4.2 Learning Analytics by Didactic Factors

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As inputs for the learning analytics component of INTUITEL, three sources are available:

1. Observations of teachers and learners
2. Input of teachers
3. Input of learners

Observation data exist in the form of log files where it is recorded which learning objects were when accessed by teachers and learners. The main input from teachers are the meta data described previously. Input from learners is either derived from profile data that is available from learning management systems or from answers learners gave to requests for input from the INTUITEL system which are called TUG messages.

Since it's pretty difficult for learners to analyze raw data while learning takes place, it seems appropriate to offer some results from learning analytics to the learner. Unfortunately, we do not know beforehand which results will be relevant to the learner, but have to prepare analytics before the learning takes place. Thus the results should only be turned into recommendations to the learner.

If for instance observation data show that the last login was a fortnight ago, it might make sense to recommend a repetition of the last topic instead of continuing with the next one. Another example is the recommendation for a learning pathway based on the age and gender of the current user: "This course can be learned by multi stage learning, inquiry based learning or programmed instruction. Other learners of your age and gender preferred programmed instruction. Which model do you prefer¿' Unfortunately it is not known yet which Feedbacks are useful. Since this is an empirical question, the system needs to be designed in a way that allows for subsequent adaptations. That's why the rules to create feedback will be written in OWL and not as software.

A Didactic Factor is a compound of a number of data items from INTUITEL in a way so that the combination of them describes a fact that is relevant for the recommendation creation. They are the fundamental building blocks of the Rating Factors, which are used to evaluate the suitability of KOs. For this purpose, everything that is available in the whole collection of INTUITEL data, meaning the SLOM meta data, the Learning Pathways and especially the learner-specific information (e.g. the learning history as contained in the INTUITEL logs) that are stored or collected just-in-time from the LMSs, can be used.

From a technical perspective, a Didactic Factor is an OWL class which contains its own textual description. It furthermore also links to a Java class, containing its Transformation Rule. These are the instructions that specify in which combination of input data the respective Didactic Factor is valid. This combination of OWL and Java allows a very high flexibility regarding their specification, because all features of a high-level-programming language can be used. This especially also includes functionalities that would not be available in an OWL-only solution, as, for instance, mathematical methods to calculate the ratio between two values.

As seen from a reasoning point of view, the basic task of a Didactic Factor is to combine information in a way that allows its usage in context of an OWL-reasoner. These complex software modules have foundationally different intentions than programming frameworks like, for instance, Java or .Net. Instead of iteratively executing program code to produce various results, OWL-reasoners are specialized on testing the consistency of statements and the identification of relations between entities. By drawing conclusions on a data set (i.e. an ontology), a reasoner can deduce statements that, for instance, allow to determine whether a CC is fitting for a certain learner's Learning Pathway (LP). The Didactic Factors are especially relevant in this process because natural or real numbers are problematic in that context. This entails that INTUITEL needs to reformat the input in a way that is compatible with such a system. One aspect of the Didactic Factors is consequently to transform the non-nominal values into a nominal form (e.g. by transforming the continuous value 5 into the categorized statement "medium“). There are four fundamental forms of Didactic Factors:

1. Trivial statement: The most basic realization of a Didactic Factor is the $n:1$ relaying of input data. This means that certain data items are combined and translated into a format that is compatible with the Engine. (example: gender as male or female)
2. Trivial input combination with grading: Different nominal data items can be connected to create a combined statement that entails some kind of grading. (example: connection type as slow, medium, fast)

3. Complex statement: A more complex use case for a Didactic Factor is the discretization of numerical values into a nominal one (example: noise level in DB is expressed as quiet, tolerable, loud)
4. Complex input combination with grading: The combination of different (kinds of) input values, via e.g. mathematical functions, can also result in graded Didactic Factors.

In the table below, we provide the list of the Didactic Factors that have been developed in INTUITEL. This list does not claim to be complete or that the respective items are final, since there is no evidence for useful factors available yet. This list will nevertheless give a detailed overview about aspects that might be relevant for the selection of suitable Learning Objects.

#	*Didactic Factor*	*Description*
01	Knowledge actuality	Ranking of time between now and the last learning session.
02	Course-focused KO learning speed	Ranking of learning time the learner on average differs from the estimated learning time in contrast to the same measure of the other course participants
03	Learner-focused KO learning speed	Ranking of learning time the learner on average differs from the estimated learning time of completed KOs of this session in contrast to same measure over all KOs over all sessions.
04	Course-focused filtered KO learning speed	Ranking of learning time the learner on average differs from the estimated learning time in contrast to the same measure of the other course participants when only having a look at KOs that have the same KT and MT.
05	Learner-focused filtered KO learning speed	Ranking of learning time the learner on average differs from the estimated learning time of completed KOs of this session in contrast to same measure over all KOs over all sessions when only having a look at KOs that have the same KT and MT.
06	Course-focused session length	Statement about the average session length as compared to the average session length of other course participants.

07	Learner-focused session length	Statement about the current session length as compared to the average session length of the learner.
08	Time exposure	Comparison between the amount of time the learner and the other course participants spent on the course.
09	Learning Pathway permanence	Ranking of the amount of KOs the learner completed on the current LP combination in contrast to the same measure for the other course participants.
10	Recent learning pace	Comparison of the actual learning time the learner needed for the last 10 KOs in contrast to the estimated learning time.
11	Session learning pace	Comparison of the actual learning time the learner needed for the KOs in this session in contrast to their estimated learning time.
12	Course-focused LP usage type	Statement about the LP usage as measured on the learners pathway switches and the switches of the other course participants.
13	Learner-focused learner type	Statement about the LP usage as measured on the learners pathway switches.
14	Course-focused learning success	Success of the learner regarding scores in contrast to the other course participants.
15	Learner-focused learning success	Success of the learner regarding scores in contrast of the own score history.
16	Course-focused KO repetition quantity	Comparison of the number of repeated KOs with the number of repetitions of the other course participants.
17	Learner-focused KO repetition quantity	Comparison of the number of repeated KOs in the recent KO history and the average of repeated KOs.
18	Course-focused CC repetition quantity	Comparison of the number of repeated CCs with the number of repetitions of the other course participants.

19	Learner-focused CC repetition quantity	Comparison of the number of repeated CCs in the recent KO history and the average of repeated CCs.
20	Course KO completion	Statement about the coverage of the course regarding the completion states of KOs.
21	Course CC completion	Statement about the coverage of the course regarding the completion states of CCs.
22	CC KO completion	Statement about the coverage of the current CC regarding the completion states of the connected KOs.
23	Course-focused KO completion tendency	Comparison of the learners and the other course participants ratio of completed KOs in contrast to the uncompleted ones of the session.
24	Learner-focused KO completion tendency	Comparison of the earners and the other course participants ratio of completed KOs in contrast to the uncompleted ones of the session.
25	Course-focused MT preference	Statement about the MT preference as measured on all course participant selections.
26	Learner-focused MT preference	Statement about the MT preference as measured by the learners learning history.
27	Course-focused MT dislike	Statement about the MT dislike as measured on all course participant selections.
28	Learner-focused MT dislike	Statement about the MT dislike as measured by the learners learning history.
29	Course-focused KT preference	Statement about the KT preference as measured on all course participant selections.
30	Learner-focused KT preference	Statement about the KT preference as measured by the learners learning history.
31	Course-focused KT dislike	Statement about the KT dislike as measured on all course participant selections.
32	Learner-focused KT dislike	Statement about the KT dislike as measured by the learners learning history.
33	LP leaving position	Statement at which point (in the sense of completed LOs) the learner leaves a LP.

34	Course-focused learning efficiency	Ranking of how much time the learner needs to complete a KO in contrast to the time the other course participants needed for it.
35	Learning attention	Statement about how much attention the learner pays to the content as measured by an eye-tracking device connected to the LMS.
36	Blindness	Statement if the learner is blind.
37	Deafness	Statement if the learner is deaf.
38	Gender	Statement about the learners gender.
39	Age	Statement about the learners age.
40	EQF Level	Statement about the learners European Qualification Framework (EQF) level.
41	Learner Level	Statement about the course specific level of knowledge the learner possesses.
42	Device resolution	Ranking of the relative resolution of the device the learner uses to access the LMS.
43	Connectivity level	Ranking of the connectivity between the learners access device and the LMS.
44	Noise level	Ranking of the environmental noise level of the learner.
45	Learning Environment	Statement about the type of environment the learner is currently located at.
46	Learning Velocity	Ranking of the time the learner needs to successfully complete Learning Objects.

As stated above, these factors need to be transformed into statements that can be computed by a reasoner. To give an example, let us assume that the estimated learning time is 3 minutes and the actual learning time was 2 minutes and 30 seconds. Lets further assume that the transformation rule differentiates five cases:

1. Estimated time actual time > 2 min $\Longrightarrow$ No rating
2. Estimated time actual time < 2 min AND > 1 min $\Longrightarrow$ fast learner

3. Estimated time actual time $<$ 1 min AND $>$ -1 min $\Longrightarrow$ normal learner
4. Estimated time actual time $<$ -1 min AND $>$ -2 min $\Longrightarrow$ slow learner
5. Estimated time actual time $<$ -2 min $\Longrightarrow$ No rating

In the present example, this would result in the statement that the learner is a normal learner. Please note that this is only an example. There can be arbitrarily many combinations of input values, but only a subset of them is pedagogically meaningful and exact enough. If, for example, the estimated learning time is quite high (e.g. 1 hour which is non-compliant to the INTUITEL guidelines), completing the KO more than one minute earlier or later is certainly common. Thus, specifying well-engineered rules is an important factor regarding the accuracy of INTUITEL.

Concluding this section, the following examples explain the transformation rules for three of the above mentioned Didactic Factors. Please note that due to a better readability, standard deviation is denoted as s. For a full definition of all transformation rules of the 46 Didactic factors, refer to the according Deliverable 3.2 [25] of the INTUITEL project.

Transformation rule for DF "Course-focused KO learning speed"

Input:
lAvgLT = learners average learning time of recent KOs
oAvgLO = others average learning time

Output:
KoSpeedFast, KoSpeedSlow, KoSpeedNormal

Transformation rule:

```
if (lAvgLT > oAvgLT + s)
   output = KoSpeedSlow
else if (lAvgLT < oAvgLT − s)
   output = KoSpeedFast
else
   output = KoSpeedNormal
```

Transformation rule for DF "Course-focused filtered KO learning speed"

Input:
lCouples[,] = Learners average difference between actual and estimated learn-

ing time of KOs, which is differentiated into KT and MT couples (only the three topmost types each),
oCouples[] = Others average difference between actual and estimated learning time of KOs, which is differentiated into KT and MT couples (only the three topmost types each)

Output:
FilteredKoSpeedFast, FilteredKoSpeedSlow, FilteredKoSpeedNormal

Transformation rule:

```
For each couple {

   if (couple not null for learner) {

      lAvg += learner s value for couple
            oAvg += others  value for couple
         }
}
lAvg /= count of not null couples
oAvg /= count of not null couples

if (lAvg > 110\% of oAvg)
   output = FilteredKoSpeedSlow
else if (lAvg < 90\% of oAvg)
   output = FilteredKoSpeedFast
else
   output = FilteredKoSpeedNormal
```

Transformation rule for DF "Learner-focused learning success"

Input:
scoRec = Recent average learner score
scoGen = General average learner score

Output:
SuccessBetter, SuccessStable, SuccessWorse

Transformation rule:

```
if (scoRec > scoGen + s)
   output = SuccessBetter
```

```
else if (scoRec < scoGen - s)
   output = SuccessWorse
else
   output = SuccessStable
```

6.4 Conclusion

We have defined four universal criteria a learning environment has to satisfy to be adaptive with respect to learning style, behavior and preferences of individual learners. Firstly, Didactic Factors have to be retrieved by measuring correlated indicators. Secondly, these factors have to be transformed into a machine-processable form. Thirdly, the Didactic Factors have to be annotated to learning content, together with didactic relations between pieces of learning content. Fourthly, the learning environment deduces the according instructional design from this formal representation.

INTUITEL satisfies the second, third and fourth of these requirements. With the Hypercube Database project we aim to close the gap to the first requirement, designing and developing a research tool for the analysis of learning histories. We model learning histories as spatio-temporal trajectories treating the time dimension as an immanent part of learning. Besides the learning content itself, the concept of the advanced hypercube also includes arbitrary additional data that may result from measured indicators. By this — inside the space of the advanced hypercube — data is lifted to a highly abstract level, mapped to purely geometric information.

This leads to a compact representation allowing us to analyze a wide range of data solely on the grounds of hyperpolylines, their spatio-temporal characteristics and their relations to each other. Not only is this a new application of a spatio-temporal database. It also offers a new approach for finding common learning pathways and Didactic Factors correlating with them. By this, we can predict learning pathways by observing a learners' current actions and retrieving the according Didactic Factors, which constitutes the enhancement of adaptive learning environments in the future.

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