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TOP-DOWN OR BOTTOM UP: A COMPARATIVE STUDY ON ASSESSMENT STRATEGIES IN THE STUDIO ADAPTIVE LEARNING ENVIRONMENT

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Introduction

Throughout all situations of life education stays as a stable companion. This seems to stay true with new and changing requirements coming with the new technology enhanced society. But as the learning environments are changing, so are the requirements for education. Technology enhanced learning promises a personalised learning experience and support, and translates the real world's instruction into a computerised learning environment. But by doing so it has to answer the same common questions for instructional design: Should education be provided top-down, starting from the general or bottom-up, visiting the specifics first. And additionally – how should this be reflected in supporting technologies of education.

In class room situations, when applying a top-down approach, a teacher will try to give a general overview first, introducing the big picture paired with an overall motivation concerning both content and outcome, showing the correlation between the different aspects of the particular field. In contrast, a bottom-up way of teaching will tackle the details of a specific area first to develop the topic step by step towards the understanding of the whole area. The approaches of top-down and bottom-up education can be translated into trade-off considerations between behaviourism- and constructivism-based learning. But how can these approaches can be built into technology enhanced and enabled learning environments? How can testing – which has to be part of a technology enhanced process of learning – reflect these methods? Bransford, Franks, Vye and Sherwood (Bransford, Franks, Vye, & Sherwood, 1989) summarise in a short manner *wisdom can't be told*, so no test can define what exactly the candidate knows. But the question is not if wisdom can be or can't be told – as experience can be transferred by communication – but if a learner can make use of it.

Technology enhanced learning needs a connection between what has to be learned, what is tested and what is still to be learned based on the results of testing. STUDIO, an integrated technology-enhanced e-learning solution, offers here the right link between testing and learning. It focuses on providing a continuous feedback loop of learning and testing. Within the system a domain-ontology is used for representing the knowledge to learn. Using the domain structure of STUDIO this paper will first introduce two alternative algorithms for technology enhanced assessment – implementing both a top-down and a bottom-up approach for testing. Using the results of a real world online test in the domain of business informatics, new light on the differences of top-down and bottom-up comprehension of learners will be provided. This paper will detail the main findings of this analysis. The survey is conducted in an environment of blended learning, where students learn through different channels.

Behaviourism and Constructivism

As summarised by Ertmer and Newby (1993), behaviourism makes use of the concept of stimulus and response. Learning, following behaviourism, occurs when a learner gives an adequate response to a presented stimulus. E.g. when showing a learner a specific math problem, the problem represents the stimulus, while the fitting answer of the learner is the response. The key question of behaviourism is then how to strengthen and sustain the association between the stimuli and a successful response. Furthermore, the long term goal is to foster positive responses by adding reinforcements to positive responses. Teaching in this framework takes a strong emphasis on preparing and controlling the arrangement of stimuli and the consequences of given responses. Furthermore, the learner is continuously assessed to recognise where to start the instruction and to detect which reinforcement actions are effective for a specific learner. For transferring learned knowledge to new situations, learners are expected to generalise situations, with features shared or similar to previous learned behaviour. The proof of the positive effects of positive and negative reinforcements is going back to the experimental work of Skinner (1974).

Furthermore summarised by Ertmer and Newby (1993), constructivism "is a function of how the individual creates meaning from his or her own experiences". Constructivism envisions the mind as a filter, which filters the world to create its own reality. In this regards the mind is conceived as the source of the derived meaning. The "knower constructs a reality or interprets it, based on his or her perception" (Jonassen, 1991). Following Jonassen, the knowledge is constructed as a result is based on previous experience, the mental structures, and beliefs a person uses to interpret objects and events. E.g. in a class room situation a teacher would introduce the general problem to solve and give the question of method to the learners for reflection and construction of their own methods in favour of connecting to their previous. In contrast to the view of behaviourism, constructivism takes the view that the knowledge of a learner is mind dependent and has to be mapped onto a learner. Learning and the transfer of knowledge always takes place in a context in the view of constructivism and the different contexts offer different links to the knowledge to learn.

Observing the different tendencies of both learning theories, they can be summarised: behaviourism as the top-down, decomposing, fact oriented learning theory which is focused on stimulus/response pairs and constructivism as a bottom-up, generalising, context oriented theory which is focused on linking experiences to new situations. Cognitivism adds here the focus on a more technology oriented theory, focusing on knowledge as symbolic mental constructs within the learner's mind, while learning stores the symbolic representations to the learner's memory.

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The STUDIO Approach for Self-assessment

Both addressed theories of learning come with aspects which cannot be translated or translated only partially into a technology driven solution. At the same time the basic logic of composition vs. decomposition can be compiled into a computerised assessment and follow the learning direction of the respective learning theory. Following the assessment paths of the test, a conclusion on the success of the learning path is possible. STUDIO is a technology enhanced learning environment that captures the relevant domain concepts and their relations by ontological entities around which a set of knowledge assessment and learning management related tasks are carried out (Vas, 2016). The ontology formalises the knowledge structure of the domain of interest by dividing it into knowledge areas and sub-areas.

The focus in STUDIO is on the knowledge assessment method which enables the exploration of test candidates' knowledge gaps in order to help them in complementing their training or educational deficiencies. It is the tutor's responsibility to define which knowledge areas (from the domain ontology) should be included in a given test. Figure 1 shows the result summary visualisation of the testing. Red/dark dots signal knowledge-elements which the learner failed, while green/light dots identify knowledge-elements which are passed. The image visualises efficiently the potential to reason on cleared and not yet cleared areas of the domain. While some concepts are known, other knowledge-elements could not be passed and are marked for further learning.

The choice of a test algorithm for a specific assessment goal has to include an initial analysis on the requirements of the assessment. In cases of a large scale selection of well-prepared learners for the assignment on specific job profiles the strict top-down testing scheme is more suitable and covers more strict the connected organisational process. For pre-filtered groups of candidates, the bottom-up assessment may provide a wider profile of the capabilities of each individual and enable a more profound selection decision.

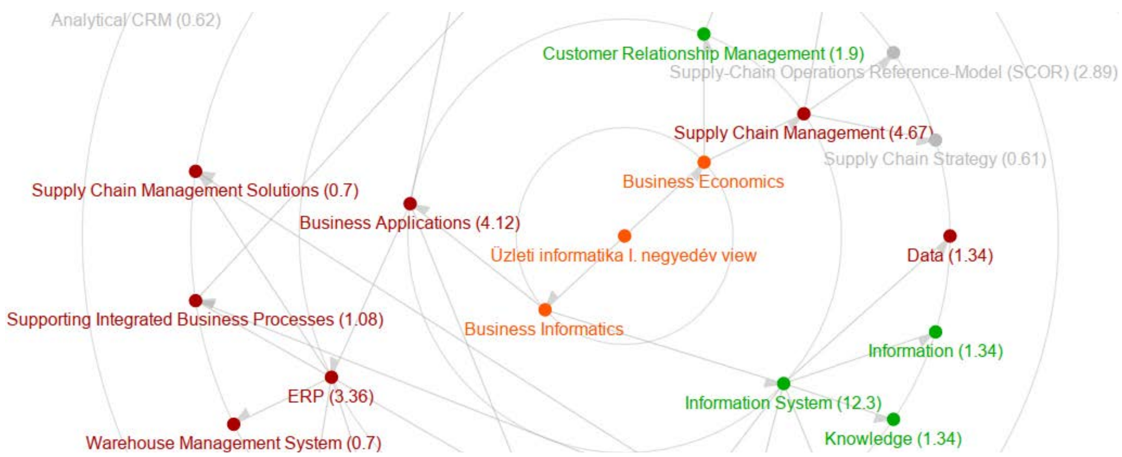

Figure 1. Result visualisation for the business informatics test as an educational feedback to the learner.

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A Top-down Approach on Testing

To offer a top-down assessment, the system follows the assumption, that missing knowledge on an early stage of the knowledge structure hierarchy disables the learner to answer questions for knowledge areas on more detailed levels. Following, the deeper a knowledge-element is placed within the knowledge structure, the more detailed is the concept. This creates an implicit hierarchy from general concepts to specialised concepts while moving down the tree structure. Based on the defined relations, this loading-process provides a tree of the knowledge structure for the test algorithm. An example visualisation, for a business informatics domain, is shown in Figure 1.

Following the tree shaped knowledge structure the top-down assessment triggers a set of steps to assess the represented knowledge: (a) Beginning with the start-element, the test algorithm activates the child knowledge-areas of the start element. (b) The top-down algorithm then selects the first child-knowledge area and extracts a random question out of the test item repository connected to the given knowledge-element and assesses the test taker's answer. (c) When the test taker incorrectly answers the question, the algorithm marks the related knowledge element as failed – else it is marked as passed. (d) The system then selects the next non-failed knowledge area, accessible directly or through passed nodes from the start-element, promotes it as a parent node and selects a random question related to it to repeat the process.

The system dives down the knowledge structure and continuously triggers more questions depending on the learner's answers. In this regards the STUDIO system adapts the test on the fly to the performance of the test taker. Answers provided by the candidate trigger whether to follow or not to follow more knowledge elements on the same branch of the knowledge tree. This process of mapping the candidates performance to the conceptualisation of the domain ontology, resembles the concept of overlay based student modelling (Chrysafiadi & Virvou, 2013). While the learner continues to use the self-assessment through phases of testing and learning, he or she will dive down further into the knowledge structure and explore more detailed areas of the target education.

One limitation of the above described testing method is that the test may stop at an early stage, (e.g. in an extreme case, if there is only one knowledge area at the top level and the test candidate fails to answer the related question correctly, the test stops and no more questions are presented) which may discourage the test candidate on the one hand while also preventing an insightful exploration of the knowledge structure. For that very reason another knowledge evaluation method has also been implemented in STUDIO that follows a bottom-up approach in contrast with the top-down approach of the above described method.

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Bottom-up: A Path Based Approach on Testing

In a bottom-up assessment, in contrast to the top-down testing, described earlier, the assumption is that learners will know details about the represented domain, even if they cannot answer questions for high level concepts. Phrasing questions for high level knowledge elements can be considerably harder to phrase as they have to take into consideration concept dependencies, the numbers of concepts needed to make a statement about the core of a concept and its implications. As such the probability for flawed or biased questions on top levels is higher than for detailed concepts. It has rational, especially in early learning cycles, to start to assess more detailed knowledge first to create an understanding of the current skill level, rather than stopping the assessment on high level concepts which are hard to decompose to be able to provide feedback for the learner. A learner may not have the overall knowledge of an educational area but it can be vital to know whether he/she has the proficiency on the prerequisite knowledge areas.

A solution that can explore the knowledge of learners in a detailed manner, while still avoiding too long testing, is the creation and application of assessment paths. Assessment paths describe routes through the knowledge structure which connects a given knowledge element to the respective start-element (aka top knowledge element in the given ontology). A path can thereby include an unlimited amount of intermediate knowledge elements which are needed to connect to the start-element. To prevent loops in the directed graph, the final algorithm makes use of black-lists of visited nodes, combined with a backtracking algorithm to continue to create and explore alternative paths.

To enable the new path concept, the assumptions about the structure, based on the top-down algorithm, have to be modified and extended. If a test-taker fails on more detailed concepts the system will assume that he or she will also fail on more general concepts. In the top-down approach, as the algorithm starts from the start-element, each passed element in an assessment is connected with a set of passed elements to the start-element. As the bottom-up algorithm starts from bottom knowledge-elements, a path from a passed element to the start-node may include failed elements too. To cope with this situation testing and evaluation are split for the bottom-up assessment, as reflected in more detail in (Weber, 2016). Following, passed elements will be only accepted if they are connected to a path of other passed elements, connecting without interruption to the start-element.

Analysing top-down and bottom-up testing within a course on business informatics

To evaluate the implications of a top-down or bottom-up approach to testing and learning, a study was conducted in a BSc course on business informatics. The students had access both to traditional learning materials and to testing and learning objects, provided through STUDIO. An additional incentive for students has been provided in the form of extra points for the final grade. The study had two stages: students used the system with a top-down implementation throughout 14 days to get prepared for the mid-term exam and with a bottom-up approach

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throughout 13 days, a month later, to get prepared for their final exam. 287 students took part in the top-down test (61,897 tested knowledge elements) and 213 in the bottom-up test (25,919 tested knowledge elements).

Figure 2 describes how many times each knowledge element had been tested using the two approaches (the larger and darker the circle, the more times the element had been tested), while Figure 3 accounts for the number of times a knowledge element was passed across all test runs. The graph visualisation of the visited and passed knowledge elements in Figure 2 and Figure 3 traces the exploration of the two different algorithms. For the top down, elements are visited more frequently when they are near to the start elements in the centre, the focus on the right part tributes partially to the clockwise selection of initial nodes. In case of the bottom-up testing, bottom elements are visited more frequently and more equally, which partially goes back to a stronger random selection component. The sets of points within the graph are scaled within the respective testing algorithms, so Figure 2 (a/b, scale [60,3300]) and Figure 3 (a/b, scale [10,900]). The overall pass/fail distribution among knowledge elements is 73.18% / 26.82% for top-down and 69.87% / 30.13% for bottom-up testing and in this regards comparable.

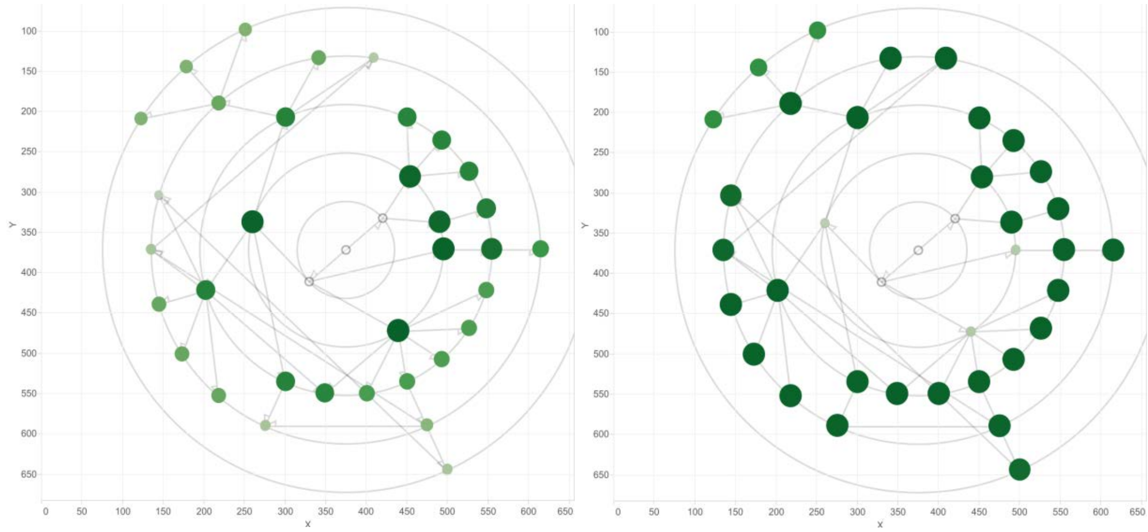

Figure 2. Aggregation of how frequent a knowledge area was visited for top-down (a/left) and bottom-up (b/right) testing visualised on the course's knowledge structure (see Figure 1). Each graph is scaled based on its own internal distribution.

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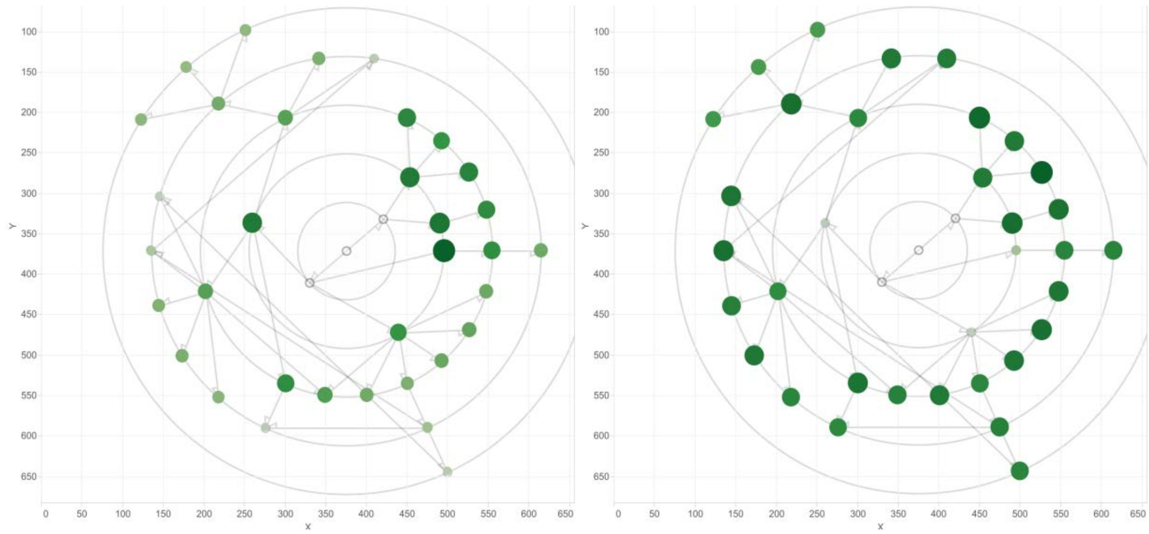

Figure 3. Aggregation of how frequent a knowledge area was answered correctly for top-down (a/left) and bottom-up (b/right) testing. Each graph is scaled based on its own internal distribution of passed elements.

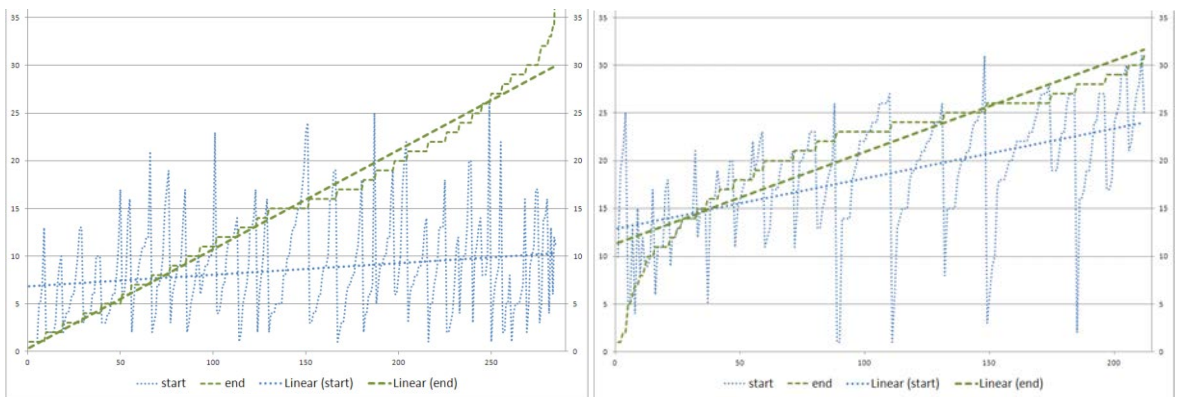

Figure 4. Amount of knowledge elements passed in the first and last test of a user within the top-down (a/left) and the bottom-up (b/right) approach, sorted by the frequency of knowledge elements within the last test.

For Figure 4 only the first and the last test for each student were taken into account to trace an overall trend across tests. The x-axis shows individual students, sorted by the performance of their last test, where the right part picture higher performing students. What is visible here is that the top down test in Figure 4 (a) has a low and flat trend for the rate of passed nodes across first tests. In a direct comparison to the bottom-up testing the top-down tests show in average a higher performance boost for the final test but the bottom-up test starts with a higher average pass-rate and rises lighter and more stable across all users, with a similar std-deviation of 6.16 for the start and 6.34 for the final number of passed nodes, against 5.21 and 8.70 for the top-down approach. The average of the std-deviations of all tests for each user is 4.97 for top-down and 2.79 for bottom-up testing. So within the top-down testing the performance of passed nodes changes in average stronger than within the bottom-up testing. This observation is especially of interest as the higher number of observations within the top-down testing (more observations) should smooth the variation of test results.

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Conclusion

This paper introduced both, a top-down and bottom-up implementation of an educational test based on a knowledge structure and investigated how different the outcomes of the specific approaches are. For the top-down/bottom-up testing, the overall pass/fail level, taking into consideration every answer regarding each knowledge element, is on a comparable level. Yet the average improvement in the test takers' performance is different, starting on different performance levels and showing a different gradient towards high results. The top-down approach seems to encourage higher results from high performing testers on the costs of more lower performing testers, while the bottom-up approach tends to stronger equalise the performance.

As technology enhanced solutions for learning and testing have additionally an initial phase of familiarisation of the tester, an extended test on a more extensive curriculum with more observations may reveal a stronger trend. Further it is likely that the influence of the different stopping-criteria for both algorithms is influencing the pass rates within test runs and creates special "early"-finished test runs which may account for the comparable high std-deviation across all testing algorithms. As a summary the first results are insightful and initiate a later deeper analysis of the specific testing strategies of both algorithms. Future analysis on more extensive knowledge structures will here reveal further insights and help to better distinguish the core performance of testers from further influencing factors as unequally distributed question-difficulties, system familiarisation and stop-criteria.

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