence of subjects before the storyboard is simplified according to the particular student's situations. Therefore, unlike in the master dynamic storyboards in Figure 4 through Figure 7, there is no semester scale at the left-hand side of the Figure 8 graph, even though this is a sub-sub-graph expanded from the episode of general cultural subjects (see also Figure 4). Figure 8 illustrates that students do not strictly depend on a fixed sequence of subjects. In accordance with their individual needs (for example, an upcoming internship abroad) and their situations (for example, a time gap in the current curriculum that should be filled for effective study), students

may take subjects such as practical English and/or technical English before taking the two English II subjects. However, if they do so, they have to make up these subjects afterwards, when they need more units in liberal arts subjects for graduation. This is illustrated by the bi-colored edges.
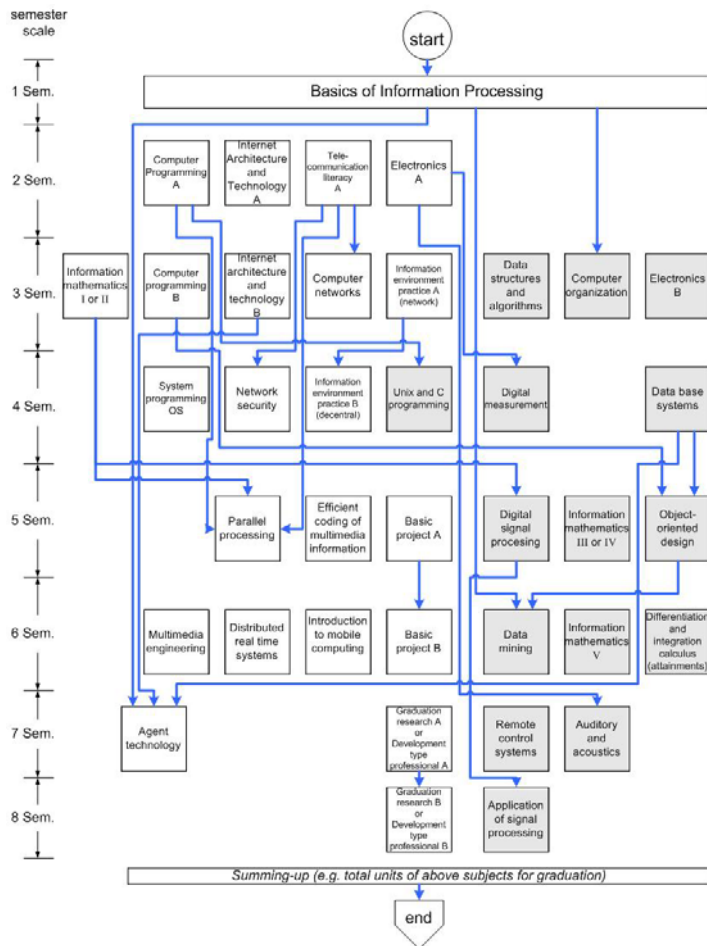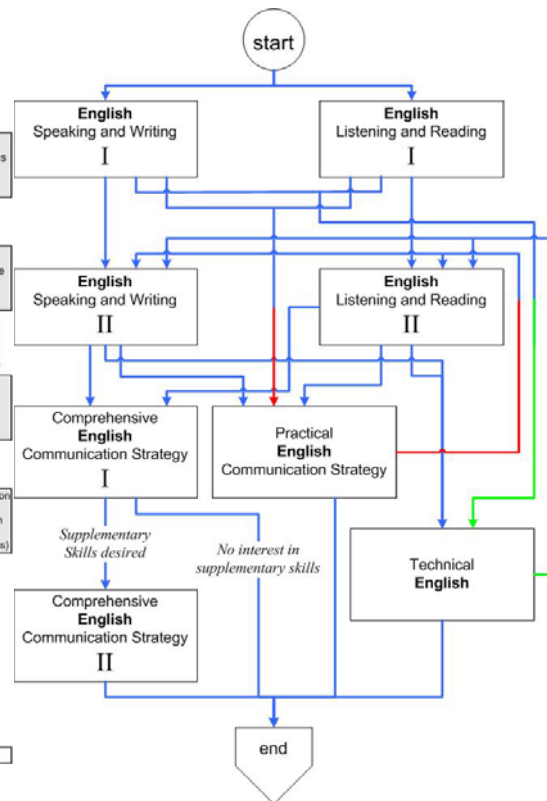

Figure 7. Subjects of the network core

Figure 8. English-language subjects

In addition, dynamic storyboards need to be more individual and dynamic than general or master-level storyboards because the composition of a learning plan for academic education depends not only on general regulations (such as in master dynamic storyboards) but also on individual dynamic facts, as follows:

➢ Individual goals, such as a company to serve, a position to reach, an individual talent to support, an amount of money to make)

➢ pre-conditions, such as a prerequisites, a required level of success in the preceding semester or in the school-leaving examinations before entering university, equipment such as a notebook or car, proficiency in a particular language, or resources such as money or time to attend the class

➢ talent, such as creativity, analytical skills, leadership skills, or athletic ability

For example at SIE of TDU, there is a system of grade-point average that limits the number of units an individual student can register in an upcoming semester (see section 2) and, as a result, narrows the individual student's storyboard for an upcoming semester.

Thus, in order to take individuality and dynamics into account when composing a high-level dynamic storyboard for academic education, factors such as career goals, pre-conditions, current or previous semester's GPA, etc. are necessary. These factors, which are key attributes or annotations in dynamic storyboards, should be formalized and associated with both the related episodes and the students.

The dynamic storyboarding system can analyze these annotations or attributes such as the unit number or grade points attached to subjects as well as the annotations or attributes attached to students, such as the achieved GPA. After each semester, high-level dynamic storyboards can be individualized and dynamically updated according to their new status.

Through temporarily omitting or hiding those items already traversed or not focused on by the student (e.g., Figure 7 shows only prerequisite edges along with their subject nodes and hides others) and items unnecessary or impossible to traverse (because they are outside of the student's area of interest or not useful for his/her career, or because of the student's low GPA in the previous semester), the storyboard is dynamically updated each semester and becomes easier for students to keep track of their program.

Thus, dynamic storyboarding is helpful for supporting the individual planning of the study. As well, it ensures that the plan satisfies students' goals and all related regulations.

Benefits through multilayered nature of dynamic storyboarding for universities

Based on the multilayered nature of dynamic storyboarding, namely, through nesting the dynamic storyboard graph, the students obtain an overview of the structure of their study and its variety of options and enjoy the graphical representation of the interdependencies of the various subjects. One graph contains a number of nodes that are easy to track. In case the graph becomes too complicated, a new nesting level is introduced. Thus, this representation is much better than any textual or tabular representations such as DS (Dohi & Nakamura, 2003) of subject interdependencies.

Resulting from these general effects of dynamic storyboarding, the "space of opportunities or selections" becomes a "space" and is no longer represented as merely a flat list or a table. Since such a structural and graphical representation is much easier to interpret by humans, students get to know this space much more thoroughly. Thus, they can come up with new ideas to compose their subjects in a way that meets both the university's regulations and the student's individual settings, such as their learning needs, learning preferences, career goals, and so on.

The fundamental benefit of dynamic storyboarding for students is that they can enjoy a much better overview of options (or alternatives) and possible ways to obtain individual dynamic plans of more flexible but more mazy university study than before. This is because the storyboard graphs can hide sub-graph structures of episodes, revealing them only on request (double-click), and the student is not bombarded with undesired information. Before, students used textual descriptions about the content of the subjects, pre-conditions for each subject, constraints regarding individual GPAs, and so on. The graphical representation and automatic reduction by dynamically masking the individually impossible options according to each student's individual situation is a remarkable advantage for maintaining an overview of the maze of dynamically changing opportunities and constraints mentioned previously.

Due to the remarkable advantage of the above-stated dynamic overview capability, the dynamic storyboard is useful for long-term planning (over several semesters). Meanwhile, the dynamic syllabus (DS) tool introduced earlier as a part of the DLNR system is a planning tool for a particular semester. These benefits of dynamic storyboarding are concretely explained below.

Let's consider a student, who
- ➢ developed a storyboard such as Figure 7 (but a slightly different sub-storyboard of it that doesn't contain all its scenes) during his/her curriculum planning class,
- ➢ finished the third semester with a GPA that allows him/her to follow the long-term plan without restrictions as to the number of units achieved, and
- ➢ did not change this plan by learning need reflection (if his/her GPA is low, this might happen by dynamically changing his/her career goals).

For the student's fourth semester, he/she is strongly advised to take the recommended subjects (denoted as scenes with a white background in Figure 7), as follows:
- ➢ system programming /OS (operating systems)

- ➢ network security
- ➢ information environment practice B

As well, the student is advised to take the less recommended subjects (denoted by scenes with a grey background), as follows:
- ➢ Unix and C programming
- ➢ digital measurement
- ➢ database systems

Finally, if these recommendations are accepted by the student, the aforementioned six subjects are sent to the DS to register a semester schedule for the fourth semester. However, each of subjects, which is a starting point of a prerequisite edge for the fifth or a later semester, remains in the dynamic storyboards as shown in Figure 7.

Further, the dynamic storyboard system is able to check or suggest an individually optimal curriculum by manually providing individual interests such as desired courses (e.g., network computing and advanced system design), interesting cores e.g., network, computer programming, or a certain preferred application domain), and individual career goals such as vocation names (e.g., a network engineer, interior designer, a preferred position level, a preferred enterprise, or a preferred location of a future entrepreneur) as well as by automatically including individual educational data from the electronic data processing (EDP) system such as the GPA history of previous semesters and the results of entrance examinations and/or preparatory education examinations.

In fact, the above-mentioned individual learning needs may dynamically change during the course of study. Thus, the curriculum will also change over the upcoming semesters. The change from one semester to the next is usually not serious. However, over many semesters, the course of study may come to look quite different from the original plan submitted in the first semester.

Difficult subjects such as mathematics and English often tend to decrease a student's GPA. These subjects are included automatically (but minimally) by the EDP system, based on students' previously achieved GPA and level.

Suggestions for successful learning patterns for students who want to become network engineers are illustrated in Figure 4 through Figure 7. Figure 7 is a particularly good example.

Manually collected information comes into the system through a related interactive webpage and is incorporated into the curriculum creation support system using a Prolog-based (inference) program. Automatically collected data is provided by the university administration's own EDP system and is also incorporated into the curriculum creation support system using a Prolog-based (inference) program.

The processing or inference mechanism in Prolog is based on the storyboard represented by facts for the following predicates:
- ➢ includes(graph , [<elements>])
- ➢ edge([<begin>] , [<end>] , [<color> , <color>])

Here, the predicate includes the elements (scenes, episodes, start nodes, end nodes, and reference nodes) of each particular graph of the nested graph hierarchy. There is one fact for each graph in the knowledge base along with a list of its elements.

Also, each edge is specified by a related fact. Since edges may have several start nodes and/or end nodes (such as the forked edge in Table 8, and its counterpart or a joining edge that re-unite the forked paths), the starting node and ending node of each edge are represented as a list of nodes. In case of simple edges, there may be just one element. Since edges may be bi-colored (see Table 7), the edge's colors are specified by a list of two elements that are identical in case of single-colored edges.

Based on such a storyboard representation, an individual curriculum can be automatically checked, edited, and displayed by a kind of artificial intelligence program or inference program. The individual curriculum suggestions are sub-storyboards, that is, dynamic storyboards that are derived from the more complete storyboard by omitting

nodes and edges that don't match the student's individual situation or request (such as learning needs, learning preferences, career goals, the previous semester's GPA, and so on).

In the case of automatic curriculum suggestions based on this storyboard representation, the top predicate of the inference looks as follows:

```
compose curriculum (Student)        :-                        /* suggests an individual sub-storyboard for a student */
collect information (Student, database, StudentsInfoList),  /* collects information via a web interface */
collect information (Student, EDP, EDPInfoList ),          /* collects information from an EDP system */
process (StudentsInfoList, EDPInfoList ),                  /* derives an individual sub-storyboard */
present result (Student ).                                 /* presents the result of the composition */
```

"Student" refers to a student's unique identification, "database" refers to information that a student has manually input via a related web interface.

The predicate "collect_information" gathers the information needed to compose the sub-storyboard. Depending on the type of information this predicate is called twice in the above Prolog-rule. Once to receive the manually input data from a database and once to receive the data automatically input by the EDP system.

The predicate "process" produces facts similar to those that represent the complete storyboard, but contain the student's identification:

➢ includes (Student , graph , [<elements>])
➢ edge (Student , [<begin>] , [<end>] , [<color> , <color>])

These facts represent the student's individual sub-storyboard.

The predicate "present result" calls a program, which graphically presents the derived sub-storyboard.

For example, in the case of the dynamic storyboard of the studies offered by SIE of TDU, our experiments indicate that these sub-storyboards are basically unique sequences with only a few remaining options. Namely, there are only a few different options left after all nodes and edges that were inappropriate, not possible, or not useful for an actual student were automatically omitted. Having few options left is key to maintaining an overview of the maze of opportunities. By narrowing down the options, students can manually make their individual choices in the maze of dynamically changing opportunities and constraints. Dynamic storyboarding has such benefits.

The results so far are quite promising. Several (at least five) students of SIE in TDU joined the experiment to prove the benefits mentioned above. The students confirmed that this approach is helpful in creating individually tailored and optimized curricula. Indeed, due to the multilayered overview nature of dynamic storyboarding, students could easily create their individual storyboard or curriculum. Meanwhile, teachers created, displayed, checked, and modified general or master dynamic storyboards using Microsoft Visio (Walker & Eaton, 2004) for the storyboard (usually for representing the syllabus of subjects) mentioned previously in the subsection "The new storyboard concept" of the "Storyboarding" section.

Using Microsoft Visio, teachers created, checked, and modified master storyboards. Such master storyboards are initially prepared so that students can use them for easy selection and combination (called individualization) of their needed, permitted, and preferable subjects in their specified program of study. Here, the model is represented at the master level of dynamic storyboards. The master dynamic storyboards are pre-generated by teachers using Microsoft Visio as the master knowledge base, displayed by the system, and checked/modified by students. The modification input by students make the master dynamic storyboards into individual dynamic storyboards with regulations such as prerequisite conditions and recommendations satisfied by the support of the system's checks, warnings, and suggestions.

The system checks the regulations using the data, including regulations and students' achievements such as GPA and subjects passed. The data are sent from the EDP system using the Prolog-based program as mentioned above.

The concrete procedure and interaction among the system, students, and teachers derive useful information for high-level, complex education support to create individual curriculum. In this experiment, the system is called the individual curriculum creation support system (ICCSS), which uses the Prolog-based program.

Using ICCSS, teachers generate master dynamic storyboards that represent curriculum creating didactics. The master dynamic storyboards are utilized to create students' individual curriculum easily. Teachers draw their subjects' master storyboards by using Microsoft Visio. More concretely, such master dynamic storyboards are derived from general dynamic storyboards, such as those shown in Figure 8, which were initially made by teachers using ICCSS and Visio. ICCSS verifies and displays the master dynamic storyboards as nested hierarchical diagrams such as those in Figure 4 through Figure 7. This allows teachers and students to easily view and check the entire storyboard. Once verified by teachers, the master dynamic storyboards are stored in the ICCSS and used by the students for curriculum planning as follows:

1. **ICCSS loads students' information.** When students enter or log in to ICCSS, it loads and displays the master dynamic storyboards or the previously created and/or partly executed individual dynamic storyboards according to the students' login information. ICCSS also loads students' personal data, such as their affiliations or achievements from the administration's own EDP system.
2. **Students select their related course/path from the master storyboards using the multilayered overview.** Students and/or ICCSS select the related path or thread from the master or previously created dynamic storyboards (Figures 4–7), which have been loaded and displayed hierarchically to allow students to obtain an overview of complicated education didactics, which includes subject groups (from Figure 4), courses (from Figure 5), core courses (from Figure 6), and subjects (from Figure 7) that they prefer or need to fulfill their academic goals or vocations after graduation. This selection is done semi-automatically. Using the information loaded in step 1, ICCSS automatically suggests the subject group courses, core courses, and subjects for students to confirm or change. Later, in step 4 and step 5, the recommendations by ICCSS and the selections by students are described in further detail.
3. **ICCSS indicates students' dynamic status diagrammatically.** ICCSS indicates the current semester, subjects already passed, credits obtained, credits necessary to graduate, etc. on the dynamic storyboard.
4. **ICCSS highlights recommendations on the dynamic storyboards.** ICCSS further contributes to students' curriculum creation by automatically suggesting the recommended combination of subjects and highlighting them on the dynamic storyboards, as shown in Figure 7. The system does this dynamic recommendation by automatically checking didactics such as prerequisite/recommended subjects in the storyboard loaded in step 1, and dynamic factors such as students' GPA from the previous semester, the number of credits required for graduation, etc. that have been loaded from the administration's EDP system.
5. **Students select unnecessary subjects, referred to ICCSS's dynamic indication.** Students manually select unnecessary or un-preferable subjects to make their own curriculum. In such instances, ICCSS stops highlighting selected subjects as well as those whose prerequisite subjects are deemed unnecessary, and makes them light-colored and changes the regulation/recommendation information as well. Of course, students can override the results or can select mandatory or preferable subjects from the unnecessary subjects, which are marked by a light color. Then, ICCSS highlights the selected subjects and light-colored subjects whose prerequisite subjects were deemed necessary.
6. **ICCSS verifies and displays the resulting individual storyboard.** When students finish their selections (individualization) and store the results for the semester or all semesters until graduation, ICCSS verifies the results. ICCSS also displays the resulting dynamic storyboards as nested hierarchical diagrams so that teachers and students can view the results and check them for accuracy. The verified storyboards are stored by ICCSS as knowledge or didactics for subsequent curriculum recommendations. Thus, after totally checking, displaying, and saving the dynamic storyboard representing student's own individual curriculum, ICCSS sends the information necessary for administration, such as students' ID numbers registered subjects, to the EDP system.

Before using the ICCSS system, students could never adequately check if these combinations (the students' individually created curricula) followed the recommendations based upon their achievements in previous semesters. However, due to the automatic suggestion and verification described in the processes step 2 through step 6, especially step 4 through step 6, these student-created curricula match their individual situations, including abilities, desires, and restrictions much better than traditional curricula do.

Meanwhile, teachers also benefit from this approach when they create general or master dynamic storyboards as well as receive the curricula that have been composed by the students based on their individual settings. Teachers can

much more easily estimate the usefulness of the submitted plans because it is easy to obtain an overview of the plans. Moreover, the overview makes it easier for the teacher and school administration to logically decide whether the specified subject compositions are really what the students intended to specify. In other words, storyboards are used to logically evaluate specifications involved with various restrictions, especially for long-term plans. In particular, through the dynamic storyboarding system, the curricula can be checked unconsciously or even against the intentions of the system users.

While these benefits are based on better knowledge processing by students, teachers, and school administration staff, the knowledge formally represented in dynamic storyboards can be used for more advanced knowledge processing by machines. This is outlined in the next section as benefits of the formal nature of dynamic storyboarding.

As described above, the dynamic storyboarding was found to be successful in supplementing DLNRS. That is, didactic knowledge in the flexible but complicated DLNRS proved to be easily and clearly represented by high-level dynamic storyboarding. Storyboards are represented as hierarchical graphs without a particular implementation tool to support their use by machine. Even at this early stage of introducing the storyboard or dynamic storyboarding technology, students already enjoy its benefits. Students can study more effectively by individually determining the subjects and their sequence based on their dynamically changing needs and circumstances. Namely, the dynamic storyboarding adaptively assists or guides students through the multilayered overview of an individual curriculum in the maze of opportunities and limitations, and beyond by improving quality management of complicated academic programs. The latter is described more in detail as follows.

Benefits of the formal nature of dynamic storyboarding for universities

The proposed dynamic storyboarding also has some promising benefits because of increased use of AI methods that are implemented as Prolog programs based on the abovementioned formal representation of dynamic storyboards.

The first benefit is that dynamic storyboarding increases logical reliability, such as consistency, completeness, and so on. To ensure consistency and completeness of our storyboards, several verification procedures were developed and implemented (Sauerstein, 2006):
1. A test for the correctness of the graph hierarchy focuses on questions as follows:
   - Does every episode have exactly one related graph?
   - Does every sub-graph have exactly one related episode node in exactly one related super-graph?
2. Reachability issues for each node are formally checked:
   - Does every traversing path terminate? (In other words: Is the end node reachable on every possible path in each sub-graph?)
   - Is every node reachable from the start node in every sub-graph?
3. Completeness and non-contradictoriness of alternative outgoing edges with the same beginning color are checked by logically analyzing conditions expressed as annotations of each node's outgoing edges with the same start color.
4. Edge colors, which express incoming/outgoing conditions, are verifying through checking the following issues:
   - Is there a unique start color? The start node's outgoing edges should have a unique color. A start node has no incoming edge, so if the outgoing edges have different colors, it is difficult to know which edge is to go out from the start node.
   - Is there at least one outgoing edge with the same beginning color for each incoming edge's finishing colors?

These verification procedures are useful for composing the general dynamic storyboard. This one represents all possible combinations of recommended subjects and their sequences, which makes it somewhat complicated. Since the individual plans are derived from the general or complete dynamic storyboard, it is important that the general dynamic storyboard is free from errors such as logical anomalies (non-reachable nodes, for example).

A second benefit is the inheritance concept that was implemented within the graph hierarchy, which distinguishes several inheritance types such as sum, maximum, or set union (Xu, 2006). This is a deductive inference over the knowledge represented as dynamic storyboards. Because of this, some features of an episode are inherited from the nodes in the related sub-graph. For example, already achieved units (e.g., in major subjects) are totalled and checked

(e.g., for graduation) using such inheritance features. Thus, students can know which of the three cores (network, computer, or programming) is most difficult, since the feature "difficulty" can be a key attribute of each node, as shown in Figure 6 by the nodes in the sub-graph. There are different ways through each core, with different levels of difficulty. The maximum value indicating the worst or most difficult case can also be found at an even higher level. Further, the following information can also be passed from each graph to its super-graph by selecting the maximum value of the graph's nodes the: Which is the less expensive one? the less time-consuming one (in terms of how many units are needed to finish a certain core, for example)? and so on.

The third benefit is a set of reliable operations, defined below, that incorporate features such as checking for logic. Their exhaustive use automatically leads to a legal dynamic storyboard. This ensures that the students' own curricula will be more reliable and free from logical anomalies so that students can enjoy a flexible but mazy university education. These operations are:

➤ adding paths
➤ adding nodes
➤ changing scenes to episodes by introducing a related sub-graph
➤ adding a concurrent path
➤ merging equivalent nodes by introducing related bi-colored edges to make sure that the linkage with the remaining graph isn't changed.
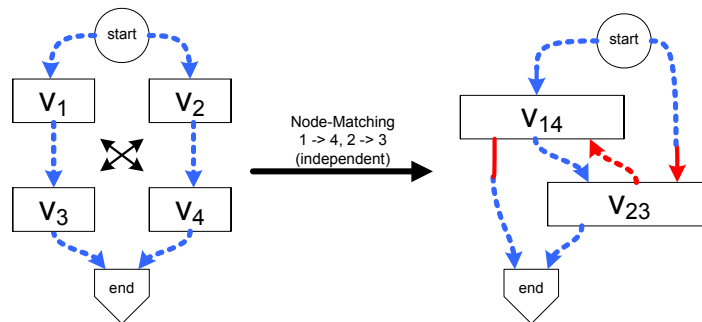

Figure 9. Merging equivalent nodes

Since the last of these operations might not be easy to understand and imagine, it is illustrated in Figure 9. Here, V_1 and V_4 are equivalent, and V_2 and V_3 are equivalent. Since different users visit V_1, V_2, V_3 and V_4 in different sequences, they are represented as different nodes on the left-hand side. By introducing a new color to express these different sequences, the equivalent nodes can be merged together.

The fourth benefit of the dynamic storyboarding is the fact that it is easy to learn because it formally represents of knowledge for university study. Since students at SIE of TDU create or modify their own timetables as mentioned before, dynamic storyboarding is expected to be effective.

A basic approach is to use AI technologies such as data mining and case-based reasoning on these formal process models for learning successful storyboard patterns and recommendable paths. This learning is based on an analysis of the paths on which former students went through the storyboard and is also based on their success that associated with these particular paths (Boeck, 2007).

The introduced storyboarding approach is very useful in assisting students suffering from the maze of opportunities and constraints in university education. More concretely, a simple prototype was recently developed to evaluate curricula created or modified by the students in advance of their study (Boeck, 2007). The basic idea is as follows:

➤ The construction and successive refinement of a decision tree based on paths that have been taken by former students, that is, paths with the students' known level of success.
➤ The application of the decision tree to estimate the possibility of success of a planned path, where current and future students want to go. Moreover, Boeck (2007) introduces a technology to supplement a given curriculum that leads to an optimum chance of success. By simulation, we found that at least half of the planned schedules have the potential to be refined towards a plan with a higher chance of success.

In greater detail, the construction of the decision tree is based on former students' paths represented as dynamic storyboards that model the opportunities or selections. Namely, from the space, the students take a particular path represented as a dynamic storyboard. Each of these paths can be associated with the degree of success that has been achieved by these students. In case a set of students choose the same path, the degree of success can be estimated by the average degree of success of all students that traverse this path.

In particular, this path begins at the start node of the top-level storyboard and terminates at its end node. Each episode on this path is replaced by its sub-graph. This replacement continues throughout the entire hierarchy of nested graphs. As a result, such a path contains atomic scenes only (Boeck, 2007).

Each scene of this dynamic storyboard for the education of SIE of DLNR represents subjects for which students can register. Figuratively speaking, the decision tree is constructed on the basis of a flattened storyboard. "Flattened," in this context, means the graph is hierarchically collapsed to just one level with no sub-graph.

The decision tree is based on the concept of bundling common starting sequences (Boeck, 2007) of the various paths to a node of the tree. In Boeck, these starting sequences are called the least common denominator. Of course, all paths traversed by the students begin with the start node that forms the root of the decision tree. Different subsequent nodes of the paths will result in different sub-trees below the actual root on the last node of the common starting sequence. This continues for each lower level sub-tree accordingly. If there are different paths with a common starting sequence from the root to the actual node different in the subsequent nodes, related sub-trees will be established.

Each node in the tree that represents a final node of a path is followed by a label node. Label nodes contain a list of marks that students receive after going through this path. Each mark appears with the number of occurrences (the number of students getting the mark). Additionally, the weighted arithmetic average value of these marks (GAM— "Gewichtetes Arithmetisches Mittel" in German) (Boeck, 2007) is also attached to this label. The value of GAM serves as an estimate of the chance of success for future students who plan to follow the same path.

The application of the decision tree, which contains knowledge gained by data mining of storyboard paths, is as follows: If a student submits a curriculum plan that is already represented in the decision tree (as a path from its root to a node that is succeeded by a label node), the prediction or estimation is very easily done by presenting the content of this label.

On the other hand, if a student submits a curriculum plan that is not represented in the decision tree, the most similar sub-path in the decision tree will be identified. In this context, similarity refers to the number of same subjects in the common part of paths that are represented in the tree. In other words, those paths in the decision tree that have the longest leading (starting and subsequent) parts in common with the path representing the submitted curriculum plan will be identified. The last node of this common starting sequence of the common leading part forms the root of several sub-trees that represent remaining paths. They are different from the submitted remaining path. The GAM value is used to estimate the chances of success.

Of course, in such a case, the student may be interested in suggestions to modify the submitted path in a way that the chances for success reach an optimum or become highest in value. For example, it is suggested that students substitute the submitted remaining path by the most successful alternative remaining path with the best GAM value among the remaining paths in the decision tree whose common leading part is the longest.

Based on this modification suggestion for the submitted path, the student can decide whether to keep the submitted curriculum or modify it in accordance with the optimization result by considering the chance of success.

Due to the benefits of the formal nature of dynamic storyboarding, which improves quality management of complicated academic programs, students are assisted and guided in the maze of opportunities. Namely, the quality of complicated academic programs or students' curriculum plans can be improved incrementally through validation (looking at the students' success chance) and refinement (restructuring the storyboards in a way that paths with bad results are removed).

Thus, academic education modeling by dynamic storyboarding opens the door for applying AI technologies such as data mining to estimate chances of success and classic inductive reasoning to derive successful didactic patterns. Didactics of teaching university subjects has not been modeled so far. As a result, dynamic storyboarding is considered effective as a modeling approach for academic education, because of the following:

- ➢ formality (causing the applicability of reasoning methods whose effects include abovementioned estimation of success chances and derivation of successful didactic patterns as well as logical reliability of complicated academic programs or students' curriculum plans)
- ➢ clarity (being simple enough to be applied without particular software tools by every university teacher and student—not only by computer scientists)
- ➢ visibility (hierarchical graph representations [instead of tables, for example] that make it easier for teachers and students to obtain an overview of the flexible but complicated university education or programs).

Summary and outlook

In contrast to basic education, such as that of primary and secondary schools, academic education at universities is characterized by a large variety of dynamically changing opportunities to compose academic timelines or class schedules and teachers (professors and tutors) who are usually experts in their subject but do not necessarily have the didactic skills to teach. In particular, at the School of Information Environment (SIE) of Tokyo Denki University (TDU), students are required to be more flexible in designing their study according to their dynamically changing needs, wishes, interests, and talents.

However, in university education, there are usually requirements and rules to guarantee a certain level of academic quality. These rules are often complex, possibly dynamic in some aspects, and difficult to keep track of. A remarkable number of students, at least those of some universities in Germany and Japan, suffer from violating such regulations. They often make mistakes because they do not know or they forget these regulations. Students need qualified assistance in this maze of dynamically changing opportunities and limitations.

A basic property of a qualified guidance is adaptability, that is, a certain dynamic with respect to varying learning needs, context conditions, and the students' educational history. At first blush, the basic benefit of the proposed storyboards compared to that of any formal knowledge representation is the fact that the storyboards provide a semi-formal but easy-to-use overview of the relevant class schedules by nesting the graphs and reducing them to individual and dynamically possible choices.

A more important benefit for our future work is that dynamic storyboarding is a step towards making academic education processes a subject of reasoning with AI technologies such as data mining and identifying successful didactic patterns for individual students. This is possible due to the fact that the proposed storyboards have a semi-formal but sufficient degree of formal knowledge representation that is controlled by a set of construction operations that ensure formal correctness when designing a storyboard (Sauerstein, 2006), and is verified for further formal features by automatic structure tests after the storyboard has been designed (Duesel, 2007).

This opens the door to designing learning plans that ensure a certain degree of learning quality, that is, a strong indication that learning ends up with a high level of success in academic education as a result of the storyboard being incrementally refined based on an automatic analysis such as data mining of its usage. In other words, dynamic storyboarding supports quality management in academic education.

Currently, this system for SIE of TDU and a similar system for supporting the computer science study at the University of Ilmenau are under construction. In the experimental use, the suggested approach was found to be very general and can easily be adopted for any other university education.

Our upcoming work focuses on the following issues:
- ➢ A definition and representation of criteria that allows the specification of individual goal-driven storyboards. In fact, this is very different depending on cultures, countries, and universities. Therefore, we plan to do that prototypically for SIE of TDU.
- ➢ Storyboards have a high performance with respect to didactical issues of planning education processes. However, there is still no way to manage these processes according to their resources (e.g., to concretely plan

weekly timetables based on requests and available capacities such as rooms, teachers, equipment, and so on). Therefore, a desirable synergy effect is expected when incorporating the planning capabilities of the dynamic syllabus tool of the DLNRS into the storyboards.

➢ Including meta-knowledge is another focus to infer learning needs, learning desires, preferences, and talents. This meta-knowledge is useful for maintaining the university's educational resources by predicting, to a certain extent, upcoming students' learning needs. This is desirable not only for need-oriented and effective planning at universities, but also for suggesting content, such as class schedules represented by storyboards according to the students' desires.

➢ As well, individual learning plans should not be based solely upon individual quantitative capability (such as GPA) or upon the success of former students who went similar ways. But also individual properties, talents, and preferences should be considered. For example, some students demonstrate talent for analytical challenges, some are more successful in creative and compositional tasks, and others may have an extraordinary talent for memorizing a lot of factual knowledge. Consequently, at some point we need to include some sort of user profile to avoid overwhelming the students with suggestions that don't match their individual preferences and talents.

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