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Learning Styles and Cognitive Styles

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Executive Summary of the First Version (April 2015)

The purpose of this document is to review the state-of-the-art in the field of learning styles (LS) and to extract the “quintessence” of this wide-spread and diverse research area that offers a huge amount of models and theories. To extract this quintessence of the learning styles literature, existing models and theories that have been considered as important and representative for the whole LS research field have been identified, selected and described. Formal Concept Analysis (FCA) has been applied to formally describe and cluster the learning styles suggested by the selected models and theories. The FCA took 70 learning styles as *objects* and 48 *attributes* (properties of learning resources, learning activities, etc.) into account.

Aiming for a non-invasive approach to measure a learner´s dominant learning style, a Competence-based Knowledge Space Theory (CbKST) assessment procedure has been outlined. Afterwards, an excursus on the so-called “matching-hypothesis” is given. The matching-hypothesis suggests that the instructional style or the nature of the learning resources to be used (e.g. “concrete” or “visual”) should be aligned with the learner´s dominant learning style. Finally, we will conclude and outline future steps on research and development activities in Lea´s Box related to learning styles.

Executive Summary of the Second Version (June 2016)

In June 2016 a second version of this deliverable has been submitted. It provides an update and improvements based on the recommendations from the 2nd project review and the according review report.

The following updates and refinements have been made:

<u>From a theoretical perspective</u>

A theoretical extension that focuses on the developments of the last decade (i.e. the developments since the work conducted by Coffield et al., 2004a, 2004b) has been included. These developments are described in Section 5. Section 5.1 deals with developments in the field of learning styles and cognitive styles from a conceptual point of view. Section 5.2 outlines recent developments in the field of technology-enhanced learning. The new Section 6 focuses on the critical aspects of the learning styles field, such as conceptual and terminological incoherence, lack of empirical evidence for some

claims, and psychometric weaknesses. Section 7 (applying Formal Concept Analysis to cluster the learning styles) has been refined by describing in more detail how the attributes have been selected and assigned to the learning styles. In addition, an explanation has been added on how the resulting concept lattice has delivered additional insights on the overlap and relationship between different learning styles.

From a practical perspective

Section 9 outlines how the research on learning styles and cognitive styles has had a practical impact in the Lea´s Box project in general and in the design and implementation its platform in particular. Section 9.1 deals with a study at the Grazer Schulschwestern where some ongoing research questions in the field are addressed. Section 9.2 describes how the FCA tool (see Deliverable D2.2) can be used to assign properties to learning resources. The outcome of such an exercise can be applied by the teacher for giving recommendations to his or her students (based on their learning styles). Section 9.3 outlines how students may evaluate learning resources via the Flower app.

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1. Introduction

Workpackage 3 of Lea's Box is concerned with research on learning analytics, based on the existing state-of-the-art and on psycho-pedagogical frameworks (*Competence-based Knowledge Space Theory (CbKST), Formal Concept Analysis (FCA)*), serving as sound foundations for advancing and developing novel and competence-based learning analytics approaches. One of the ambitious aims of Lea´s Box is to refine an implicit assessment procedure of a learner´s skills, competences and learning styles (LS). This implicit or "non-invasive" assessment procedure is based on the observation and interpretation of learning analytics.

This present report focuses on the aspects of learning styles and cognitive styles. There are a wide range of models and theories on learning styles, cognitive styles and teaching styles, as well as learning preferences, strategies and attitudes. To extract the "quintessence" of the learning styles literature, existing models and theories need to be identified and systematically described. Such a quintessence is the basis for establishing the above mentioned non-invasive assessment procedure. FCA (see also Deliverable D3.1 - *Review article about LA and EDM approaches*) has been applied as a method to systematically and formally describe the wide range of learning styles derived from a corpus of different models and theories, and to cluster these by combining those learning styles which are "conceptually the same".

Building on its learning styles approach, Lea´s Box will establish an implicit assessment procedure.
The research in this context includes the utilisation of CbKST-inspired methods for associating learning data with learning styles to derive characteristic patterns for different styles, or investigating whether different learning paths in a knowledge or competence structure can be related to learning styles. This is considered as the main building block when aiming to establish comprehensive and comparable learner models.

This document is structured as follows:

Section 2 (*Overview on Learning Styles Theories and Research*) details a brief introduction into the research topic of learning styles. There are several other terms and concepts used in the literature, however, quite often these terms are used as synonyms or at least in a very similar way, and in some cases, different authors use different labels for the same concepts. Some examples of these terms are learning strategies, cognitive styles, learning preferences, and instructional or teaching styles. An excursus on the matching-hypothesis is given in Section 3. Empirical results on the hypothesis that learners learn better when the instructional style or the nature of the learning resources match (i.e. are aligned) with the learner´s dominant learning style are not that coherent. Section 4 gives a brief

overview of 13 learning style theories and models that have been considered as important and relevant in the field as well as representative for a large set of models and theories that haven´t been selected. Section 5 outlines recent developments in the learning styles field, from a conceptual perspective and in the area of technology-enhanced learning. Section 6 focuses on critical aspects of the learning style research area; some of those critical aspects are still unresolved. Section 8 describes the results of the FCA, which took 70 learning styles as *objects* and 48 *attributes* (properties of learning resources, learning activities, etc.) into account. Section 8 deals with the CbKST-inspired non-invasive assessment procedure. Section 9 outlines how the research on learning styles and cognitive styles has had a practical impact in the Lea´s Box project in general and in particular in the design of its platform. Finally, we will conclude and outline future steps on research and development activities in Lea´s Box related to learning styles.

2. Overview on Learning Styles Theories and Research

The research field on learning styles, including the terminology used by its proponents, the models and theories, and the instruments used their measurement, are each far from being unified, and thus it appears as complex and potentially confusing when entering the field. The most obvious indication for the diversity is the different terms and labels that are used in parallel to “learning styles” or even interchangeably, or which have a different meaning by different authors — such as learning approaches, learning styles, attitudes to learning, cognitive styles and teaching styles (Lopez et al., 2013). In addition, there is still an ongoing discussion as to whether learning styles are stable (over time and in different learning situations) or flexible. Some theories represent learning styles as “flexibly stable”, arguing that previous learning experiences may create preferences or styles that may vary from context to context, or even from task to task. Other authors define learning styles as “a consistent way of functioning that reflects the underlying causes of learning behaviour’’ (Keefe, 1987) and they are considered the learner´s personal traits, i.e., “relatively consistent preferences for adopting learning processes, irrespective of the task or problem presented” (Entwistle & Peterson, 2004, p. 537).

It is not the aim of this report to contribute to these ongoing discussions, considerations or even disputes. For an overview on the research field, we would like to point towards the comprehensive reports from Coffield, Moseley, Hall and Ecclestone (2004a, 2004b). Coffield, et al. (2004a) gives a significant overview of a wide range of different models and theories, their theoretical background, empirical results, available instruments / questionnaires (including results on their psychometric quality such as internal consistency, test–retest reliability, etc.), as well as implications for pedagogy.

Coffield, et al. (2004a) also suggests a systemisation of learning style theories and models based on the continuum stable-flexible (or "trait-state"). The work identifies (ranging from stable to flexible) the following families of learning style theories (examples from these clusters that have been selected for a more in-depth analysis in the present report are listed below):

I) LS as largely constitutionally-based (including preferences for different modalities):

- Gregorc´s Mind Styles Model (see Section 4.1)
- The Dunn and Dunn Model of learning styles (see Section 4.2)
- The VARK Model (see Section 4.3)

II) LS as cognitive structure (or patterns of ability):

- Riding´s model of cognitive style (see Section 4.4)

III) LS as part of a relatively stable personality type:

- Jackson´s Learning Style Profile (see Section 4.5)

IV) LS as flexibly stable learning preferences:

- Kolb´s learning style theory (see Section 4.6)
- The Felder-Silverman model of learning styles (see Section 4.7)
- Honey and Mumford´s learning style model (see Section 4.8)
- The Herrmann ´whole brain´ model (see Section 4.9)
- Allison and Hayes´ cognitive style model (see Section 4.10)

V) LS as learning approaches, strategies, orientations and conceptions of learning:

- Entwistle´s approaches and study skills inventory (see Section 4.11)
- Vermunt´s framework for classifying learning styles (see Section 4.12)
- Sternberg´s theory of thinking styles (see Section 4.13)

3. The "Matching-Hypothesis"

One might intuitively say that learners learn "better" (from different points of view, e.g. in the sense that they learn faster, with greater ease, or that the learning outcome is greater) if the teaching or instructional style, the nature of the learning resources (e.g. aural, visual, etc.) or the learning activities (e.g. role play, lecture, etc.) are aligned with the learner´s dominant learning style. However, this "matching-hypothesis" is still an ongoing research topic in the research community on learning styles

since the empirical results are ambiguous. As stated by Smith, Sekar and Townsend (2002): "*for each research study supporting the principle of matching instructional style and learning style, there is a study rejecting the matching hypothesis*" (p. 411). They found 8 supporting and 8 rejecting studies on the "matching-hypothesis". In general, this hypothesis is based on the assumption that learning styles are at least to some extent stable over time (i.e. they are considered as a personal trait rather than a state). The assumption that learning styles are more fluid would be supported by studies rejecting the matching-hypothesis, for example where these may be preferences that change over time or that adapt to contextual factors in which the learning takes place (for example intrinsic or extrinsic motivation of the learner, short-term or long-term learning goals etc.).

For some of the models and theories on learning styles described in Section here and in more detail in section 4, the empirical evidence is more coherent and in favor of the matching hypothesis. As an example, for the Dunn and Dunn Model of learning styles (see Section 3.2) a meta-analysis of Dunn, Griggs, Olson, Beasley and Gorman (1995) indicated that learners with dominant learning styles (auditory, visual, tactile or kinaesthetic) showed greater learning outcomes (gains in knowledge) when the instructional style was congruent with their learning style(s) than with learners with moderate dominant or mixed learning styles. For Kolb´s learning style theory, Katz (1990) it was found that in a cross-cultural study that students (from the US and Israel), whose learning styles matched the teaching method, would learn more effectively and would need less time to study outside the classroom. In line with that, Sein and Robey (1991) assigned undergraduate computer scientists randomly to one of two different training methods based on the results of a questionnaire aiming to measure preferences for Kolb´s learning styles. The results indicated that "performance can be enhanced by tailoring instructional methods to accommodate individual preferences in learning style" (1991, 246).

However, some of these studies or meta-analyses have been criticized by other authors for methodological weaknesses or unreasonable interpretations of the results. As an example, the Dunn et al. (1995) meta-analysis mentioned above has been harshly criticised by Kavale, Hirshoren and Forness (1998) when they concluded that the "weak rationale, curious procedures, significant omissions, and circumscribed interpretation should all serve as cautions" (p. 79, cited by Hattie, p. 196). The study from Sein and Robey (1991) mentioned above also had no control group and no numbers on the size of the effect have been provided.

A "mismatching-hypothesis" has also been suggested; students should learn with a learning style (or different styles) they do not exhibit (nor prefer). Potentially, this would likely reduce or even avoid the feeling of boredom, or alternatively students learn things "from another perspective". A prominent proponent of this mismatching-hypothesis is for example Apter (2001).

The availability of studies in favor as well as against the matching-hypothesis may be the reason for a medium effect size in Hattie´s meta-analysis of meta-analyses (Hattie, 2009).

4. Models and Theories

This section briefly outlines the following models and theories on learning styles, cognitive styles and approaches to learning:

- Gregorc´s Mind Styles Model
- The Dunn and Dunn Model of learning styles
- The VARK Model
- Riding´s model of cognitive style
- Jackson´s Learning Style Profile
- Kolb´s learning style theory
- The Felder-Silverman model of learning styles
- Honey and Mumford´s learning style model
- The Herrmann ´whole brain´ model
- Allison and Hayes´ cognitive style model
- Entwistle´s approaches an study skills inventory
- Vermunt´s framework for classifying learning styles
- Sternberg´s theory of thinking styles

Eleven of these 13 models have been described in great detail in Coffield et al. (2004a) and summarized for practitioners in Coffield et al. (2004b); i.e. all but the VARK model and the Felder-Silverman model of learning styles. This includes their theoretical background, according questionnaires and assessment instruments, empirical studies on their psychometrical quality (e.g. reliability and validity). Coffield et al. (2004a) selected 13 learning style theories and models from an initial set of 71 theories and models available in the literature. For these 13 learning style theories and models, at least questionnaires (or generally speaking, assessment instruments) were available. Two out of the 13 learning style theories and models selected by Coffield et al. (2004a, 2004b), the Apter´s reversal theory of motivational styles (Apter, 2001) and the Myers-Brigg type indicator (Myers & McCaulley, 1985) have been substituted by two alternative theories and models, the VARK Model (Hawk & Shah, 2007) and the Felder-Silverman model of learning styles (Felder & Silverman, 1988).

The rationale behind this substitution is as follows. The Apter´s reversal theory of motivational styles is more related to motivational styles, respectively different motivational needs such as need for

competitiveness or need for achievement. Achievement-motivation is unquestionable as an important and highly relevant concept in learning and educational settings, however, the different motivational styles proposed by Apter are not related to the individual learning styles, preferences, cognitive styles and learning resources and their modalities as described by the other theories and models. Thus, they have been excluded from the analysis in the present report. A similar argument holds for the Myers-Brigg type indicator, which is a model on personality (rather than on learning or learning styles) with psychoanalytical origins (Carl Gustav Jung). Furthermore, the following models have been incorporated in the analysis of the present report: the VARK model and the Felder-Silverman model of learning styles. The VARK model focuses on preferred perceptual modes when consuming learning resources (e.g. visual, aural or kinaesthetic). It is also considered as representative for other models that focus on perceptual modes. Finally, the Felder-Silverman model of learning styles has been included in the present analysis, since it is – compared to the other models – quite prominent in the technology-enhanced learning field (potentially because it originated from teaching engineering sciences).

4.1. Gregorc´s Mind Styles Model

The Gregorc´s mind styles model assumes two main underlying dimensions (Gregorc, 1982b):

i) *Perception* (the way people interpret information);

ii) *Ordering* (the order in which the pieces of information are presented).

Both dimensions are bounded by two poles: perception ranges from concrete to abstract; and ordering might be sequential or random. These four poles result in four prototypical learning styles (Gergorc, 1982a):

- The concrete sequential (CS) learner,
  (who is a perfectionist, practical and thorough);
- The abstract sequential (AS) learner,
  (who is analytical, rational and evaluative);
- The abstract random (AR) learner,
  (who is emotional and spontaneous);
- The concrete random (CR) learner
  (who is independent, impulsive and original).

4.2. The Dunn and Dunn Model of Learning Styles

The Dunn and Dunn model divides learning styles into 5 major strands or "variables" that determine how individuals learn (Dunn, 2003a): i) environmental, ii) emotional, iii) sociological, iv) physiological, and v) psychological. Each of these strands has a set of factors assigned to it:

- Environmental
  - Sound
  - Temperature
  - Light
- Emotional
  - Motivation
  - Degree of responsibility
  - Persistence
  - Need for structure
- Sociological
  - Learning groups
  - Support from authority figures
  - Motivation from authority figures (e.g. parents or teachers)
  - Working alone or with peers
- Physiological
  - Intake (i.e. food or drink)
  - Time of day
  - Mobility
  - Modality preferences (see also VARK model, Section 4.3):
    - Visual
    - Auditory
    - Kinaesthetic
    - Tactile

Most of the factors are considered as a continuum with 2 poles; e.g. prefers sound vs. prefers no sound for the environmental factor "sound", or prefers cool temperature vs. prefers warm temperature for the environmental factor "temperature".

Finally, the psychological strand encompasses information-processing elements such as global vs. analytical and impulsive vs. reflective information processing. According to Dunn (2003b), the majority of students are global rather than analytic and they learn better when information is thought of globally than analytically. Incorporating the often used left / right brain hemisphere analogy, Dunn et al. (1990) suggested that it is possible to identify two main "types" of learners:

i) Left-hemisphere, analytical, inductive, successive processors;
ii) Right-hemisphere, global, deductive, simultaneous processors.

4.3. The VARK Model

The acronym VARK stands for Visual (V), Aural (A), Read/Write (R), and Kinaesthetic (K), a sensory and instructional model of learning styles that focuses on preferred perceptual modes (Fleming, 2001). There are several models that are very similar to the VARK model; they differ primarily in the naming of the perceptual modes – for example *Auditory* instead of *Aural* (see also the Dunn and Dunn model of learning styles in Section 4.2). In some cases the *Visual* and the *Read* part of Fleming´s model (2001) are combined as a single factor.
The following figure gives an overview of the preferred learning activities and learning resources for the four learning styles (Figure from Hawk & Shah, 2007, p. 8, adapted from Fleming, 2001).

Visual	Aural	Read/Write	Kinesthetic
Diagrams	Debates, Arguments	Books, Texts	Real-Life Examples
Graphs	Discussions	Handouts	Examples
Colors	Conversations	Reading	Guest Lecturers
Charts	Audio Tapes	Written Feedback	Demonstrations
Written Texts	Video+Audio	Note Taking	Physical Activity
Different Fonts	Seminars	Essays	Constructing
Spatial Arrangement	Music	Multiple Choice	Role Play
Designs	Drama	Bibliographies	Working Models

Figure 1: Learning activities and types of learning resources accommodate VARK learning styles. (Figure taken from Hawk & Shah, 2007, p. 8, adapted from Fleming, 2001.)

4.4. Riding´s Model of Cognitive Style

The Riding model primarily focuses on cognitive styles that have been defined as “the way the individual person thinks” and as “an individual’s preferred and habitual approach to organising and representing information” (Riding and Rayner, 1998, pp. 7-8). In contrast, learning styles have been defined by the same authors as those “processes that are used by the learner to respond to the demands of a learning activity” (Riding and Rayner, 1998, p. 8). A more clear differentiation between cognitive styles and learning styles has been made by Riding and Cheema (1991), where it is claimed that learning strategies may vary from time to time, might be learned and cognitive styles are considered as more static, trait-like features of the individual.

The Riding´s cognitive style model has two independent (i.e. uncorrelated) dimensions. One axis is related to an individual´s cognitive organisation and is bounded by the poles *holistic* and *analytic*. The other axis is related to an individual´s mental representation and encompassed by the extremes of *verbal* and *imagery*. Riding and Cheema (1991) claim that their holistic vs. analytic dimension is conceptually the same as Entwistle's *surface* vs. *deep* dimension (see Section 4.11).

4.5. Jackson´s Learning Style Profile

Jackson (2002) proposed four learning styles that are considered as part of an individual´s personality (i.e. a personality trait) and described as (proto-) types of learners: i) initiator, ii) reasoner, iii) analyst, and iv) implementer. These prototypical types of learners are from a conceptual point of view very similar to the ones suggested by Honey and Mumford (2000; see Section 4.8); however, they are not considered as independent from each other nor considered to form a learning cycle. The key characteristics of the four prototypical types of learners are (from Coffield et al., 2004, based on Jackson, 2002):

- **Initiator** (sensation seeking, impulsive, extroverted)
  - Does not usually think carefully before doing anything
  - Generally does and says things without stopping to think
  - Mostly speaks before thinking things through
  - Considers all the advantages and disadvantages before making up his/her mind
- **Reasoner** (intellectual, rational, objective, has 'theory of mind')
  - Rarely gets the feeling that it is useless trying to get anywhere in life
  - Rarely feels that he/she doesn't have enough control over the direction his/her life is taking
  - Rarely feels that he/she has little influence over the things that happen to him/her
  - Rarely finds life difficult to cope with
- **Analyst** (introverted, responsible, cautious, wise, methodological, insightful)
  - Does not have a tendency to be inconsistent and untidy in his/her work
  - Rarely leaves things to the last minute
  - Does not have a tendency to 'let things slide'
  - Can always be fully relied upon
- **Implementer** (expedient, realistic, practical)
  - Rarely philosophises about the purpose of human existence
  - Is not overcome by a sense of wonder when he/she visits historical monuments

- Rarely discusses the causes and possible solutions of social and political problems with friends
- Rarely pauses just to meditate about things in general

4.6. Kolb´s Learning Style Theory

The learning style theory proposed by Kolb is one of the most prominent ones and has been enormously influential in education, medicine and management training (Coffield et al., 2004a). It belongs to a group of learning style theories and models that consider learning styles as a preference that changes slightly from situation to situation, rather than as a fixed trait-variable. However, on the long term it is assumed that there is some stability in an individual´s learning style (Kolb, 2000). Kolb´s model consists of four different learning styles: i) *diverging*, ii*) assimilating*, iii) *converging*, and iv) *accommodating*. These four learning styles are located at the four quadrants resulting from two independent dimensions: i) the *active experimentation* (AE) vs. *reflective observation* dimension (RO), and ii) the *concrete experience* (CE) vs. *abstract conceptualization* (AC) dimension. AE, RO, CE and AC are called adaptive learning modes and part of Kolb´s experiential learning approach, which follows a four-stage learning cycle. According to Kolb, effective learners need to learn from all four learning modes (see also Figure 2). The learning styles that are located at the quadrants have been summarized by Coffield et al. (2004a, p.61) as follows:

- The **converging style** (abstract, active):

Relies primarily on abstract conceptualisation and active experimentation; is good at problem solving, decision making and the practical application of ideas; does best in situations like conventional intelligence tests; is controlled in the expression of emotion and prefers dealing with technical problems rather than interpersonal issues.

- The **diverging style** (concrete, reflective):

Emphasises concrete experience and reflective observation; is imaginative and aware of meanings and values; views concrete situations from many perspectives; adapts by observation rather than by action; interested in people and tends to be feeling-oriented.

- The **assimilating style** (abstract, reflective)

Prefers abstract conceptualisation and reflective observation; likes to reason inductively and to create theoretical models; is more concerned with ideas and abstract concepts than with people; thinks it more important that ideas be logically sound than practical.

- The **accommodating style** (concrete, active)

Emphasises concrete experience and active experimentation; likes doing things, carrying out plans and getting involved in new experiences; good at adapting to changing circumstances; solves problems in an intuitive, trial-and-error manner; at ease with people but sometimes seen as impatient and ‘pushy’.

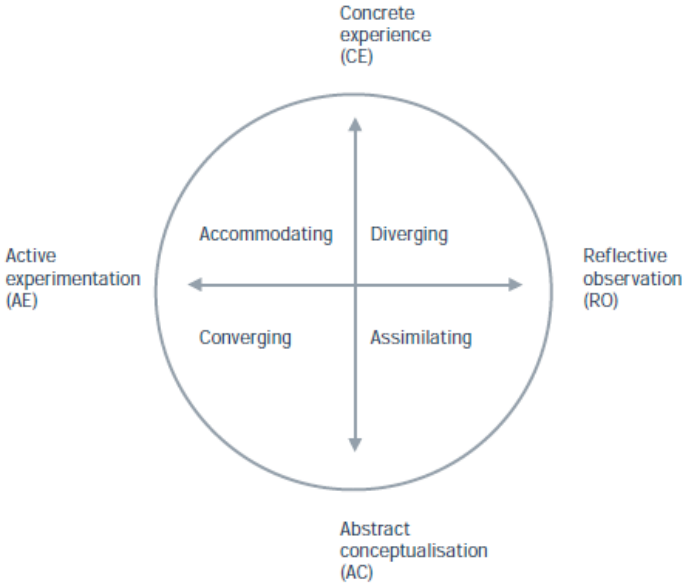

Figure 2: Kolb´s experiential learning model and the resulting learning styles. (Figure taken from Coffield et al. 2004a, p. 62.)

The following figure gives an overview of the preferred learning activities and types of learning resources for the four learning modes.

Concrete Experience	Reflective Observation	Abstract Conceptualization	Active Experimentation
Lecture Examples	Thought Questions	Lecture	Lecture Examples
Problem Sets	Brainstorming	Papers	Laboratories
Readings	Discussions	Analogies	Case Studies
Films	Logs	Text Readings	Homework
Simulations	Personal Journals	Projects	Projects
Laboratories		Model Building	Fieldwork
Observations		Model Critiques	
Field work			

Figure 3: Learning activities and types of learning resources that accommodate VARK learning styles. (Figure taken from Hawk & Shah, 2007, p. 4, based on Kolb, 1984, as well as Svinicki & Dixon, 1987.)

4.7. The Felder-Silverman Model of Learning Styles

The Felder–Silverman Learning/Teaching Style Model (Felder & Silverman, 1988) originated in the field of engineering sciences. (It is still very prominent in teaching engineering sciences and, maybe as a consequence, in the technology-enhanced learning field.) In its initial version (Felder & Silverman, 1988), it encompasses five bipolar dimensions: i) *perception* (with the poles sensory vs. intuitive), ii) *input* (with the poles visual vs. auditory), iii) *organization* (with the poles inductive vs. deductive), iv) *processing* (with the poles active vs. reflective), and v) *understanding* (with the poles sequential vs. global). Every preferred learning style has an according teaching style assigned to it (see Figure 4).

Preferred Learning Style		*Corresponding Teaching Style*	
sensory / intuitive	perception	concrete / abstract	content
visual / auditory	input	visual / verbal	presentation
inductive / deductive	organization	inductive / deductive	organization
active / reflective	processing	active / passive	student participation
sequential / global	understanding	sequential / global	perspective

Figure 4: Dimensions of Learning and Teaching Styles in the Felder–Silverman Learning/Teaching Style Model (Figure taken from Felder & Silverman, 1988, p. 675)

In a more recent update of the model (Felder, 2002) two significant changes have been made: i) the *organization* dimension (deductive / inductive) has been dropped and ii) the poles of the *input* dimension have been changed into visual vs. verbal. Felder (2002, p.1) explains the reasons behind deleting of the organization dimension as follows:

"*I have come to believe that while induction and deduction are indeed different learning preferences and different teaching approaches, the "best" method of teaching — at least below the graduate school level — is induction, whether it be called problem-based learning, discovery learning, inquiry learning, or some variation on those themes. On the other hand, the traditional college teaching method is deduction, starting with "fundamentals" and proceeding to applications.*

The problem with inductive presentation is that it isn't concise and prescriptive — you have to take a thorny problem or a collection of observations or data and try to make sense of it. Many or most students would say that they prefer deductive presentation." (Felder, 2002, p.1.)

The renaming of auditory into verbal has been done to be more precise. The remaining dimensions, respectively learning styles, are summarised by Felder and Spurlin (2005, p.103) as follows:

- **Sensing** (concrete thinker, practical, oriented towards facts and procedures) or **intuitive** (abstract thinker, innovative, oriented toward theories and underlying meanings);
- **Visual** (prefer visual representation of presented material, such as pictures, diagrams and flow charts) or **verbal** (prefer written and spoken explanations);
- **Active** (learn by trying things out, enjoy working in groups) or **reflective** (learn by thinking things through, prefer working alone or with a single familiar partner);
- **Sequential** (linear thinking process, learn in small incremental steps) or **global** (holistic thinking process, learn in large steps).

4.8. Honey and Mumford´s Learning Style Model

Honey and Mumford (1992) define a learning style as a mixture of attitudes and behaviour. This determines learners' preferred way of learning. Similar to the Jackson´s learning style profile (see Section 4.5), their model encompasses four (proto-) types of learners: i) activists, ii) reflectors, iii) theorists, and iv) pragmatists. Similar as in Kolb´s learning model (see Section 4.6), their four learning styles are arranged as part of a learning cycle (Honey & Mumford, 2000): first, in an "activist"-stage, the learner should have a learning experience; in the second "reflector"-stage, this experience should be reviewed and reflected upon. In the third "theorist"-stage, conclusions should be drawn from the experience. Finally, a single iteration of the whole learning cycle concludes with a "pragmatist"-stage, in which the next steps are to be planned before the cycle repeats.

According to Honey and Mumford (2000) the different (proto-) types of learners prefer the following learning activities:

- **Activists** prefer (for example): action learning, business game simulations, job rotation, discussions in small groups, role playing, training others and outdoor activities.
- **Reflectors** prefer (for example): E-learning, learning reviews, listening for lectures or presentations, observing role plays, reading, self-directed learning and studying alone rather than with others.
- **Theorists** prefer (for example): analytical reviewing, exercises with a right answer, listening to lectures, self-directed learning, studying alone rather than with others, watching lecture and discussion videos.
- **Pragmatists** prefer (for example): action learning, discussions in small groups, problem-solving workshops, project work, and group work with tasks where learning is applied.

4.9. The Herrmann "Whole Brain" Model

This model is based on a four categorical classification of mental preferences, which are also called thinking styles and sometimes referred to as 'learning styles' (Coffield et al. 2004). The Herrmann ´whole brain´ model (Herrmann, 1989) is influenced by neurological research on brain-hemisphere dominance, which indicates different "strengths" of both hemispheres (very roughly and over-simplistically speaking: the left hemisphere is said to be the "rational" part and the right hemisphere is said to be the "creative" part of the brain). This is inspired by the hypothesised function of the limbic system (and takes into account different functions of the limbic and the cerebral areas of the brain). According to Herrmann (1989) the four types of learners also prefer different learning content and respond to different instructional methods and teaching styles:

- **Theorists** (cerebral, left: the rational self),
    - learn by: acquiring and quantifying facts, applying analysis and logic, thinking through ideas, building cases, and forming theories.
    - respond to: formalised lectures, data-based content, technical case discussions, textbooks and programmed learning.
- **Organisers** (limbic, left: the safe-keeping self),
    - learn by: organizing and structuring content, sequencing content, evaluating and testing theories, acquiring skills through practice, implementing course content.
    - respond to: thorough planning, sequential order, textbooks, programmed learning, structure and lectures.
- **Innovators** (cerebral, right: the experimental self),
    - learn by: taking initiative, exploring hidden possibilities, self-discovery, constructing concepts and synthesising content.
    - respond to: spontaneity, free flow, experiential opportunities, experimentation, playfulness, visual displays, individuality, aesthetics and by being involved.
- **Humanitarians** (limbic, right: the feeling self),
    - learn by: listening and sharing ideas, integrating experiences with oneself, moving and feeling, harmonising with the content and emotional involvement.
    - respond to: experiential opportunities, sensory movements, music, group interactions and people-oriented case discussions.

4.10. Allinson and Hayes´ Cognitive Style Model

Similar to the above outlined Herrmann ´whole brain´ model (see Section 4.9), the cognitive style

model by Allinson and Hayes (1988, 1996) is influenced by research on specific dominance of both brain-hemispheres. They see only one dimension, namely intuition-analysis, as the most fundamental dimension of cognitive style and state that:

> "*Intuition, characteristic of right-brain orientation, refers to immediate judgment based on feeling and the adoption of a global perspective. Analysis, characteristic of left-brain orientation, refers to judgment based on mental reasoning and a focus on detail.*"
> Allinson and Hayes (1996, p. 122).

4.11. Entwistle´s Approaches and Study Skills Inventory

Entwistle primarily uses the term *approaches to learning* rather than learning styles. He (e.g. Entwistle 1978, 1988) and his colleagues have developed over three decades an encompassing learning model that. "aims to capture students' approaches to learning, their intellectual development, a subject knowledge base, and the skills and attitudes needed for effective approaches to learning" (Coffield et al. 2004a, p. 91). Besides these obviously very significant facets of learning, in the following we focus on the approaches to learning part only. There are basically three approaches to learning in the model from Entwistle: i) the deep approach, ii) the surface approach, and iii) the strategic approach. These three approaches to learning can be described as (Entwistle, McCune & Walker, 2001; adapted from Coffield et al., 2004a, p. 94):

- **Deep approach**
  - Learner´s intention is to understand ideas for him or her self
  - Relating ideas to previous knowledge and experience
  - Looking for patterns and underlying principles
  - Checking evidence and relating it to conclusions
  - Examining logic and argument cautiously and critically
  - Being aware of understanding developing while learning
  - Becoming actively interested in the course content
- **Surface approach**
  - Learner´s intention is to cope with course requirements
  - Treating the course as unrelated bits of knowledge
  - Memorising facts and carrying out procedures routinely
  - Finding difficulty in making sense of new ideas presented
  - Seeing little value or meaning in either courses or tasks set
  - Studying without reflecting on either purpose or strategy
  - Feeling undue pressure and worry about work

- **Strategic approach**
  - Learner´s intention is to achieve the highest possible grades
  - Putting consistent effort into studying
  - Managing time and effort effectively
  - Finding the right conditions and materials for studying
  - Monitoring the effectiveness of ways of studying
  - Being alert to assessment requirements and criteria
  - Gearing work to the perceived preferences of lecturers

4.12. Vermunt´s Framework for Classifying Learning Styles

Vermunt (1996) defines a learning style as a coherent whole of learning activities that students usually employ, their learning orientation and their mental model of learning' (p. 29). In addition to that, he emphasises the flexibility of learning styles, i.e. they can change from time to time and may vary in different learning situations, and the importance of metacognitive knowledge and self-regulation.
He proposed four learning styles: i) meaning-directed, ii) application-directed, iii) reproduction-directed and finally, iv) undirected. Each learning style has distinguishing features in five areas: a) cognitive processing, b) learning orientation, c) affective processes, d) the mental model of learning, and iv) the regulation of learning. The four learning styles, as well as how they are affected in the above mentioned areas of learning, are summarised in the following figure.

	Meaning-directed	Application-directed	Reproduction-directed	Undirected
Cognitive processing	Look for relationships between key concepts/theories: build an overview	Relate topics to everyday experience: look for concrete examples and uses	Select main points to retain	Find study difficult; read and re-read
Learning orientation	Self-improvement and enrichment	Vocational or 'real world' outcomes	Prove competence by getting good marks	Ambivalent; insecure
Affective processes	Intrinsic interest and pleasure	Interested in practical details	Put in time and effort; afraid of forgetting	Lack confidence; fear of failure
Mental model of learning	Dialogue with experts stimulates thinking and engagement with subject through exchange of views	Learn in order to use knowledge	Look for structure in teaching and texts to help take in knowledge and pass examinations. Do not value critical processing or peer discussion	Want teachers to do more; seek peer support
Regulation of learning	Self-guided by interest and their own questions; diagnose and correct poor understanding	Think of problems and examples to test understanding, especially of abstract concepts	Use objectives to check understanding; self-test; rehearse	Not adaptive

Figure 5: Vermunt´s learning styles and how they influence different areas of learning. (Figure taken from Coffield, 2004a, p. 104, based on Vermunt, 1992.)

4.13. Sternberg´s Theory of Thinking Styles

Sternberg´s theory of thinking (and learning styles) is based on mental self-government. The theory of mental self-government uses an analogy of four forms of government in the political sense: i) monarchic, ii) hierarchic, iii) oligarchic, and iv) anarchic. The model encompasses three functions of government: i) legislative, ii) executive, and iii) judicative; two levels (global vs. local), two scopes of government (internal vs. external) and finally, two leanings (liberal vs. conservative). Overall, these factors lead to 13 learning styles, which have been summarized by Coffield et al. (pp. 110-111) as follows (page numbers relate to Sternberg, 1999):

1. *Legislative* people like to come up with their own ways of doing things and prefer to decide for themselves what they will do and how they will do it. This style is particularly conducive to creativity: 'In schools as well as at work, legislative people are often viewed as not fitting in, or perhaps as annoying.' (p.33).
2. *Executive* people 'like to follow rules and prefer problems that are pre-structured or prefabricated … executive stylists do what they are told and often do it cheerfully' (p. 21). They are implementers who like to follow as well as to enforce rules. They can often 'tolerate the kinds of bureaucracies that drive more legislative people batty' (p. 35).
3. *Judicial* people 'like activities such as writing critiques, giving opinions, judging people and their work, and evaluating programs' (p. 21). They like to evaluate rules and procedures; they prefer 'problems in which they can analyse and evaluate things and ideas' (p. 39).
4. *Monarchic* people are single-minded and driven by whatever they are single-minded about, and do not let anything get in the way of them solving a problem. They tend to be 'motivated by a single goal or need at a time' (p. 46).
5. *Hierarchic* people recognise the need to set priorities, accept complexity and 'tend to fit well into organisations because they recognise the need for priorities' (p. 23). 'They tend to be systematic and organised in their solutions to problems and in their decision making' (p. 51).
6. *Oligarchic* people 'tend to be motivated by several, often competing goals of equal perceived importance' (p. 23). 'The oligarchic person is a cross between a monarchic person and a hierarchic one' (p. 54).
7. *Anarchic* people seem to be motivated by 'a potpourri of needs and goals that can be difficult for them, as well as for others, to sort out' (p. 23). 'They are at risk for anti-social behaviour … they are the students who challenge teachers, not necessarily on principled grounds, but rather for the sake of challenging the teachers or any other authority figures' (p. 58). They can challenge the system and have a potential for creativity.

8. *Global* individuals 'prefer to deal with relatively large and abstract issues. They ignore or don't like details, and prefer to see the forest rather than the trees' (p. 24).
9. *Local* individuals 'like concrete problems requiring working with details. The danger is they may lose the forest for the trees' (p. 24).
10. *Internal* individuals 'tend to be introverted, task-oriented, aloof and sometimes socially less aware. They like to work alone' (p. 25).
11. *External* individuals 'tend to be extroverted, outgoing and people-oriented. Often, they are socially sensitive and … like working with other people wherever possible' (p. 25).
12. *Liberal* individuals 'like to go beyond existing rules and procedures, to maximise change, and to seek situations that are somewhat ambiguous' (p. 26).
13. *Conservative* individuals 'like to adhere to existing rules and procedures, minimise change, avoid ambiguous situations where possible, and stick with familiar situations in work and professional life' (p. 26).

5. Developments of the Last Decade

5.1. The Conceptual Perspective

A majority of the critical issues addressed in the seminal work from Coffield et al. (2004a, 2004b) and elsewhere (e.g. Entwistle & Peterson, 2004; Rayner, 2007; Kirschner & van Merrienboer, 2013; De Bruyckere, Kirschner & Hulshof, 2015) are still unresolved. The effect sizes of learning style factors for various measurements in educational and work related context remain small. These unresolved issues have severe consequences for the learning style field as a whole, summarized by Rayner (2015, p.114) as follows: *"the issues of these critiques of style research persist to date and invalidate by association a good deal of rigorous and robust work. Nonetheless, continuing criticism of styles research reflecting a mix of ideological conflicts and perspectival differences has led at times to a rejection of any need for styles research."*

The continuous dispute has resulted in three main (not necessarily mutual exclusive) strategies or attempts by the learning styles community or parts thereof (besides the "strategy" of continuing as usual): i) some have suggested to put greater emphasis in renewing a factor analytic mode in style research and are in favour for "sorting out the theories of style" (e.g. Sternberg, 2012, p. 416); ii) some suggested realising a paradigm shift by supplementing the traditional methodologies in style research, i.e. primarily quantitative self-reporting, with qualitative, pluralistic approaches in the design and use of psychological assessment in different contexts such as cognition, learning and management (Rayner,

2011). Hattie (2009) employed the approach to put the learning styles research into a wider perspective to refute bloated claims about its usefulness. A wider perspective that is indeed helpful when it comes to addressing the question of where the current research paradigms lack, even though Hattie's (2009) study has itself serious doubts clouding the methodological soundness of its far-reaching claims, as illustrated by Schulmeister and Loviscach (2014). Finally, iii) some (have already) applied a conceptual shift, i.e. from learning and cognitive styles to learning strategies, learning patterns, an orientation to learning, learning dispositions and learning power (as described below in more detail).

As outlined by Rayner (2015), some current trends and research questions on learning and cognitive style are for example:

- The interactions between learning and cognitive styles on the one side and metacognition and self-awareness as a learner and thinker on the other side. Some mediating variables and constructs that should be incorporated into a holistic analysis are, for example: (achievement) motivation, self-efficacy and attribution theory (i.e. identifying the reasons for personal achievement).
- The interplay between styles and self-regulation in learning (e.g. Zimmerman & Schunk, 2001).
- Matching hypothesis: the proponents of learning and cognitive styles still need to demonstrate the significant and positive effect on learning outcome by matching a learner´s style with the instructional design or learning resources. This matching hypothesis (also called *learning styles hypothesis*) is considered by some authors (and critics) as the only potential and serious implication of the learning style field. However, more recent work focuses on more flexible approaches of the matching hypothesis (e.g. Sharma & Kolb, 2011, cited by Rayner, 2015).
- Technology-enhanced learning and personalisation (see also Section 4.2 below)
- The significance and effectiveness in the context of organisational learning and training, business management and human resource development.

5.2. From Learning Styles to Learning Dispositions and Learning Power

As mentioned above, the concept of learning styles has been reformulated to learning strategies, learning patterns, orientations to learning or learning dispositions. Learning dispositions are

considered to influence the learners´ engagement with new learning opportunities, in both formal and informal contexts. They form "*an important part of learning-to-learn competences, which are widely understood as a key requirement for life in the 21st Century*" (Buckingham Shum & Deakin Crick, 2012, p.2). Deakin Crick and others have identified a set of learning dispositions, as a multi-facetted construct also called *learning power*. The according self-report questionnaire, the Effective Learning Inventory (ELLI; Deakin Crick et al., 2004), has seven scales to measure the learning power of a learner. The following scales and their conceptual definitions are from Deakin Crick and Goldspink (2014, p. 2):

- **Strategic awareness**: being aware of my thoughts, feelings and actions as a learner, and able to use that awareness to manage learning processes.
- **Meaning making**: making connections and seeing that learning "matters to me".
- **Critical curiosity**: an orientation to want to "get beneath the surface".
- **Creativity**: risk-taking, playfulness, imagination and intuition.
- **Changing and learning**: a sense of myself as someone who learns and changes over time.
- **Learning relationships**: learning with and from others, and also able to manage without them.
- **Resilience**: the readiness and openness to persevere in the development of my own learning power in the face of challenge. (This scale is sometimes also called "**Dependence and Fragility**", which is the opposite pole of resilience, Buckingham Shum & Deakin Crick, 2012).

As an outcome of a structural equation modelling including an exploratory factor analysis incorporating data from around 10 years of research (from 2003-2013), the scales above have been slightly reformulated and further factorised (Deakin Crick, et al. 2015): For example, the scale "Strategic awareness" has been renamed into "**mindful agency**" with the three factors "agency", "managing feelings" and "managing processes". "Making meaning" has been renamed into "**sense making**" and consists of the factors "making meaning" and "making connections". The exploratory factor analysis on the items of the creativity scale returned the two factors of "imagination and intuition" and "risk-taking and playfulness". The scale "changing and learning" has been renamed into "**hope and optimism**". The exploratory factor analysis on this scale as well as the curiosity scale returned no sub-factors. The scale "learning relationship" has three factors: i) "dependence on others", ii) "collaboration" and iii) "belonging to a learning community". "Dependence and fragility" (or "resilience") operates independently from the remaining scales and "*there is no clear pattern, except with those individuals who score lowest on all learning power scales*" (Deakin Crick, et al. 2015, p.144). The exploratory factor analysis resulted in two factors: i) "a submissive mindset" and ii) "dependence on others" (or

"dependence"). Since both factors refer to the learners´ openness (or closeness) to the learning environment, the scale has been reformulated into "**openness to learning**".

This shift in research reflects the ideals that underpin the LEA's box project, namely that it is of great importance to make educational research outcomes "work in the field" and have the outcomes soundly employed by practitioners under real-life conditions while at the same time closely tie it to sound theories, models derived thereof and, finally, have a far range of empirical sources that can either substantiate or falsify the appropriateness in the face of learners' and teachers' conduct.

The learning dispositions as modelled by the multi-facetted learning power and assessed by the ELLI have been implemented as a web-based warehouse platform (Buckingham Shum & Deakin Crick, 2012). This platform supports a range of social learning analytics (Ferguson and Buckingham Shum, 2012). It also delivers a diagram of visual analytics aiming to support self-reflection, metacognition, and change. The so-called "ELLI spider" is like the "radar plot" of the Lea's Box Open Learner Modelling tool (see Deliverable 4.2 – First Release of Visualisation and OLM Services and Tools).

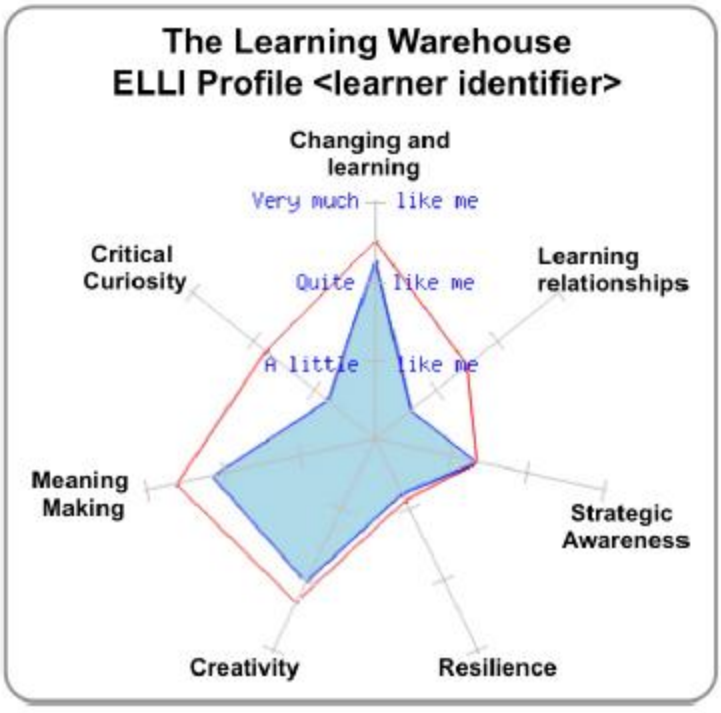

Figure 6: The ELLI Spider spider diagram generated from the Learning Warehouse (Figure taken from Buckingham Shum & Deakin Crick, 2012.)

The blue area represents the initial profile, the area indicated by the red lines represents the profile at a later phase.

5.3. Learning Styles and Open Learner Modeling

Using Open Learner Models, links can be found between learning styles and visualisations preferences. Thus, in (Sek et.al, 2014), links are made between learning preference for activities (classified as visual, aural, read/write and kinaesthetic), and the preferred visualisations when using an OLM (classified as observing, seeing and watching). However, in this study does not investigate if the learning styles can be determined using the visualisation preferences. The interest of providing students with several types of visualisations in an OLM has been showed by several studies, like (Bull et al., 2007) and (Bull et al., 2016).

In (Papanikolaou, 2015), the OLM INSPIREus is used to produce interpretative views of the learner interaction behaviour with activities. This study showed the interest of students to visualise indicators representing their behaviour with the learning system, and it motivates them to use more functionalities of the system and help student to choose activities to do in order to improve their knowledge.

5.4. Learning Styles in the Field of Technology-Enhanced Learning

In the last decade, learning styles became popular in the field of technology-enhanced learning (TEL) and in e-learning applications. To be more concrete, learning styles have been considered as an important factor for personalisation in TEL (e.g. Filippidis & Tsoukalas 2009). Personalisation is referred to as the provision of individualised instructions, the provision of learning content such as learning resources, and as learning paths from a current to a target knowledge state based on static (trait variables) and dynamic (state variables) characteristics of the person (e.g. learner, student, user, trainee). Examples include: current knowledge or competence state; motivational state; age; and gender.

In history, a wide range of different TEL applications were developed, which adapt to individual learning styles such as ‘Intelligent Tutoring Systems’ or even game-based learning applications (e.g. Hwang et al., 2012; Hsieh et al., 2011; Tseng et al., 2008; Papanikolaou & Grigoriadou, 2003). In addition to the traditional assessment of learning styles (e.g. by providing questionnaires), research has also implemented solutions that attempts to capture and determine users’ learning style from their interaction with a learning technology (Sanders & Bergasa-Suso, 2010) or via analysing social digital traces, such as Twitter stream (Hauff, Berthold, Houben, Steiner, & Albert, 2012).

The main building blocks of these TEL applications from a computer science point of view are i) the detection or assessment of a user´s learning style (either automated or “offline”, either static or

dynamic), ii) the personalisation procedures based on the user´s learning style, i.e. the provision of personalised learning resources or learning paths (also scaffolding), iii) providing feedback on the user´s learning style with view to fostering metacognition and self-reflection. In the following we will describe a few examples.

A vast majority of the authors of papers on TEL-applications have a background in computer science or artificial intelligence rather than psychology or pedagogy. At the very beginning of the development of a personalised TEL-application the main question is about which learning style model or theory to select. Most of them apply existing and well known theoretical frameworks such as those described in Section 3. As it is indicated in a review by Truong (2015), a vast majority of the work applies the Felder-Silverman model (see Section 3.7), respectively make use of the according Index of Learning Styles Questionnaire: from 51 papers published between 2004 and 2014 which have been included in the review, 36 (70.6 %) applied the Felder-Silverman model. The reasons for this might be that i) the model originates in the engineering sciences and is still very prominent in teaching engineering sciences, ii) it is freely available (https://www.engr.ncsu.edu/learningstyles/ilsweb.html), which is rarely the case for learning styles inventories, and iii) due to a publication bias: once critical mass is reached, it is getting even more prominent (also called preferential attachment process - “the rich get richer”).

With regards to the automated detection of a users´ learning style, there are two prototypical approaches: a “theory-driven” approach and a “data–driven” approach (but combinations are also possible). For the theory-driven approach, several indicators and interaction patterns that potentially distinguish the different styles are identified and operationalised beforehand, based on a comprehensive analysis of the underlying model and theory. Examples have been published by Graf, Kinshuk and Liu (2008) and Latham et al. (2012). The pre-defined indicators (or “hints”) are then the building blocks of a rule-based approach by e.g. assigning weights to each indicator — the extent to which they contribute to one or several of the learning styles (Graf, Kinshuk & Liu, 2009).
For the second approach, the data-driven approach, users’ interaction patterns when engaged with the TEL-application are correlated or mapped with the results of the questionnaire by machine learning algorithms. The goal is to identify patterns that allow users to be classified by means of a learning style.

With regards to the personalisation procedures based on the user´s learning style, as indicated by Truong (2015), around 50% of the papers (25 out of 51) included in the review adapt learning contents and learning resources based on the learning style of the users (e.g. Yang et al., 2013; Kurilovasa, Kubilinskienea, & Dagiene, 2014). The remaining 50% adapt the learning resources format (mainly due to models such as the VARK Model, see Section 4.3), the teaching and instructional strategies, and other recommender systems.

6. A critical view on Learning Styles

In the concluding sections of their seminal work, Coffield et al. (2004a) summarise not only the beneficial uses and valuable features but also the main problems, drawbacks and insufficiencies of the learning styles field in general they see, and the most prominent learning-styles models and theories in particular. A positive aspect mentioned by the authors is that psychometrically sound instruments could encourage self-development, not only by assessing how students learn, but by showing how they could improve their learning processes. This refers to self-awareness and metacognition. In this context, self-development is referred to as self-awareness or self-reflection and metacognition. Examples of this include the knowledge about one owns strengths and weaknesses, the ability to set goals and to choose appropriate strategies to reach these goals, and the monitoring e process towards these goals. Each have been shown to be important ingredients for a successful learning experience (e.g. Hattie, 2009). As briefly outlined in Section 9, Lea's Box supports such aspects, i.e. self-reflection and metacognition, by applying the FCA Tool, the OLM and the Flower app. However, as mentioned above, Coffield et al. (2004a) also described a series of problems in the learning styles field, and even if their report(s) have been published more than a decade ago, these problems are still unresolved to a large extent. In the following sections we will describe these issues in more detail.

Theoretical Incoherence and Conceptual Confusion

As briefly outlined in Section 2 and shown in Section 3, within the research field of learning styles, there exists a broad and scattered field of different frameworks and approaches; they often vary significantly in the terminology used and applied in questionnaires and inventories. Despite differences, there are also some overlaps and similarities between subsets of the models, theories or their proposed learning styles (cf. Section 4).

The fragmentation as well as the large number of approaches, the partially overlapping terminology, and a lack of initiatives to find a common umbrella has been criticised by several authors (e.g., Tiedermann, 1989; Sadler-Smith, 2001; Armstrong & Rayner, 2002; Entwistle & Peterson, 2004; Rayner, 2007; Kirschner & van Merrienboer, 2013; De Bruyckere, Kirschner & Hulshof, 2015). And also the proponents themselves acknowledge this fragmentation of researchers in the field of learning styles are stating that "it is such a messy area" (cited by Peterson, Rayner & Armstrong, 2009, p.521). Furthermore, the sheer amount of dichotomies (such as adaptors vs. innovators, see also Section 3 for more examples of such dichotomies) can be considered as a symptom for the conceptual confusion and the lack of theoretical coherence.

Labelling, Vested Interests and Claims

Even if learning styles labels are considered as neutral or value-free by its proponents, they are not neutral in many cases. Many proponents warn of the dangers of labelling (e.g. Entwistle), but "categorising" others is a human tendency and an important part of social life: it reduces the complexity we live in. The problem here is that not all teachers are immune against such cognitive heuristics and strategies of simplifying and categorisations. It seems to be problematic to label students with some of the learning style labels, in particular those which are far from neutral (e.g. "undirected" in the case of Vermunt´s Framework, see section 4.12 or "surface approach" in the case of Entwistle´s model). In particular for younger students, self-labelling as being part any kind of social category or group might foster the assumption that this identity is stable and unchangeable.

The learning style field, however, seems to offer great market opportunities for some leading developers and proponents. Pashler et al. (2008) noted that there is "a thriving industry devoted to publishing learning-styles tests and guidebooks" that also sell "professional development workshops for teachers and educators" (p. 105). Kirschner and van Merrienboer (2013) also make a similar argument. Peterson et al. (2009) examined the opinions and attitudes of the "learning style community" (such as attendances of previous European Learning Style Information Network Conferences) on the field. They report that parts of the community had some "concern over the commercialisation of style tests and its impact on test development and scholarly research. Respondents commented that commercial interests were "infecting style research" because tests were kept "in house" leading to a "lack of independent testing" with "test evaluations carried out by supporters" One researcher said "…too many tests reflect an interest for making money and gaining power rather than actually really providing sound research" (Peterson et al., 2009, p. 520).

Variable Quality and Psychometric Weaknesses

As pointed out by Coffield et al. (2004a) there is not only a variability and diversity among the learning styles inventories and questionnaires from a conceptual and theoretical point of view, but also from the perspective of psychometric quality. Psychometric quality encompasses (among others) reliability (test-retest reliability and internal consistency) and validity (construct and predictive validity). Ten out of the 13 models and theories reviewed by Coffield et al. (2004a) meet less than three out of these four criteria. However, it has to be noted that a high test-retest reliability of an instrument is only required in case this instrument is attempting to measure a construct that is considered as relatively stable over time. From a purely psychometric point of view, only those inventories whose underlying models and theories claim that learning styles are relatively stable personality types or stable preferences should show high test-retest reliability, for example the Dunn and Dunn Model of learning styles (see Section 3.2), which also lacks this psychometric quality. In particularly the Dunn and Dunn model, as well as meta-analysis conducted and conclusions drawn from its proponents, has been

criticised (e.g. Kavale, Hirshoren & Forness, 1998). The second reliability measurement, internal consistency, is a must have for all questionnaires that have separated sub-scales. The two validity measurements are at least desirable qualities of an instrument, otherwise there would be too large an overlap with other constructs or there would be no predictive power, which makes the construct (or at least the instrument) more or less meaningless. According to Coffield et al. (2004a) only the Allison and Hayes´ cognitive style model meets all four above mentioned psychometric criteria.

Unwarranted Faith Placed in Simple Inventories

Most of the learning style questionnaires and inventories are self-report tests, but the adequacy of such self-reports for assessing learning styles is according to De Bruyckere, Kirschner and Hulshof (2015) “questionable at best” (p. 21, see also Veenman, Prins, & Verheij, 2003). It seems questionable if younger students are actually able to report adequately on how they learn best or on how they use specific strategies to reach learning goals (since it requires a certain level of metacognition and self-awareness, see above). Entwistle´s approaches and study skills inventory (see Section 3.11) and Vermunt´s framework for classifying learning styles (see Section 3.12) apply a broader methodology by also encompassing in-depth qualitative evaluations. As stressed out by Krischner and van Merrienboer (2013), and De Bruyckere, Kirschner, and Hulshof (2015), what counts in the end is better learning outcomes and performance: the assessment of learning preferences and attempts to match these preferences (e.g. watching videos) with learning resources is meaningless if this preference doesn´t lead to better learning outcomes.

The main problem is that psychometric invalid instruments that, for example, are not measuring what they attempt to measure, are taken and used too seriously. Following this approach might have actual and severe consequences in the classroom (e.g. by applying different instructional methods to different “categories” of students).

Lack of Clear Implications for Pedagogy

The main question in the learning styles field is if students´ with a particular style should be treated differently (i.e. by receiving a special instruction or by using particular learning resources) compared to students with another learning style. Research on this matching-hypothesis or sometimes simply called “learning style hypothesis” has delivered mixed results to say the least (see also Section 6). In some cases there are interactions in the sense that students with learning style A tend to profit more from instructional method A, however, instructional method B might be superior for all learning styles. As iterated by De Bruyckere, Kirschner & Hulshof (2015), learning style studies “have no real practical educational implications since only crossover interactions provide acceptable evidence for learning styles” (p. 21).

Decontextualized and Depoliticised Views of Learning and Learners

Coffield et al. (2004a) argues that some items of some learning style questionnaires and inventories are decontextualized as they make sense in one part of the world or in the context of a particular social class, but not for other contexts. This might be true, however, it is a problem of all sorts of questionnaires or inventories, not only those attempting to assess learning styles. The inventories have to be checked and reviewed by the researcher, teacher or trainer who would like to apply it in a particular context in advance (e.g. checking if the language used is comprehensible for younger students, etc.). It might be worthwhile to consider including interactions between social class, gender, and other categories that constitute social reality and psychological or pedagogical constructs into one's own research questions.

Problematic Attributions

It has been argued that many proponents of the learning styles field prominently place attitudes, opinions or preferences on learning but tend to ignore the main goal of learning (Kirschner & van Merrienboer, 2013), i.e. to develop skills and to gain knowledge. The concept of learning styles allows both learners and parents to attribute any lack of skills or knowledge, which might result in a bad exam or bad certificates, not to themselves but rather to the mismatch between the learning resources used by the teacher and the learning style of the learner.

7. Applying Formal Concept Analysis to Cluster Learning Styles

As outlined above (section 2) and as exemplified in section 4, there is a wide range of different theories, models and inventories on learning and (cognitive) styles. However, there are also some overlaps and some similarities between the styles (i.e. their definitions and conceptualizations). The formal concept analysis (FCA) seems to be a suitable framework to further investigate these overlaps, similarities, dissimilarities and relations between the learning styles. We applied the FCA cluster them in order to extract the quintessence and to enable us to answer the following (highly interrelated) questions:

- Are there overlaps between some of the learning styles?
- Are some of them more or less synonyms, i.e. equivalent or „conceptually the same"?
- Which pairs / triples / etc. of learning styles are „similar to each other", are some of them more specific / more generic than others?

The FCA describes concepts and concept hierarchies in mathematical terms, based on the application of order and lattice theory (Wille, 1982). The starting point for identifying formal concepts is the definition of the formal context K. The formal context K is a triple (*O*, *A*, *I*) consisting of the set *O* of objects, the set *A* of attributes and *I* as binary relation which connects objects and attributes, i.e. o*I*a means that object o has an attribute a. A formal context can be best represented as a cross table, with objects in the rows, attributes in the columns and assigned relations as selected cells (see Table 1).

In the formal context shown in Table 1, we included 70 learning styles as objects and 48 attributes.

The "objects" in the formal context are the learning styles derived for the 13 theories and models on learning styles outlined in section 4. As mentioned in section 2, the selection of these models and theories was primarily based on the Coffield, Moseley, Hall and Ecclestone (2004a, 2004b) reviews.
Two out of the 13 learning style theories and models selected by Coffield et al. (2004a, 2004b) have been substituted by alternative theories and models: the VARK Model (Hawk & Shah, 2007) and the Felder-Silverman model of learning styles (Felder & Silverman, 1988). The reasons for these substitutions are described in the introduction of section 4.

The "attributes" are potential "content-related" properties of learning resources (e.g. "abstract"), "physical" properties of the learning resources (e.g. "graphs"), notions on the preferred order in which learners consume them (e.g. "sequential" or "random"), broader learning activities (e.g. "discussions"), instructional methods (e.g. "Analogies") as well as properties of the test items or exams (e.g. "Multiple Choice"). They have been selected based on the suggestions from Hawk and Shah (2007) who suggested such learning activities for some of the learning styles outlined in section 4.

The crosses in the cells indicate suggested relationships between the learning styles and the attributes. These suggested relationships have been assigned by one researcher at the Graz University of Technology. Some of these relationships have been implicitly made by Hawk and Shah (2007) - the remaining assignments were based on an extensive review of the literature on learning styles. However, since the assignments are only based on one evaluator and since there is no cross-validation available, these assignments as well as the resulting concept lattices (see Figure 8) should be dealt with great caution.

Theoretical background of the FCA

To get formal concepts out of this cross table, for all subsets of objects $X \subseteq O$ and all subsets of attributes $Y \subseteq A$ the following derivation operators need to be defined:

$X \rightarrow X' := \{a \in A \mid oIa \text{ for all } o \in X\}$ which is the set of common attributes of the objects in *X*, and

$Y \rightarrow Y'$:= {o $\in$ *O*| o*I*a for all a $\in$ *Y*} which is the set of objects that have all attributes in *Y.*

A formal concept is a pair (*X*, *Y*) with the subsets $X \subseteq O$ and $Y \subseteq A$ which fulfil $X' = Y$ and $Y' = X$. The set of objects *X* is called the *extension* of the formal concept; it is the set of objects that belong to the formal concept. The set *Y* is called the formal concept's *intension*, i.e. the set of attributes, which apply to all objects of the formal concept. In the resent case each formal concept is a set of learning styles which have a particular set of attributes in common. The formal concepts can be ordered by a sub-supra concept relation and represented as a labelled line diagram (see Figure 7). This hierarchical representation of the formal concepts is called the concept lattice $\mathfrak{B}$(K) (see Wille, 2005 for details).

Table 1: The formal context with learning styles as objects, attributes, and incidence relations.

	Sequential	Random	Concrete	Abstract	Diagrams	Graphs	Colors	Charts	Written Text	Different Fonts	Spatial Arrangement	Designs	Debates	Discussions	Conversations	Audio Tapes	Video + Audio	Seminars	Music	Drama	Books, Texts	Handouts	Reading	Written Feedback	Note Taking	Essays	Multiple Choice	Bibliographies	Real-life examples	Examples	Guest Lectures	Lecture	Demonstartions	Physical Activity	Constructing	Role Play	Working Models	Laboratories	Case Studies	Homework	Projects	Fieldwork	Problem sets	Simulations	Observations	Thought Questions	Brainstorming	Analogies
Concrete sequential (Gregorc)	X		X																																										
Abstract sequential (Gregorc)	X			X																																									
Abstract random (Gregorc)		X		X																																								
Concrete random (Gregorc)		X	X																																									
Visual (Dunns)					X	X	X	X	X	X	X	X									X	X	X	X	X	X	X	X																
Auditory (Dunns)													X	X	X	X	X	X	X	X																									
Kinaestethic (Dunns)																				X								X	X	X		X	X	X	X	X	X		X		X	X		
Tactile (Dunns)																																X	X	X			X	X		X				
Working alone (Dunns)																X	X			X	X	X																	X					
Working with peers (Dunns)													X	X	X			X																									X	
Wants structure (Dunns)	X																																											
Wants no structure (Dunns)		X																																										
Global (Dunns)				X	X	X																														X	X				X			
Analytical (Dunns)	X		X																										X								X							X
Impulsive (Dunns)							X		X	X	X								X	X				X	X			X	X			X	X	X		X		X	X		X			
Reflective (Dunns)					X	X		X	X				X	X	X	X	X	X			X	X	X	X			X	X			X	X	X				X		X	X		X	X	X	X
Visual (VARK)					X	X	X	X	X	X	X	X									X	X	X	X			X	X			X	X	X				X		X	X		X	X	X	X
Aural (VARK)													X	X	X	X	X	X	X	X																									
Read/Write (VARK)																					X	X	X	X	X	X	X	X																
Kinesthetic (VARK)																				X									X	X	X		X	X	X	X	X							
Holistic (Riding)				X	X	X																														X	X					X			
Analytic (Riding)	X		X																										X								X							X
Verbal (Riding)													X	X	X	X	X	X	X	X																									
Imagery (Riding)					X	X	X	X	X	X	X	X									X	X	X	X	X	X	X	X																
Initiator (Jackson)							X			X	X	X							X	X					X	X			X	X			X	X	X		X			X	X		X		
Reasoner (Jackson)					X	X		X	X				X	X	X	X	X	X			X	X	X	X			X	X			X	X	X		X		X	X	X		X	X	X	X
Analyst (Jackson)	X		X																										X								X							X
Implementer (Jackson)					X			X	X									X			X	X					X											X						
Converging style (Kolb)									X												X		X			X		X	X	X	X	X				X	X	X	X	X	X				X
Diverging style (Kolb)									X	X			X	X	X		X				X		X	X	X	X		X	X	X	X	X		X			X			X	X	X	X	X	
Assimilating style (Kolb)									X				X	X	X						X		X		X	X					X	X				X						X	X	X	
Accommodating style (Kolb)									X	X							X				X		X	X		X		X	X	X	X		X				X	X	X	X	X	X	X	X	
Sensing (Felder/Silverman)	X		X																										X								X							X
Intuitive (Felder/Silverman)				X	X	X																														X	X					X			
Visual (Felder/Silverman)					X	X	X	X	X	X	X	X																																		
Verbal (Felder/Silverman)													X	X	X	X	X	X	X	X																									
Active (Felder/Silverman)							X			X	X	X							X	X					X	X			X	X			X	X	X		X			X	X		X		
Reflective (Felder/Silverman)					X	X		X	X				X	X	X	X	X	X			X	X	X	X			X	X			X	X	X			X		X	X		X		X	X	X
Sequential (Felder/Silverman)	X		X																										X								X							X
Global (Felder/Silverman)				X	X	X																														X	X				X			
Activists (Honey/Mumford)			X										X	X	X																		X	X	X				X	X	X	X			
Reflectors (Honey/Mumford)				X	X	X		X	X				X	X	X	X	X	X			X	X	X	X			X	X			X	X	X			X		X	X		X		X	X	X
Theorists (Honey/Mumford)				X				X								X	X	X			X		X				X			X	X				X	X		X		X	X	X		X
Pragmatists (Honey/Mumford)			X											X	X			X			X						X												X	X		X	X		
Theorists (Hermann)				X				X								X	X	X			X		X				X				X	X				X	X		X		X	X	X	X		X
Organisers (Hermann)	X								X												X	X	X	X							X	X					X					X	X		
Innovators (Hermann)							X			X	X	X							X	X					X	X			X	X			X	X	X		X				X	X		X		
Humanitarians (Hermann)													X	X	X				X	X											X		X			X								X		
Intuition (Allinson/Hayes)							X			X	X	X							X	X					X	X			X	X			X	X	X		X			X	X		X		
Analysis (Allinson/Hayes)	X		X																										X									X					X		X		X
Deep approach (Entwistle)	X		X	X	X	X			X				X	X	X	X	X	X			X		X	X	X						X	X					X	X	X	X	X	X	X	X	X	X
Surface approach (Entwistle)			X											X	X			X								X														X	X			X		X
Strategic approach (Entwistle)			X																			X				X																			X
Meaning-directed (Vermunt)	X		X	X	X	X			X				X	X	X	X	X	X			X		X	X	X						X	X					X	X	X	X	X	X	X	X	X	X
Application-directed (Vermunt)			X											X	X			X								X														X	X			X		X
Reproduction-directed (Vermunt)			X																			X				X																			X
Undirected (Vermunt)															X							X	X	X																					
Legislative (Sternberg)													X																											X	X					
Executive (Sternberg)	X		X						X																							X						X							
Judicial (Sternberg)													X	X	X												X											X								
Monarchic (Sternberg)	X		X																		X										X					X	X	X	X		X	X	X	X	
Hierarchic (Sternberg)	X			X																	X										X					X	X	X	X		X	X	X	X	
Oligarchic (Sternberg)	X																				X										X					X	X	X	X		X	X	X	X	
Anarchic (Sternberg)		X										X	X	X	X				X	X						X																			X	
Global (Sternberg)				X	X	X																														X	X					X			
Local (Sternberg)	X		X																										X								X							X
Internal (Sternberg)																X	X				X	X	X																X						
External (Sternberg)													X	X	X			X																											X	
Liberal (Sternberg)		X		X									X	X	X				X	X						X												X	X	X	X	X	X			X	X
Conservative (Sternberg)	X		X		X	X			X													X										X													

Figure 7 shows the concept lattice which results from the formal context represented in Table 1. The concept lattice (which has been created with the Concept Explorer, http://conexp.sourceforge.net) consists of 480 formal concepts and 1390 edges. Due to this complexity, it is rather hardly readable as a static picture (to engage with a concept lattice of this size, interactive tools are highly recommended).

Each node of this ordered structure represents a formal concept, consisting of its extension (i.e. the set of objects belonging to it) and its intension (i.e. the set of attributes constituting the objects of the concept). We apply the minimal labelling approach as suggested by Wille (1982) that aims to avoid redundancy: All the object-labels and the attribute-labels occur only once in the lattice. Object-labels are assigned to formal concepts where they would first occur in the extension when following the paths from the bottom to the top. Analogously, attribute-labels are assigned to the formal concepts which are “minimal” with regards to their intensions when following the paths from the top to the bottom. The object-labels are in white boxes, the attribute-labels are in the grey boxes.

A more readable representation of the same information is shown in Figure 8. This chain decomposition only includes the “more important” formal concepts whereas “more important” in this context means that those formal concepts are minimally required to rebuild the whole concept lattice via set-unions of the extensions and set-intersections of the intensions.

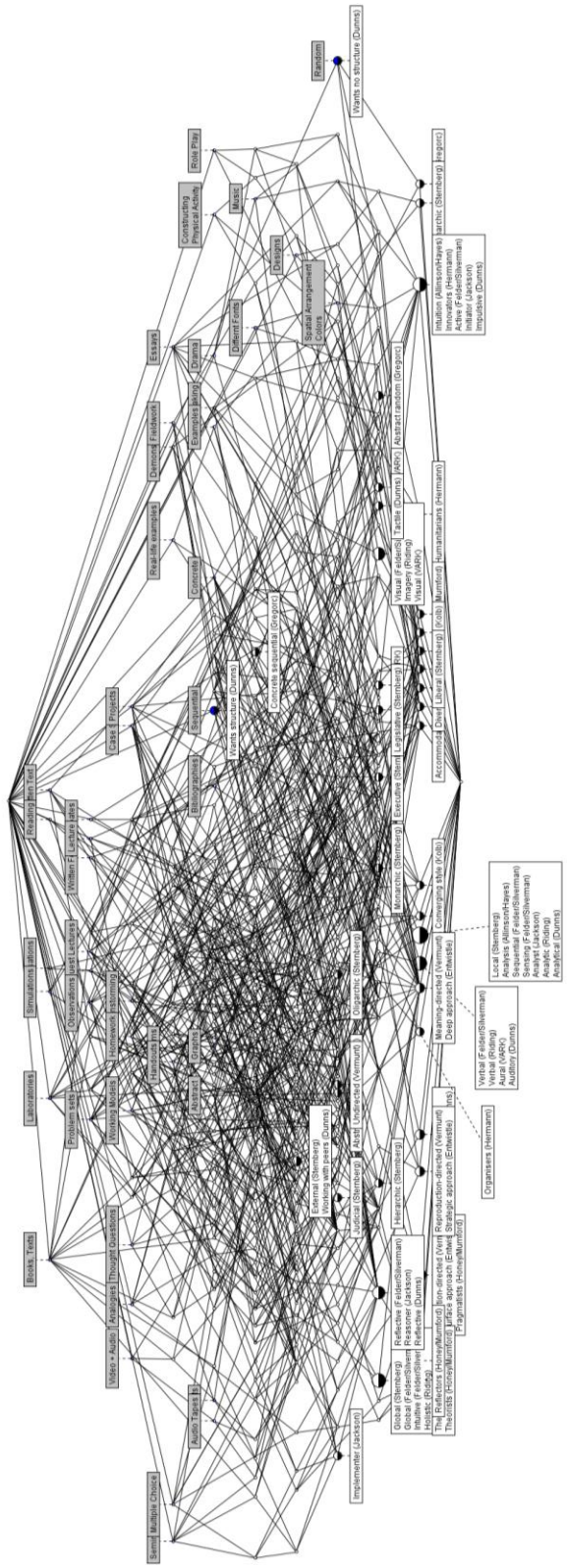

Figure 7: The resulting concept lattice as ordered set of formal concept.

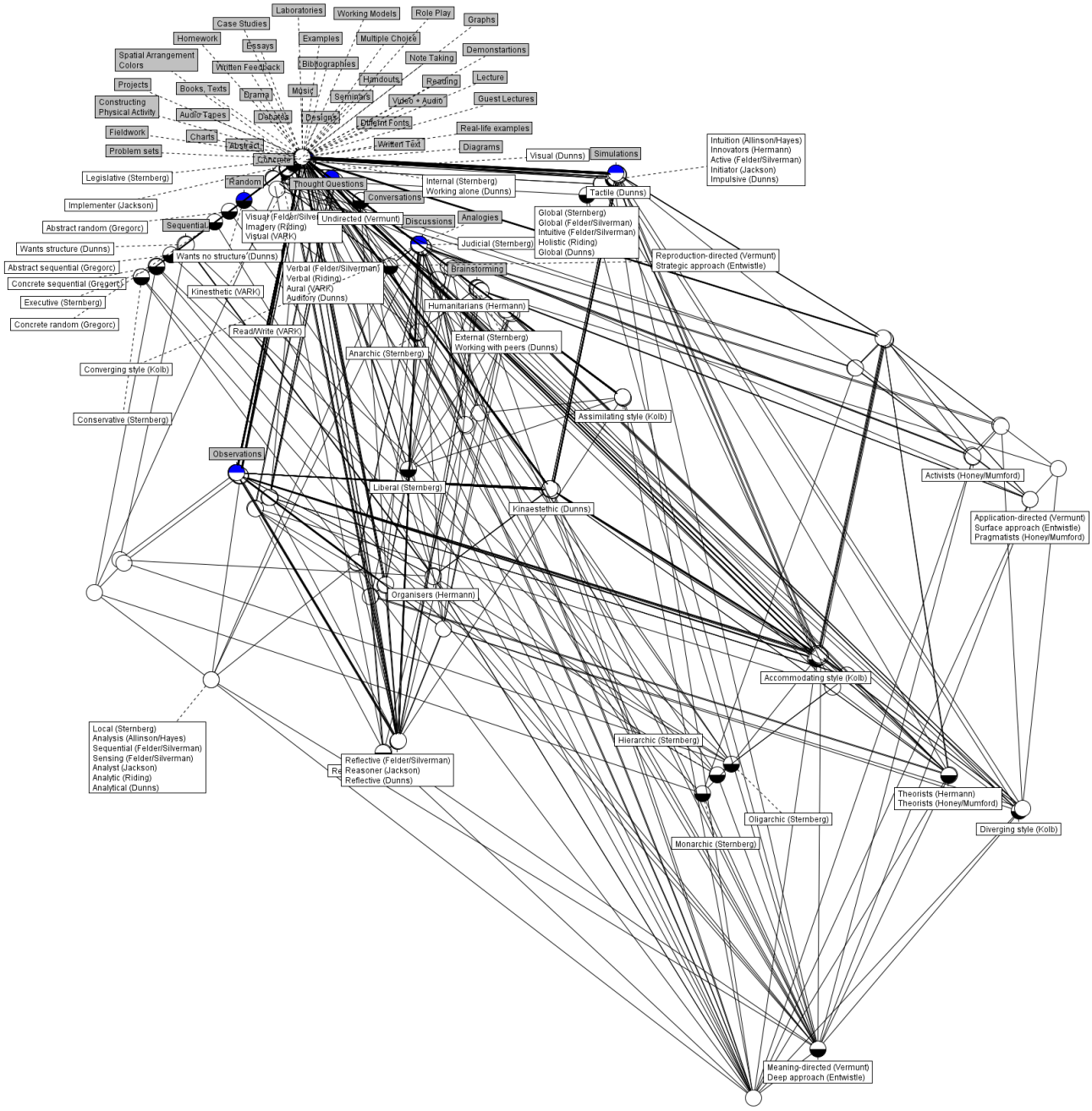

Figure 8: Chain decomposition as simplified visualization of the ordered set of formal concepts.

"Clusters" of learning styles are indicated by the white boxes which include more than one object-label. As an example, the set {*Intuition* (as described by Allinson & Hayes, see section 4.10), *Innovators* (as described by Hermann, see section 4.9), *Active* (as described by Felder & Silverman, see section 4.7), *Initiator* (as described by Jackson, see section 4.5), *Impulsive* (as described by Dunns, see section 4.2) shown in the white box at the top right-hand corner of Figure 8 is considered as a cluster of learning styles: they have been assigned to the exactly same set of attributes. From this point of view they are conceptually the same. If they are (from a face validity point of view) conceptually not the same, at least one attribute that distinguishes between them has to be added to the formal context.

"Clusters" of learning styles are indicated by the white boxes which include more than one object-label. They have been assigned to the exactly same set of attributes. From this point of view they are conceptually the same.

An initial analysis of these FCA results suggested that different kinds of "attributes" can be clearly distinguished from each other, such as: "content-related" properties of the learning resources (e.g. "abstract") or "physical" properties of the learning resources (e.g. "graphs").

In Table 2 we color-coded these "factors" (again, this exercise has been only done by one researcher and a larger sample size and maybe also cross validation would be required to draw more meaningful conclusions from it):

Content-related properties of learning ressorces:
e.g. "abstract" or "concrete"
Physical properties of learning ressorces:
e.g. "graphs" or "written"
Order:
this refers to notions on the preferred order in which learners consume them (e.g. "sequential" or "random")
Broader learning activities:
such as „role play" or "brainstorming"
Instructional methods:
e.g. "providing examples" or "providing analogies"
Properties of test items:
e.g. "Multiple Choice"

In addition to that, the following Table 2 makes it easier to identify the above mentioned "clusters" of learning styles since they are highlighted by the grey and white areas. These clusters are in line with the white boxes (with the object-labels) in the Figurs 7 and 8.

Table 2: Clusters and factors of learning styles and related learning resources and activities

	Order	Broader learning activities	Physical properties of LRs	Physical properties of LRs	Physical properties of LRs	Instructional methods	Broader learning activities	Broader learning activities	Broader learning activities	Physical properties of LRs	Physical properties of LRs	Broader learning activities	Broader learning activities	Instructional methods	Broader learning activities	Broader learning activities	Broader learning activities	Content-related properties of LRs	Broader learning activities	Instructional methods	Broader learning activities	Properties of test items	Broader learning activities	Broader learning activities	Physical properties of LRs	Broader learning activities	Broader learning activities	Broader learning activities	Physical properties of LRs	Physical properties of LRs	Instructional methods	Instructional methods	Order	Physical properties of LRs	Broader learning activities	Content-related properties of LRs	Broader learning activities	Broader learning activities	Broader learning activities	Instructional methods	Broader learning activities	Broader learning activities	Instructional methods	Instructional methods	Broader learning activities	Broader learning activities	Broader learning activities	Broader learning activities	Broader learning activities
	Random	Bibliographies	Colors	Spatial Arrangement	Designs	Examples	Physical Activity	Constructing	Role Play	Charts	Different Fonts	Note Taking	Demonstartions	Written Feedback	Music	Essays	Handouts	Abstract	Fieldwork	Thought Questions	Audio Tapes	Multiple Choice	Guest Lectures	Lecture	Graphs	Drama	Reading	Brainstorming	Video + Audio	Diagrams	Real-life examples	Working Models	Sequential	Written Text	Seminars	Concrete	Debates	Homework	Projects	Analogies	Books, Texts	Case Studies	Observations	Discussions	Conversations	Laboratories	Problem sets	Simulations
Wants structure (Dunns)																																1																
Wants no structure (Dunns)	1																																																
Concrete sequential (Gregorc)																		1														1			1														
Abstract sequential (Gregorc)																		1														1																	
Abstract random (Gregorc)	1																	1																																
Concrete random (Gregorc)	1																																		1														
Legislative (Sternberg)																																			1	1	1											
Strategic approach (Entwistle)																	1					1													1				1									
Reproduction-directed (Vermunt)																	1					1													1				1									
Undirected (Vermunt)														1			1									1																			1				
External (Sternberg)																											1						1			1								1	1			
Working with peers (Dunns)																											1						1			1								1	1			
Executive (Sternberg)																							1										1	1		1		1									
Judicial (Sternberg)																						1															1	1						1	1			
Working alone (Dunns)																	1				1				1			1								1			1								
Internal (Sternberg)																	1				1				1			1								1			1								
Global (Dunns)																		1						1					1		1														1		1
Holistic (Riding)																		1						1					1		1														1		1
Global (Felder/Silverman)																		1						1					1		1														1		1
Global (Sternberg)																		1						1					1		1														1		1
Tactile (Dunns)							1	1					1						1																						1				1		1
Analytical (Dunns)																														1		1			1				1		1	1			1	
Analytic (Riding)																														1		1			1				1		1	1			1	
Analyst (Jackson)																														1		1			1				1		1	1			1	
Sequential (Felder/Silverman)																														1		1			1				1		1	1			1	
Analysis (Allinson/Hayes)																														1		1			1				1		1	1			1	
Local (Sternberg)																														1		1			1				1		1	1			1	
Conservative (Sternberg)																	1						1	1					1			1	1		1											
Auditory (Dunns)															1						1				1			1						1		1							1	1			
Aural (VARK)															1						1				1			1						1		1							1	1			
Verbal (Riding)															1						1				1			1						1		1							1	1			
Visual (VARK)			1	1	1					1	1													1					1				1														
Visual (Felder/Silverman)			1	1	1					1	1													1					1				1														
Imagery (Riding)			1	1	1					1	1													1					1				1														

	Order	Broader learning activities	Physical properties of LRs	Physical properties of LRs	Physical properties of LRs	Instructional methods	Broader learning activities	Broader learning activities	Broader learning activities	Physical properties of LRs	Physical properties of LRs	Broader learning activities	Broader learning activities	Instructional methods	Broader learning activities	Broader learning activities	Broader learning activities	Content-related properties of LRs	Broader learning activities	Instructional methods	Broader learning activities	Properties of test items	Broader learning activities	Broader learning activities	Physical properties of LRs	Broader learning activities	Broader learning activities	Broader learning activities	Physical properties of LRs	Physical properties of LRs	Instructional methods	Instructional methods	Order	Physical properties of LRs	Broader learning activities	Content-related properties of LRs	Broader learning activities	Broader learning activities	Broader learning activities	Instructional methods	Broader learning activities	Instructional methods	Instructional methods	Broader learning activities	Broader learning activities	Broader learning activities	Broader learning activities	Broader learning activities
	Random	Bibliographies	Colors	Spatial Arrangement	Designs	Examples	Physical Activity	Constructing	Role Play	Charts	Different Fonts	Note Taking	Demonstartions	Written Feedback	Music	Essays	Handouts	Abstract	Fieldwork	Thought Questions	Audio Tapes	Multiple Choice	Guest Lectures	Lecture	Graphs	Drama	Reading	Brainstorming	Video + Audio	Diagrams	Real-life examples	Working Models	Sequential	Written Text	Seminars	Concrete	Debates	Homework	Projects	Analogies	Books, Texts	Case Studies	Observations	Discussions	Conversations	Laboratories	Problem sets	Simulations
Read/Write (VARK)		1										1		1		1	1					1				1														1								
Implementer (Jackson)										1							1					1							1				1	1			1			1						
Verbal (Felder/Silverman)															1						1				1			1					1		1							1	1			
Sensing (Felder/Silverman)			1	1																									1		1			1				1		1	1				1	
Kinesthetic (VARK)						1	1	1	1				1									1			1					1	1															
Humanitarians (Hermann)									1				1		1							1			1		1									1								1	1		
Anarchic (Sternberg)	1					1									1	1									1		1								1								1	1		
Pragmatists (Honey/Mumford)																						1					1						1	1		1	1						1	1	
Surface approach (Entwistle)																						1					1						1	1		1	1						1	1	
Application-directed (Vermunt)																						1					1						1	1		1	1						1	1	
Activists (Honey/Mumford)							1	1	1										1																1	1		1						1	1	
Organisers (Hermann)														1			1						1	1		1						1	1					1		1		1			1	
Oligarchic (Sternberg)																				1				1								1				1	1		1	1	1			1	1	1
Intuitive (Felder/Silverman)			1	1	1						1	1							1						1				1							1							1		1
Monarchic (Sternberg)																			1				1								1			1		1	1		1	1	1			1	1	1
Hierarchic (Sternberg)																		1		1			1									1				1	1		1	1	1			1	1	1
Kinaesthetic (Dunns)						1	1	1	1				1						1				1			1				1	1									1	1			1		1
Assimilating style (Kolb)												1				1				1			1	1			1	1			1		1			1		1	1	1		1	1		
Visual (Dunns)		1	1	1	1					1	1	1		1		1	1					1			1		1			1			1						1							
Converging style (Kolb)						1							1			1			1				1	1			1				1	1				1	1	1	1	1				1		
Impulsive (Dunns)			1	1	1	1	1	1	1		1	1			1	1			1						1				1							1								1		1
Initiator (Jackson)			1	1	1	1	1	1	1		1	1			1	1			1						1				1							1								1		1
Active (Felder/Silverman)			1	1	1	1	1	1	1		1	1			1	1			1						1				1							1								1		1
Innovators (Hermann)			1	1	1	1	1	1	1		1	1			1	1			1						1				1							1								1		1
Intuition (Allinson/Hayes)			1	1	1	1	1	1	1		1	1			1	1			1						1				1							1								1		1
Theorists (Honey/Mumford)										1								1		1	1	1	1	1		1		1			1			1			1	1	1		1			1	1	1
Theorists (Hermann)										1								1		1	1	1	1	1		1		1			1			1			1	1	1					1	1	1
Liberal (Sternberg)	1						1	1	1						1	1		1	1	1					1		1				1				1			1		1		1	1	1	1	
Accommodating style (Kolb)		1				1					1		1	1		1			1				1			1		1		1		1				1	1		1	1	1			1	1	1
Diverging style (Kolb)		1				1					1	1	1	1		1			1	1			1			1	1	1		1					1				1		1	1	1	1	1	1
Reflective (Dunns)		1								1			1	1			1			1	1	1	1	1	1		1	1	1	1		1	1		1	1		1	1	1	1	1	1	1		1	
Reasoner (Jackson)		1								1			1	1			1			1	1	1	1	1	1		1	1	1	1		1	1		1	1		1	1	1	1	1	1	1		1	
Reflective (Felder/Silverman)		1								1			1	1			1			1	1	1	1	1	1		1	1	1	1		1	1		1	1		1	1	1	1	1	1	1		1	
Reflectors (Honey/Mumford)		1								1			1	1			1	1		1	1	1	1	1	1		1	1	1	1		1	1		1	1		1	1	1	1	1	1	1		1	
Deep approach (Entwistle)												1		1				1	1	1	1		1	1	1		1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Meaning-directed (Vermunt)												1		1				1	1	1	1		1	1	1		1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

8. "Stealth Assessment": Gaining Insight into Cognitive States and Styles in a Unobtrusive Fashion

To realise educationally intelligent personalisation and meaningful learning analytics, the pedagogical underpinnings must be complemented with an educational AI that is capable of assessing psychological states (such as motivation) and learning progress, and problem solving behaviour and to reason over the incoming information in order to get some kind of "understanding" about the learners and about what is going on within an aware learning space.

Learning styles or cognitive styles are often considered being a key factor to improve learning. Thus, an important task for learning analytics is to identify existing learning styles, to assess them in real-time within learning situations and provide an educational meaningful and intelligent response, for example by providing or recommending suitable learning objects.

A key factor of smart user modelling and educational AI features to fill the models with information is a seamless, a "stealth" assessment of performance and activities. The reason why it is critical not to disturb learners is to avoid directing their attention towards tasks or questions peripheral to their actual learning focus. In turn, having a certain degree of understanding of preferences and styles is key to a better and perhaps more effective and satisfying learning.

One of the most advanced approaches is so-called micro adaptivity (Kickmeier-Rust & Albert, 2010; Kickmeier-Rust, Mattheiss, Steiner, & Albert, 2011) an attempt to intelligently interpret all activities and actions of a learner within the virtual world of a game without interrupting or harming flow and gaming experience. Theoretical foundation is a well-elaborated and applied cognitive theory named Competence-based Knowledge Space Theory (CbKST; cf. Albert & Lukas, 1999; Doignon & Falmagne, 1999). In the past years the approach to user and domain modelling was implemented in various environments including educational computer games (cf. Baalsrud Hauge, Bellotti, Kickmeier-Rust, & Nadolski, 2013; Kickmeier-Rust & Albert 2012; Reimann, Kickmeier-Rust, & Albert, 2013). Recently, the strong focus on learning and competence development of this modelling approach was extending to psychological states such as motivation (cf. Mattheiss, Kickmeier-Rust, Steiner, & Albert, 2009). Within this (and similar approaches) the idea is to use more or less reliable and valid user behaviours as indicators for a learner's motivation.

To account for the specific needs of learning analytics and to achieve a non-invasive, unobtrusive assessment, Kickmeier-Rust & Albert (2010) developed a formal model of the problem solving behaviour in learning situations (e.g., virtual scenarios or games). Such learning situations (LeS) are characterised by a large degree of freedom and complex problem solving demands. The problem

solution process is considered to be a meaningful sequence of problem solution states establishing a problem space. Stochastic process models are applied in order to estimate the likelihood of certain state transitions and to estimate the probability of reaching a solution state (within a specific time interval). In other terms, a LeS is segmented in to a set of possible problem solution states, each mapped to one of a set of possible competence states. By this means, the educational AI of a game can interpret the behaviour of the learner in terms of available knowledge, un-activated knowledge, or missing knowledge, simply by mapping the actions of the learner to competence states. In the context of learning styles and cognitive styles, problem solving behaviour may serve substantially to the identification of learning styles.

A similar approach was developed by Mattheiss and colleagues (Mattheiss et al., 2010) in the context of motivation. They reviewed the literature in the fields of achievement motivation and flow and developed a global framework that allows linking performance indicators to motivational states and to provide tailored interventions to stabilise flow experience while learning or to increase achievement motivation by adapting the learning environment and contents.

9. Learning Styles in LEAs Box

In the following sub-sections, we describe how the research on learning- and cognitive styles has a practical impact in the Lea´s Box project in general and how some Lea's tools can be applied for learning-style related activities in the classroom. Facing the fact that learning styles per se can be viewed critically, we suggest that the priority and extent to which the concrete tasks of the project are affected by learning styles related features should be rather limited.

9.1. Studies at Grazer Schulschwestern

In the following section we describe the two pilot studies at the Grazer Schulschwestern. Initial methodological considerations have been described in Deliverable 5.5 (Piloting and Evaluation Report II). Since the submission of this deliverable several minor methodological issues, such as the questionnaires and instruments to be provided to the students have been modified and refined. In this section we focus on those modifications and changes compared to the description in D5.5 and in particular ***on the research activities which are related to the learning styles field***. The results and outcomes of these studies will be described in Deliverable 5.6 (Piloting and evaluation report III).

As described in D5.5, two studies will have been carried out at the Grazer Schulschwestern until the end of the summer semester 2016 (i.e. until mid of July). The first study has been carried out from April to begin of June 2016 and students learn about the knowledge domain of applied ecology (ecosystems). The second study is currently in progress (start date: June 2016) until the mid of July

2016 and deals with the domain “the senses” (i.e. sight, hearing, taste, smell, balance and acceleration).

For both studies, the teacher had to do some preparations in advance: they defined the knowledge domain, i.e. he decided upon the objects their properties and assigned them by using the weSPOT-FCA tool (see Section 4.1 in D5.5). They also assigned learning resources to subsets of objects and attributes. This effort resulted in a concept lattice, indicating the sub- and super concept relations between the entities of the knowledge domain. Finally, they evaluated all learning resources with regards to the dimensions of the Index of Learning Styles Questionnaire based on the Felder-Silverman model (see also next subsection as well as Section 3.7). In other words, for all the learning resources there are expert evaluations available (i.e. from the teacher) indicating their locations on the four bipolar continua: i) perception (sensory vs. intuitive), ii) input (visual vs. auditory), iii) organization (inductive vs. deductive) and iv) understanding (sequential vs. global).

Both studies can be divided into three consecutive phases: a pre-phase, intervention-phase and post-phase. The details regarding the procedure and instruments for the students are listed below.

Study 1

Pre-phase

In the pre-phase, the students filled out the following questionnaires and inventories:

1.) Self-constructed knowledge test

To measure the student’s declarative knowledge states, a (domain-) knowledge test in line with the topic of the inquiry (i.e. applied biology) has been created by the teacher. To be more precise, the whole knowledge test has been separated into 2 parallel versions. Half of the students received parallel test A as pre-test and parallel test B as post-test (and vice versa for the other half of students).

2.) Index of Learning Styles Questionnaire

To measure the student’s learning styles, the Index of Learning Styles Questionnaire which is based on the Felder-Silverman model (see also Section 3.7) has been provided to the students. This questionnaire consists of 44 Items and covers 4 bipolar scales: i) perception (sensory vs. intuitive), ii) input (visual vs. auditory), iii) organization (inductive vs. deductive) and iv) understanding (sequential vs. global). The reasons for providing this particular questionnaire (or why we selected this particular model are as follows):

i) There is actually a very pragmatic aspect: it is one of rather few questionnaires which is freely available (https://www.engr.ncsu.edu/learningstyles/ilsweb.html).

ii) As described in Section 5.4, it is by far the most used model / questionnaire in the field of Technology-enhanced learning and many other authors and researchers seem to have made good experiences with this particular inventory.

iii) As described in Section 0 it covers the most important factors of the extended FCA analysis such as Content-related properties and physical properties of the learning resources, suggestions on the order in which the learning resources should be consumed, etc.

The items have been translated into German and partly simplified (e.g. by avoiding foreign words) to avoid misconceptions or confusion on the side of the 14-15 year old students.

Intervention phase

The students interacted with the weSPOT platform (see Section 4.1 in D5.5) in general and the weSPOT FCA tool in particular: They interacted with the concept lattice, scanned through the learning resources and selected those learning resources they wanted to consume and learn more intensely. Once they had learned a particular learning resource, they were asked to fill out an evaluation form (see Appendix, Section 13.1) to make the following pieces of information explicit: the date, a short summary of the learning resource (to foster reflection and to check if they actually consumed the learning resource) and an evaluation of the learning resource (by a 5-point Likert scale) indicating to which extend this particular learning resource has been considered as helpful and useful in their current learning progress.

During the whole inquiry process, the students had to deliver several tasks and work orders (e.g. describing and visualizing the differences between a food pyramid and a food chain). These work orders had to be uploaded by the students to the weSPOT platform.

During the intervention phase, the teacher uses the Lea´s Box MyClass tools (for an ongoing and formative assessment of the students) and the Flower app (for a final and global assessment of the students).

Post-phase

In the post-phase, the students filled out the 2nd parallel version of the self-constructed knowledge test (see above).

The teacher makes a final and global assessment of the student´s competence state with regards to 4 competences by using the Lea´s Box Flower App.

Study 2

Pre-phase

1.) Self-constructed knowledge test (see above)

In study 2 we applied the same principles as for study 1 with respect to the declarative knowledge test (see above).

2.) Intrinsic Motivation Inventory

To assess the intrinsic motivation of the students, we adapted the Intrinsic Motivation Inventory (IMI; Deci & Ryan, 2004; Ryan, 1982) to the needs of our sample, i.e. the inventory has been translated and simplified a bit. From the original six subscales of the IMI, three subscales (interest/enjoyment, effort/importance, value/usefulness) have been selected since they are considered as most important for the purpose of this use case. Each subscale is represented by three statements, which have to be rated on a 7-point scale ranging from 1 (not at all true) to 7 (very true). We also created a slightly modified version of the IMI by reformulating the items into the future sense and in terms of expectations. Otherwise, the items wouldn´t make much sense as a pre-test. As an example, the item "I thought this activity was quite enjoyable" has been formulated into "I think this activity will be quite enjoyable". Both versions of the IMI are provided in the appendix (Sections 13.2 and 13.3).

Intervention phase

The intervention phase is similar as for Study 1, i.e. the students interact with the weSPOT platform and the concept lattice, they select learning resources by their own, they fill out the evaluation form and deliver work orders. In the middle of the intervention phase, they will be provided with the IMI (see above).

Compared to Study 1, the teacher also makes use of the LEAs Box´ FCA Learning Analytics (i.e. the 3 different views: competence X activities, competences X students, and activities X students; see D5.5 for more details).

Post-phase

In the post-phase, the students are going to fill out the following questionnaires and inventories:

1.) Self-constructed knowledge test (see above)

2.) Index of Learning Styles Questionnaire (see pre-phase of Study 1, above)

3.) Intrinsic Motivation Inventory (see above)

Analysis and contributions to the learning styles research questions

Taking both studies together, we will have the following measurements and assessments:

- Students learning styles (paper-and-pencil format) and their stability over 4 months (the Index of Learning Styles Questionnaire has been provided at the pre-phase of Study 1 in April 2016 and will be provided again at the post-phase of study 2 in July 2016).
- Students evaluations of learning resources (paper-and-pencil format)
- Teacher´s evaluation of learning resources (paper-and-pencil format)
- Students gain in declarative knowledge (paper-and-pencil format, difference between post- and pre-test)
- Students (global) self-assessment (via the Lea's Box Flower App)
- Teacher´s (global) assessments of the students (via the Lea's Box Flower App)

- Teacher´s (specific) assessments of the students´ work orders (offline)
- Teacher´s formative assessment of the students (via the Lea's Box MyClass Tools)
- weSPOT´s automated, non-invasive assessment (via weSPOT LARAe tool, see D5.5)
- Students´ intrinsic motivation fluctuations over time (only for Study 2)

The students learning styles (as measured in the pre-phase of Study 1) can be compared with their evaluation of the learning resources (as measured during the in the intervention-phase of Study 1) by taking also the learning resources modalities and learning-style relevant features (as measured by the teachers evaluation of the learning resources) into consideration. This analysis is testing to bring insight into the matching hypothesis (see also Section 3), at least by considering the students (subjective) self-assessment if or if not a particular learning resource was helpful, suitable and useful or not.

As pointed out by Kirschner and van Mennienboer (2013), the preferred way of learning might not be the most efficient or productive way of learning, Thus, a probably more relevant aspect of the matching hypothesis is the question if the "matching between learners and learning resources" actually leads to better (objective) performance. This research aspect will be covered by the including also the students gain in declarative knowledge, the teacher´s (global) assessment of the students, and the teacher´s (specific) assessments of the students´ work orders as dependent variables in the analysis.

By assessing the students' learning styles after 4 months again (see pre-test Study 1 and post-test Study 2) we can evaluate the test-retest reliability, one of the main psychometric qualities of a questionnaire or instrument (as described in Section 6, many learning styles inventories do have severe psychometric weaknesses).

Finally, a correlative analysis which includes all the above mentioned variables might lead to unexpected insights or new hypothesis for further investigations in the field of learning styles.

The concrete result of this work is to contribute another piece of experimental results from practice to the general learning styles community.

9.2. Applying FCA to Categorize Learning Resources

The FCA tool can be used to structure the learning resources in terms of their modalities as well as any other properties that are considered relevant concerning learning styles.

As described in Section 9.1, the FCA tool has already applied in the context of two pilot studies at the Grazer Schulschwestern. In a first step, the teacher evaluated all learning resources with respect to the four dimensions of the Index of Learning Styles Questionnaire (which is based on the Felder-Silverman model). This experts´ assessment has been done in a paper-and-pencil format on a 5-point

Likert scale (ranging from 0 to 4). The following table shows the actual outcomes of this procedure for Study 1 (a value of 0 means that the according learning resource is definitely leaning towards the first pole of the scale, e.g. “active”, “sensing”, “visual” or “sequential” and a value of 4 means that the learning resource is definitely leaning towards the second pole, e.g. “passive”, “intuitive”, “verbal” or “global”.

Table 3: Teachers evaluation of the learning resources for Study 1 (raw values)

Learning Resources	active-reflective	sensing-intuitive	visual-verbal	sequential-global
Ökosystem 1	4	1	4	2
Ökosystem 2	4	1	4	2
Ökosystem 3	4	1	3	2
Ökosystem 4	3	1	1	2
Dienstleistungen 1	4	1	4	1
Dienstleistungen 2	4	0	4	1
Dienstleistungen 3	3	1	1	3
Dienstleistungen 4	2	2	2	4
Biozönose 1	4	1	3	4
Biozönose 2	3	1	1	4
Biozönose 3	4	1	4	2
Biotop 1	4	1	3	4
Biotop 2	3	1	1	4
Biotop 3	4	1	4	2
Nahrungsnetz 1	1	2	2	2
Nahrungsnetz 2	2	2	2	2
Nahrungsnetz 3	3	2	2	2
Nahrungsnetz 4	3	1	1	3
Nahrungkette 8	4	1	3	2
Nahrungspyramide 4	3	1	1	3
Nahrungspyramide 5	3	2	2	2
Nahrungspyramide 6	2	2	2	2

However, to effectively apply the FCA, ratings have to be dichotomous. Thus, in a second step, assessments given by the teacher were dichotomised. The next table shows the dichotomised values assigning all learning resources to one of the two poles of the four dimensions. If a learning resource has been evaluated as being in-between the two extrema, the FCA table shows no assignments with regards to this dimension (see for example the case of learning resource “Ökosystem 1” with regards to the dimension sequential-global). This “FCA table” constitutes a formal context (Wille, 2005).

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As described in Deliverable D3.1 (“Review Article about LA and EDM Approaches”) the final outcome of the FCA based on such a knowledge context is a concept lattice (see Figure 9).

Table 4: Teachers evaluation of the learning resources for Study 1 (dichotomised values).

Learning Resources	active	reflective	sensing	intuitive	visual	verbal	sequential	global
Ökosystem 1	0	1	1	0	0	1	0	0
Ökosystem 2	0	1	1	0	0	1	0	0
Ökosystem 3	0	1	1	0	0	1	0	0
Ökosystem 4	0	1	1	0	1	0	0	0
Dienstleistungen 1	0	1	1	0	0	1	1	0
Dienstleistungen 2	0	1	1	0	0	1	1	0
Dienstleistungen 3	0	1	1	0	1	0	0	1
Dienstleistungen 4	0	0	0	0	0	0	0	1
Biozönose 1	0	1	1	0	0	1	0	1
Biozönose 2	0	1	1	0	1	0	0	1
Biozönose 3	0	1	1	0	0	1	0	0
Biotop 1	0	1	1	0	0	1	0	1
Biotop 2	0	1	1	0	1	0	0	1
Biotop 3	0	1	1	0	0	1	0	0
Nahrungsnetz 1	1	0	0	0	0	0	0	0
Nahrungsnetz 2	0	0	0	0	0	0	0	0
Nahrungsnetz 3	0	1	0	0	0	0	0	0
Nahrungsnetz 4	0	1	1	0	1	0	0	1
Nahrungkette 8	0	1	1	0	0	1	0	0
Nahrungspyramide 4	0	1	1	0	1	0	0	1
Nahrungspyramide 5	0	1	0	0	0	0	0	0
Nahrungspyramide 6	0	0	0	0	0	0	0	0

The following concept lattice can be “read” as follows: every node constitutes a formal concept – which is a pair of two sets: a set of learning resources and their properties (or attributes). By collecting all labels of learning resources which can be reached by descending paths one can see the extension of the formal concept: a formal concept´s extension is the set of objects which belongs to it. By collecting all labels of properties or attributes which can be reached by ascending paths one can see the intension of the formal concept: a formal concept´s intension is the set of attributes which belongs to it.

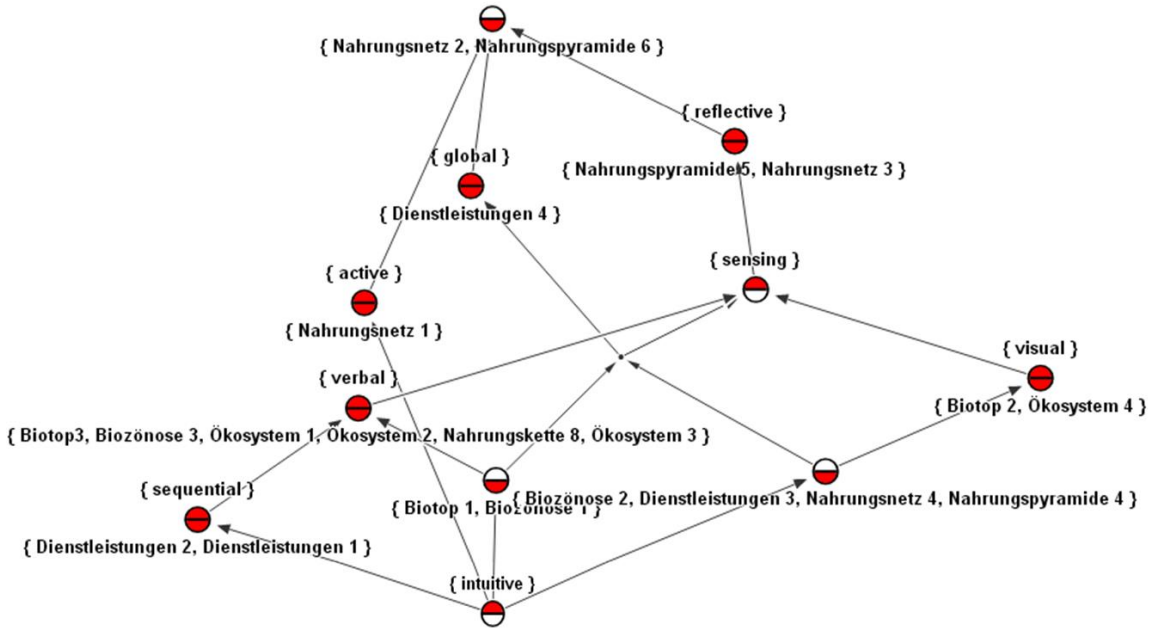

Figure 9: Resulting concept lattice with learning resources and the learning style-relevant properties from study 1

In case there are several learning resources assigned to a particular formal concept (see for example the concept with the label “Nahrungspyramide 5, Nahrungsnetz 3”), this means that these set of learning resources share the same properties (in this case they share the property “reflexive”). Learning resources which are located above others and can be reached by ascending paths are more generic, i.e. they possess fewer properties than the learning styles located below. As an example, compare the formal concept “Biotop 2, Ökosystem 4” (which share the properties “visual”, “sensing” and “reflective”) with the concept with the label “Nahrungspyramide 5, Nahrungsnetz 3” attached to it.
Such a clustering (combining learning styles which share the same features into a single formal concept) and structuring (ordering the learning styles hierarchically) approach by applying the FCA enables teachers and students to get an overview of learning resources with respect to properties considered as relevant for learning styles (of course the same can be done with properties considered as relevant for cognitive styles). It might support the decision process to select learning resources (either by the teacher or by the students themselves).

The concrete result of this work is to demonstrate to use FCA and related software tools to support teachers in categorizing and characterizing learning materials and activities. This is not trivial since usually learning materials can be linked to various characteristics (such as styles).

9.3. Analysing "big data"

As described in the following subsection, partner SCIO has large data sets of students (11k) who completed a learning styles inventory covering the four dimensions additive, visual, kinesthetic, and analytical learners. For parts of these students, SCIO holds test data for various school subjects as well. To contribute to the research community, we can perform correlation studies and apply data mining procedures to identify possible relationships between the results in the learning styles inventory and test achievements. In such study, Lea's Box can contribute to the state of the art in the research field by (a) providing results on the basis of large samples but also (b) to address open questions such as the degree to which individual learning styles are moderated by the nature of the respective subject matter (STEM vs. language learning, vs cultural subjects, or arts). In parallel we can demonstrate how Lea's Box can handle big data sets (e.g., by using a csv import function).

The efforts in the context of existing large data sets on learning styles can contribute the state-of-the-art in the learning styles research community.

9.4. Guidelines for Teachers

SCIO has addressed the topic of learning styles in multiple previous projects, including *INIDIVIDUALIZACE* (funded by the European Social Fund), which focused on forms of individualization of teaching according to the various needs of students. Voices from schools called for concrete and specific advice on how to differentiate teaching depending on learning styles. The work of the project resulted in a final product in form of a teacher handbook.

Based on the work in Lea's Book and this particular task, SCIO updated and revised their approaches, which until then had been favorite among the professional pedagogical public in the Czech Republic (in 2010). These included:

1. Approaches based on information processing, assuming that learning style is a characteristic of how a person receives and processes information from their environment (cf. Kolb, Gregorc);
2. Approaches based on personality, assuming that learning style is very dependent on personality characteristics (cf. Myers-Briggs, Holland, Geering);
3. Approaches based on a typology of human senses. They conclude that differences in learning styles are based on differences in activity and preference for one of the senses (cf. Bandler, Grinder);

4. Approaches based on the environment pursuing different environment variables, e.g. physical, psychological or social (cf. Witkin, Eison);
5. Approaches based on social interaction, assuming learning styles to be related to various forms of social relationships to others (cf. Grasha-Reichman, Perry Merrill);
6. Intelligence based approaches, assuming learning style to be derived from a student´s intelligence. This includes a well-known theory of Multiple Intelligences by Howard Gardner;
7. Approaches based on the identification of different dominant structures in the brain, e.g. cerebral hemispheres, assuming relation between learning styles and higher activity in certain parts of the brain (cf. Sperry, Edwards).

At the time of review of the existing scientific literature in 2010, it was clear that the topic of learning styles is often too academic and too psychological for application in everyday school practice. There are a multitude of interwoven theories and models of learning styles published in 2004 there were seventy-one published scientific categorisations of learning styles stated). There were obvious problems related to the validity and reliability of any tests aimed at learning styles. Therefore, SCIO built their approach on the real needs and daily practice of Czech schools. Amid other issues, Czech schools were largely familiar with LSI questionnaire (Dunn, Dunn, Prize, 1989). This was translated to Czech by Jiri Mares. Czech version was tested on 891 pupils of primary schools and 402 secondary school students.

Within the INIDIVIDUALIZACE project SCIO developed also a simple questionnaire distinguishing in the perceptual field between visual, auditory and kinesthetic preferences, and then between global and analytical types. The questionnaire was made available to students for free and it was taken by some 11 thousand participants around the age of 15 years. Furthermore, we conducted a series of workshops with teachers at Czech schools where we showed them relevant and specific tips how to individualise instruction, including the possibility of adapting teaching to the needs of learning styles. On the basis of the current task we are updating and revising the test and re-evaluate its meaningfulness.

In conclusion, in the prior project we prepared an extensive publication (170 pages) reviewing the topic of learning styles from a purely practical point of view, i.e. what specific activities are suitable for working with students of a certain type. This publication was available free of charge to teachers from all schools in the Czech Republic and in 2011 it enjoyed great popularity. The current work in the field of learning styles in the Lea's Box project will allows us to further reflect on the current state of knowledge and to modify the established practice in Czech schools, including already existing procedures. Given the extent and experience SCIO has working with schools in the Czech Republic on the topic of learning styles, a smooth implementation of the theoretical knowledge into school daily practice can be assumed.

The efforts spent on Learning Styles will allow for updating and revising existing products for teachers. Specifically, we will provide the revised handbook for teachers through the Lea's Box portal as a feature.

9.5. Applying Lea' s Platform tools for Learning Styles related Analyses

Being aware of the shortcomings of typical learning styles inventories, we want to equip the Lea's Box platform with the options for teachers to conduct related analyses. The conceptual or theoretical foundations, however, remain up to the teacher. We will provide guidelines in form of a handbook (see above) as starting point. On this basis a teacher can define a set of characteristics (this might be Kolb's learning styles, a set of 21st century skills, or any other set of categories) for learning activities. Such activity might be attending a certain learning object in an external learning app. All activities that are pushed into the Lea's Box system, subsequently can be analysed and displayed to the teachers by the visualizations of Lea's Box, including the OLM.

In addition to characterizing external activities, the internal 'flower app', which is a handy tool to allow students to perform self-evaluations, can be used to provide students with typical learning styles inventories (Figure 10). Likewise, the flower app can be used to evaluate learning materials (learning objects).

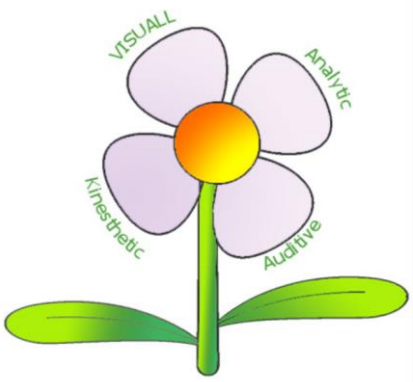

Figure 10: Lea's Box' flower app applied for presenting learning styles inventories or simply asking for individual preferences.

Finally, Lea's Box' integrated FCA tool can be used to display distinct clusters of specific students and/or activities/learning materials. For example, we can describe students along certain dimensions (say the four typical learning styles dimensions). However, if students are not labeled with a single style but along various continua, it's very difficult for teachers to grasp the full picture in their class and to adjust their teaching accordingly. FCA helps displaying distinct clusters; in this particular case the

clusters are students with similar characteristics. This, in turn, helps teachers individualizing teaching, perhaps in form of selecting learning and/or assessment materials tailored to the concrete characteristics.

The concrete tangible result of this strand is to demonstrate how Lea's Box' tools can be used to identify individual learning styles / characteristics and to identify distinct clusters and groups among students and learning materials.

10. Summary and next steps

This report provides an overview of the state-of-the art in the field of learning styles. As pointed out in section 2 and exemplified in section 4, the learning style field is characterised by a wide range of theories, models, inventories, basic assumptions about how students learn, and recommendations on how students should learn. In section 7 we attempted to extract the quintessence of this set of most prominent theories, models and inventories. The goal of this exercise of applying the formal concept analysis was to further examine the overlaps, the similarities and the dissimilarities, as well as relations between the models. However, as outlined in section 6, even if the idea that there are students with certain characteristics and the main exercise of the teacher (and the educational system in general) is just to match students with the appropriate learning resources and activities seems intuitively appealing, the reality is of course more complex. The "reality", as covered by scientifically sound research activities and the analysis and interpretation of gathered data, seems to suggest that this intuitively appealing idea doesn't work out that straightforward. Besides that, there is a wide range of other problems and insufficiencies in the field. Additionally, we at Lea´s Box tried to keep "agnostic" with regards to the matching hypothesis or to build upon more recent developments in that direction (see section 5, respectively section 5.1).

This also points strongly to one area in which the learning styles' research is overly confident: an ideal pedagogical setting is not one in which a student, at a given point in time, is assessed thoroughly and accordingly provided with a "matching" or "non-matching" battery of learning content to follow his or her most efficient path to whichever learning goal may be set by whomever. The desires, dispositions and changes of a learner that range beyond "style" or "strategy" are huge blind spots in the learning styles' research paradigms as have been brought forth by the community so far. That the research community cannot even falsify the matching hypothesis after decades of research is a dreadful statement about the lack of coherent, converging and interconnected insights. One has to wonder in which state the teaching of languages would be should it still be in debate whether it is more appropriate to let students learn, at the start of secondary education, five languages or three or one to better grasp the concept of grammar and by which way these languages should be chosen by whom.

Neither teachers' characteristics or learners' personalities nor organisational settings or the interests at stake of learners, teachers and third parties (parents, employers, customers) feature prominently (every model presented here, except Dunn, 2003a) or at all in the styles available. Neglecting a basic fact of everyday life such as the very different behaviour of a student during physical education in school and during a sport's club activity leaves the theories struggling to reproduce findings. And it should be no wonder to anyone that there is a potpourri of models out there when neither the scope, nor the acting subjects or delimitation of the research field is agreeable between different schools of thought, which would be axiomatic to compare models in a falsifiable manner with each other.

In section 9 we described how some of the parts of the learning style field which seem to work and which are appreciated by teachers have been incorporated in the project, not only by attempting to answer interesting research questions but also by providing pieces of software and tools to the teachers which hopefully do have an added value for them. In this vein, the further steps and work with regards to learning styles (or learning preference, learning dispositions, learning patterns) of the Lea´s Box consortium in general and its partners in particular are as follows:

Even if considered as a problematic construct, Lea's Box provided tools to the teachers which can be used by them with regards to learning styles. This has also to be understood in the context of "established practice" by teachers. For most of them "learning styles" are a reality, however loosely based on empirical or reproducible findings they may be for social scientists. We will ensure to stress out to teachers the outcomes of learning styles questionnaires should be dealt with great consciousness. The "diagnosis" as such should not have any great impact on personalised treatment of the students, but the diagnosis could be used to foster self-awareness, metacognition and thinking about one owns strengths and weaknesses. Students should be encouraged to make use of their strengths and to overcome their weaknesses (e.g. by also engaging with learning resources which is not in line with their preferred style). Besides that, the strength of Lea's Box is that it provides a more holistic view on the learner, not only on the results of a single written exam, but on a wide range of formative, quantitative and qualitative assessments from different sources. So the conclusions which might be drawn from a learning style inventory can be related to a holistic student model. As outlined by Kirschner and van Merrienboer (2013) and De Bruyckere, Kirschner, and Hulshof (2015), in the end what counts are better learning outcomes and performance (rather than preferences).

One of the partners in Leas Box, SCIO, has several years of experience in the field of learning styles. They provided teachers and students with basic information on learning and perception preferences and some recommendations on how these preferences can be utilized and developed, and they organized workshop for teachers. These set of activities resulted in a 160 pages teacher's manual, an introductory handbook on learning styles and preferences. This handbook is currently only available in Czech, however, it is planned to combine parts of this deliverable with translated parts of this handbook, which can then also be used by teachers in wider Europe. In addition to that, SCIO developed and adapted a questionnaire on learning styles which builds on the Dunn and Dunn Model of learning styles (see section 4.2), the VARK model (see section 4.3) and the Felder-Silverman model of learning styles (see section 4.7). This questionnaire has been provided to and answered by 10k+

students. In addition to that, performance-relevant data of these students is available. The whole dataset would enable us to carry out a large scale study; something which rarely exists in the field of learning styles.

11. Conclusions

Many teachers intuitively believe that there must be something inclusive about learning styles, accounting for findings of much academic research and associated critical considerations. The practice shows, almost overwhelmingly, that: some learners like to work fast, some take their time; some are accurate, some inattentive; some brachiate through the details, some focus on a broader vision; some ask questions, others reflect silently. There is an infinite array of such every day experiences. Experience also warns us, that if taken too literally, we run the risk of stifling the learning environment and are just as likely to entrap, as empower, learners, for example with tools that implement a scientific approach to match learners to their estimated preferred way of thinking.

In this literature review we face the challenge to bridge the gap between academic scepticism, every day beliefs and the features of a technical solution such as the learning analytics platform in Lea's Box. Our approach to close the gap is to move away from the term "learning style", and perhaps from more accepted ideas such as Gardner's Multiple Intelligence Theory (Gardner, 1983), and to consider to a greater extent individual preferences, individual characteristics, and individual traits that change on a daily basis. These individualisms perhaps interact to a greater extent[1] with the nature of the learning domain (STEM vs. languages vs. cultural/art subjects). Furthermore, this means that the idea of reducing the learner characteristics to four types needs to be left behind.

This also means that Lea's Box, as a toolbox for teachers and learners, provides the possibility to link activities (including typical learning objects, achievements in digital environments/applications/tests, and teacher assessment) with certain characteristics. Characteristics may be Kolb's learning styles (Kolb, 1984), or a teacher-made set of preferences, traits or states. The number of characteristics assigned to a specific activity may be arbitrary (cf. Figure 11) and can be defined by each teacher. Activities that are recorded in Lea's Box can then be aggregated and analysed according their characteristics. Teachers can benefit from a broad range of views on their students' preferences and ideas; this also allows the 'mining' certain relationships/correlations between preferences and achievements and also an FCA-type clustering of students or activities.

[1] Some correlation was reported by: Wu, D. (2014). Learning Styles, Subject Matter, and Effectiveness in Undergraduate Distance Education" (2014). Doctoral Dissertations and Projects. Paper 803. http://digitalcommons.liberty.edu/doctoral/803

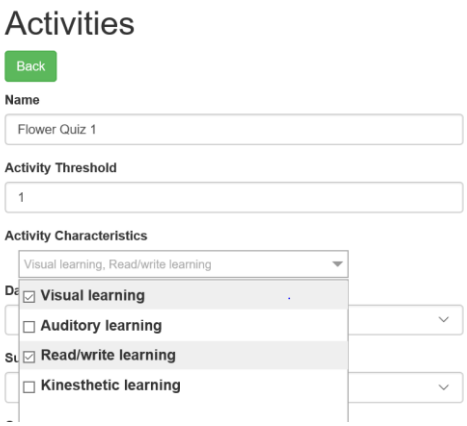

Figure 11: Assigning characteristics to activities is a new system feature.

Finally, as a result of the project and this task, we are providing teachers with a handbook about how to action this notion of learning styles, and also how to perhaps find different ways of using the typical inventories for improving their own teaching. A very interesting way for teachers and students to use learning styles inventories is to learn and reflect about themselves. In Essays, UK (2015) it is described how reflecting on one's own learning styles inventory results can alter teaching and learning attitudes, and that it raises awareness about learning processes. This, in turn, facilitates teaching, learning and perhaps also the interaction between students and teachers.

As this literature review shows, every learning style theory has dedicated supporters and firm critics. We suggest to leave it up to educators and teachers to find a balance and ensure questionnaires, tests and analyses do not overwhelm learners or apply unwanted effects. Nevertheless, learning styles tools can be practical to help individuals find out more about their strengths and areas for improvement, which is an issue at the very heart of Lea's Box. However, as concluded in Essay, UK (2015), "time and resources should not be wasted on evaluating results that may have an insignificant or no impact on students' learning. Also there is a certain amount of risk of children being confused with various labels and approaches, which may change as pupils leave school settings". This is an area in which discretion need be applied.

In conclusion, even if learning styles in themselves are myths, the methods and tools orbiting around the theories might well support teaching, learning, self-reflection, changing of attitudes and the strengthening of meta-competencies and, in particular, meta-cognition. This is what we are supporting in Lea's Box.

12. References

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13. Appendix

13.1. Evaluation Form

This Evaluation Form has been used by the students of the Grazer Schulschwestern (see Section 9.1) to evaluate the learning resources provided by their teacher.

Datum [Date]	**Lernressource [Learning Resource]**	**Stichwortartige Zusammenfassung [Short summary]**	**Bewertung (von 0 bis 5 Punkte) [Evaluation – from 0 to 5 points**
…	…	…	…

13.2. Intrinsic Motivation Inventory – Original English Version

The following statements concern with your experience with the task you just engaged with. For each statement, please indicate how true it is for you, using the scale from 1 to 7. A 1 indicates that the statement is not at all true for you - with a 7 you indicate that the statement is very true for you.

	Not at all true						Very true
1. I thought this was a boring task.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
2. I think that working on this task could be useful.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
3. I tried very hard to do well at this activity.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
4. This task was fun to do.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7

5. I believe working on that task could be beneficial to me.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
6. It was important to me to do well at this task.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
7. I would describe this task as very interesting.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
8. I believe working on this task could be of some value for me.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
9. I put a lot of effort into this.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7

13.3. Intrinsic Motivation Inventory – Adapted German Version

Bitte gib für jede Aussage an inwieweit sie auf dich zutrifft. Sollte eine Aussage überhaupt nicht auf dich zutreffen, dann kreuze das Kästchen mit der „1“ an. Solltest du einer Aussage absolut zustimmen, dann kreuze das Kästchen mit der „7“ an.

	Überhaupt nicht						Absolut
1. Ich glaube das wird eine langweilige Aufgabe werden.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
2. Ich glaube dass die Bearbeitung dieser Aufgabe nützlich sein wird.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
3. Ich habe vor mich sehr anzustrengen um die Aufgabe gut zu erfüllen.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
4. Die Bearbeitung der Aufgabe wird mir Spaß machen.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
5. Ich glaube dass es mir Vorteile bringen wird an dieser Aufgabe zu arbeiten.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
6. Es ist wichtig für mich gut abzuschneiden.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7

7. Ich glaube die Aufgabe wird interessant sein.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
8. Ich glaube dass es mir einen Nutzen bringen wird an dieser Aufgabe zu arbeiten.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
9. Ich habe vor mich sehr einzusetzen.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7