

Individualizing Tutoring with Learning Style Based Feedback

Shahida M. Parvez and Glenn D. Blank

Computer Science and Engineering Department

Lehigh University

Bethlehem, PA 18015 USA

001-610-758-4085, 001-610-758-4867

sparvez@rcn.com, glennblank@gmail.com

[*Intelligent Tutoring Systems*, 9th International Conference, Montreal, June 23-27, 2008, Springer, pp. 291-301]

Abstract: To approximate more closely effective human tutors, intelligent tutoring systems should adapt not only to a student's knowledge but also her learning style. We introduce a pedagogical framework that incorporates the Felder-Silverman learning style model and validated instrument for assessing individual learning style. The framework provides a feedback infrastructure based on the learning style model dimensions (such as visual, verbal, intuitive, sensor, etc.). It has been implemented as part of the DesignFirst-ITS, helping novices learn how to design a class in UML from a problem description. The system has been evaluated with high-school students and results show that learning style based feedback helps students realize higher learning gains.

1. Introduction

Though ITSs are quite successful in helping students learn, they still fall short of the ability of effective human tutors to consider their individual characteristics and preferences in order to customize both the tutoring content and process. The individual characteristics and preferences of the student are dubbed individual learning style. For the ITSs to match the success of good human tutors, ITSs need to adapt not only to the knowledge level but also to the learning style of the student to maximize learning.

Learning style refers to individual skills and preferences that affect how a student perceives, gathers, and processes learning materials [14]. People learn more when the instruction is matched to their individual learning styles [4, 6]. As a result, a number of adaptive educational systems have been developed that are based on learning style research: CS383 [3], Arthur [13], iWeaver [30], EDUCE [15]. These systems maintain a learning style profile for each student and use this profile to adapt the presentation and navigation of instructional content to each student.

Developing e-learning systems that adapt to student learning styles is not a trivial task. Design and development challenges include selecting the appropriate learning style model and instrument, creating course content consistent with the various learning styles, and determining the level and degree of adaptation of domain content. It is even more challenging to design an ITS that adapts to individual learning style because the ITS focuses more on student interpretation and understanding of the domain knowledge rather than just the presentation mode and delivery as in adaptive hypermedia systems.

This paper presents a pedagogical framework that generates multidimensional feedback based not only on the knowledge level of the student but also on the individual learning style of the student. The pedagogical framework is based on the Felder-Silverman learning style model and is implemented in DesignFirst-ITS (once known as CIMEL-ITS), an ITS that helps novices learn object-oriented design by creating UML class diagrams. Evaluation with high-school students shows that students made significant learning gains

after using the ITS. A GUI feedback maintenance tool makes it possible for teachers to add and update feedback in the ITS without any programming or assistance from the ITS developer.

The rest of this paper is organized as follows: section 2 describes related work; section 3 gives a brief overview of the Felder-Silverman learning style model; section 4 describes the pedagogical framework; section 5 describes the DesignFirst-ITS; section 6 describes evaluation results; and section 7 presents the conclusion and future work.

2. Related Work

Learning style research became very active in the 1970's and has resulted in over 71 different learning style models and theories. Some of the most cited theories are Myers-Briggs Type Indicator [23], Kolb's learning style theory [17], Gardner's Multiple Intelligences Theory [11] and Felder-Silverman Learning Style Theory [7, 8]. Learning style research has been used in various settings and at different levels. In industry, corporations are using learning style research to create supportive work environments that foster communication and productivity. In academia, learning style research is being used for different purposes: to provide learning support to K-12 children who are either struggling or are gifted; to help college students maximize their learning gain by providing them insight into how they learn; and to help instructors design courses that appeal to students of various learning styles.

Learning style is also being integrated in adaptive e-learning environments with many designers creating systems based on learning style research. Adaptive e-learning systems are ideal for creating learning style based instructional material as they do not face the same limitations as human instructors who are unable to cater to individual students due to lack of resources [14]. Some of the adaptive systems that incorporate learning style are CS383 [3], ACE [25], AES-CS [27] and Flexi-OLM[18].

All these systems are based on different learning style models and use different methods to obtain the learning style of the user. One method is to have the user fill out a learning style questionnaire which usually accompanies the learning style model on which the system is based. Another method is to infer the student preferences from her interaction with the system, such as the pages the student visits and the links that she follows. After obtaining the student learning style, these systems use that information to adapt the sequence and/or presentation form of the instructional material to the student.

CS383 [3], an adaptive educational hypermedia system for a computer systems course (CS383), modifies content presentation using the Felder-Silverman learning style model. Learners fill out the Index of Learning Style questionnaire (ILS) that categorizes them as sensor/intuitive, verbal/visual and sequential/global. For example, sensor learners like facts while intuitive learners prefer concepts; visual learners like pictures and graphics while verbal learners like written explanations; sequential learners prefer step by step presentations while global learners like to see the big picture first. In CS383, the presentation form of the content matches the student's learning style. For example, visual students are presented information in a graphical form while the verbal students receive the information in text form, etc.

The Flexi-OLM system [18] models a learner's understanding of basic C programming based on her answers to multiple-choice and short-answer questions. The system supports an open learner model that enables the learner to view information about her skill level,

knowledge and misconceptions in a choice of seven formats, designed according to the Felder-Silverman learning style model.

Formal and informal evaluation studies of CS383, ACE and AES-CS suggest that students learn more when the system adapts to individual learning style. However, not all adaptive systems that incorporate learning style support the hypothesis that learning style adaptation results in increased gains. For example, evaluation studies of EDUCE [15] suggest that students learn more when they receive instruction that is mismatched to their learning style. One reason for these inconsistent evaluation results is that different systems are based on different learning style models and all these models have a different perspective of which individual characteristics affect the learning process. Another reason is that there are no set guidelines or standards that designers can use to create learning style based systems. Lack of standard methodologies also makes it difficult to determine the effectiveness of these systems. Yet another reason could be that some adaptive hypermedia systems use learner navigation data to keep an updated learning style profile of the learner and the learners do not necessarily only browse the information format that would be considered the best match for their learning style.

3. Felder-Silverman Learning Style Model

The Felder-Silverman Learning Style Model [7] categorizes a student’s learning style on a sliding scale of four dimensions; *sensor-intuitive*, *visual-verbal*, *active-reflective* and *sequential-global*. Table 1 summarizes learning environment preferences of typical learners from each of these four dimensions of the Felder-Silverman model.

Active	Tries things out, works within a group, discusses and explains to others
Reflective	Thinks before doing something, works alone
Sensor	Learns from and memorizes facts, solves problems by well-established methods, patient with details, works slower
Intuitive	Discovers possibilities and relationships, innovative, easily grasps new concepts, abstractions and mathematical formulation, works faster
Visual	Learns from pictures, diagrams, flow charts, time lines, films, multimedia content and demonstrations
Verbal	Learns from written and spoken explanations
Sequential	Learns and thinks in linear/sequential steps
Global	Learns in large leaps, absorbing material almost randomly

Table 1 - Felder-Silverman learning style model dimensions

The Index of Learning Styles (ILS) instrument supports the Felder-Silverman learning style model by categorizing individual learning style preferences along four different dimensions of the model [10]. The ILS is a questionnaire containing 44 questions, 11 questions corresponding to each of the four dimensions of the learning style model. Each question is designed to determine if a respondent tends to belong to one category or another on that dimension. It does so by asking the respondent to choose only one of two options where each option represents a category. Since there are 11 questions for each dimension, a respondent is always classifiable along each dimension. The range of data for each

dimension is from 0 to 11. Since there are four dimensions and each dimension has two poles there are 16 possible combinations, i.e. types of learner, in this model. However, the learning style dimensions of this model are continuous and not discrete categories at each pole. The learner's preference on a given scale does not necessarily belong to only one of the poles and may be strong, mild, or almost non-existent.

The Felder-Silverman learning style model was chosen for several reasons; its ease of use; the Index of Learning Styles which has been validated and provides a convenient way to assess student learning style [10, 19, 31, 28]; the limited number of dimensions of the model make it easier to incorporate it into an educational system; it has been used by educators at various institutions to help improve education [7, 26]; many adaptive educational hypermedia systems, such as CS383 [3], TANGOW [24], and WHURLE [2], use this model to adapt the course presentation and/or sequence to individual learners.

4. Pedagogical Framework

Our pedagogical framework is designed to provide feedback that addresses multiple dimensions of the Felder-Silverman model. This framework consists of two parts: a *feedback infrastructure* that contains the feedback components and a *feedback generation process* that dynamically chooses these components to create coherent feedback based on students' learning style and students' erroneous actions. This pedagogical framework supports multiple levels of feedback, from a gentle reminder to a detailed explanation of the concept. This multiple hint strategy is called "hint sequencing" [12] and it refers to a sequence of hint templates that are used to generate feedback. The first hint is usually very general. As the student continues to need help about a given concept, the hints keep on getting more and more specific. Many of the successful tutors such as PAT [16], an algebra tutor, and LISPITS [5], a tutor for LISP, use this strategy. This strategy is also used by successful human tutors who offer multiple levels of feedback: they tend to start with a general hint and proceed to more specific hints related to students' erroneous actions [21].

Unlike other systems, our system does not end up providing the solution (since a design does not have only one solution), but instead offers more help in the form of pop-up hints or an extended tutorial. The tutorial mode (<http://designfirstui.cse.lehigh.edu:8080/servlets-examples/servlet/GetLoginID>) provides a student with a detailed explanation of the concept with examples. The tutorial mode can also help students who just want to learn a concept before working on their solution. The student learning style information is obtained using the Index of Learning Style instrument (ILS) [9] which the students fill out prior to using the system for the first time. We now examine each part of our framework in more detail.

4.1 Feedback Infrastructure

The feedback architecture consists of the following components that contain information in the form that is suitable for different dimensions of the Felder-Silverman learning style model.

1. **Definition** – This component verbally introduces definitions of domain concepts. This particular component is useful for many learning style dimensions such as verbal, sensor, intuitive. An example of this component would be "Attributes are characteristics of an object that persist through the life of that object."
2. **Example** – This component illustrates a given concept. It can be used for almost any learning style, especially the sensor style which prefers a practical approach to

concepts. An example of feedback in this component might be “Attributes of a car might be its color, model, make, etc.”

3. **Question** – This component contains questions that could serve as hints during the interactive mode. There are two different types of questions: closed-ended questions that require a learner to simply answer yes/no or just provide a factual answer, and open-ended questions that require a student to think about her problem solving behavior. An example of a closed-ended question in this component might be “Is the correct data type to represent money a double?” while an example of open-ended question would be “Why did you set the data type for money to string?” Open-ended questions encourage the student to reflect about her reasoning process. This component is important for a “reflective” type learner as it gently nudges her to reflect on her action. It can also be useful for intuitive, global, and sequential learners as the open-ended questions can lead them to think about the relationships between different steps/things, about the big picture and about the steps involved in creating the solution.
4. **Scaffold** – This component nudges a learner who might be lost towards a correct solution by pointing her in the right direction. Often it is not enough to tell a novice that her action is incorrect; she needs guidance about where to learn more. For example, “Use the tutorial to learn about ‘datatypes.’” This component is useful for global, intuitive, and sensor learners.
5. **Picture** – This component contains images, animation, or video that visually explains a concept. For example, when teaching the concept of data type, one could create an image consisting of transparent containers marked as int, long, double, string, etc. These containers could have things such as a dollar sign in the double container, age in the int container, name in the string container, etc. Aimed at visual learners, this component also helps global learners see the big picture.
6. **Relationships** – This component contains information that helps a learner understand how a concept fits into the overall problem solving activity. Often learners understand a concept but have a difficult time understanding how it fits into the context of the problem. For example, a student might understand what attributes and methods are but might not know the relationship between the two in the context of the problem. This component is mainly for global learners.
7. **Application** – This component contains information about a concept that extends beyond the concept definition by showing an application. For example, a student might know the definition of a constructor but might not know that a class could have multiple constructors. This component is mostly suitable for sensor learners.
8. **Exercise** – This component supports active learning through hands-on activities or by applying a concept. It occurs in tutorial mode rather than hint mode, for all learning styles.

Each of these components has the following attributes that are used by the assembly algorithm to create feedback to be presented to the student.

- Concept:** unique concept in curriculum associated with the student’s error;
- Related_concept:** relationship concept that the student may not understand;
- Level:** indicates the feedback level for which the component is designed;
- Type:** component feedback type (definition, question, etc.);
- Category:** component dimension (visual/verbal, active/ reflective, etc.);
- Content:** name of the visual / animation file;

Text: feedback text string;
Times_used: how many times this component has been used;
Status: active / inactive;
Presentation_mode: textual / graphical.

4.2 Feedback Generation Process

The feedback generation process uses the feedback infrastructure, domain knowledge and certain inputs to generate learning style based feedback. Feedback generation first *selects* feedback components based on inputs, then *assembles* a feedback message from the selected components. Inputs to the selection process include the student feedback history, learning style profile, student model information, and current student problem solving action packet. The student feedback history contains all the feedback that the student has received for each concept in the past and the feedback components that were used to generate the feedback. The learning style profile categorizes the preferred learning style of the student along the dimensions active/reflective, sensor/intuitive, sequential/global or verbal/visual. The student model specifies probabilistically how well the student understands each concept. The current student problem solving action packet provides the system with the action that the student performed, the error that was generated and the concept for which the student needs feedback.

The selection process uses these inputs to create a selection criterion which is then used to select feedback components from the feedback infrastructure. The selection criterion specifies information such as the concept the student needs help with, the presentation style of the feedback, current level of feedback and applicable feedback component types. Components whose attributes satisfy the selection criteria are chosen and put on a selected list of components.

The assembly process uses the components from the selected component list to create a feedback message. A feedback message first reiterates the action the student performed, second tells the student if the action was correct or incorrect, and third gives feedback about the given concept. The assembly process applies rules to sub-select components from selected component list. One of the rules is that only a certain number of components can be used for each feedback level. Another assembly rule is that only one visual component is allowed in each feedback message, because each component explains a given concept in its entirety. After selecting components based on the assembly rules, the assembly process creates a feedback message by putting all three parts of the feedback message together.

Generating learning style based feedback is a complex task, since the feedback must address the knowledge gap of the student and it must also be adapted to the student's learning preference. Besides its content, presentation of feedback also impacts its effectiveness.

Our pedagogical framework uses various dimensions of the Felder-Silverman learning style model to customize different aspects of the feedback. For example, the verbal / visual dimension is used to individualize the presentation style. Verbal learners receive feedback in the form of written words while visual learners receive feedback that also emphasizes images, pictures and multimedia. The active / reflective dimension is used to integrate hands-on activities for active learners and open-ended questions for reflective learners. The sequential / global dimension helps to determine if the learner should only receive feedback for the given concept itself or other information about how this concept relates to other

concepts. The intuitive / sensor dimension determines whether to explain the concept abstractly or with concrete facts.

The system maintains a cross-reference of dimensions of the Felder-Silverman model and components in the feedback infrastructure. The system uses this cross-reference to choose components to generate learning style based feedback.

5. DesignFirst-ITS

DesignFirst-ITS is an intelligent tutoring system that provides one-on-one tutoring to help beginners in a CS1 course learn object-oriented analysis and design, using elements of UML [1]. DesignFirst-ITS is based on a “design-first” curriculum that teaches students to design a solution and the objects that comprise it before coding [22]. This curriculum enables students to understand and comprehend the problem without getting bogged down with programming language syntax.

The Curriculum Information Network (CIN) consists of domain knowledge which is object-oriented design concepts. These concepts are linked together through various relationships such as prerequisite and equivalence and are assigned a measure of learning difficulty. For example, Prerequisite (class: object) shows that the concept “object” is a prerequisite of “class.” In other words, the student must understand what an object is before he can create a class.

The Expert Evaluator (EE) interfaces with a student through the LehighUML plug-in, created for the Eclipse Integrated Development Environment (IDE). Eclipse IDE is a Java development environment that can be extended by integrating plug-ins (software modules) to provide additional functionality. The LehighUML plug-in allows the student to create UML class diagrams. (A stand-alone version of LehighUML has also been created, for use outside of the complex Eclipse environment.) As the student designs a solution for a given problem in the plug-in environment, LehighUML reports each student action in a database on a server. The EE evaluates each of the student’s steps in the background by comparing it with its own solution and generates an information packet for a correct student action and an error packet for an incorrect action. The Student Model (SM) analyzes these packets to determine the knowledge level of the student for each concept and attempts to find reasons for student errors [29]. The SM uses this information to update the student profile and passes the original packets along with the reason packet that contains possible reasons for the student error to the Pedagogical Advisor (PA).

The PA is based on the learning style based pedagogical infrastructure described above. Taking into account the curriculum information network (CIN), the EE’s analysis of the student’s actions and the SM’s analysis of the student’s understanding of concepts in the CIN, the PA determines what feedback to provide to the student.

6. Evaluation experiments and results

DesignFirst-ITS was evaluated with 42 high-school students in the spring and summer of 2007 during multiple studies with identical materials. (Over 80% of the subjects were from underrepresented minorities and over a third of them were women.) The data from these studies were compiled and analyzed to determine if the learning style feedback resulted in bigger gains. The students who participated in the studies were novices to object-oriented design and programming. The evaluation procedure began by setting up three groups: a non-feedback group which did not receive any feedback at all; a textual-

feedback group which received feedback in the form of plain text; and a learning-style-feedback group which received feedback that matched their learning style. The students filled out the Index of Learning Style (ILS) questionnaire, which the PA of DesignFirst-ITS used. The students were to learn the basic concepts of objects and classes and how to manipulate them in the Eclipse environment through a multimedia lesson. Then an instructor explained a step-by-step procedure for creating an object-oriented design solution for a problem description in English to generate the primary class, its attributes, and methods. As an assignment, the students were given a problem description of a movie ticket vending machine. The students followed the procedure to generate a solution from the problem description and to create a class diagram using the LehighUML plug-in and the DesignFirst-ITS.

Prior to using the system, the students took a pre-test to measure their prior knowledge and to give a baseline on which to compare the post-test. The pre-test and post-test consisted of thirteen multiple choice questions pertaining to definition, identification and application of object oriented concepts such as class, attribute, method, data type, etc. Then the students logged into DesignFirst-ITS and started to input their design in LehighUML. The students who belonged to the no-feedback group did not receive any feedback as their work was not supervised by the system. The textual-feedback group and the learning-style-feedback group both received feedback from the system as their designs were analyzed as they input them into the system. After the students had completed their designs, they were given the post-test.

The paired t-test suggests that there is no significant difference ($p > .05$) between the pre-test and post-test for the no-feedback group and the textual-feedback groups. However, the t-test shows a significant difference ($p < .001$) between the pre-test and the post-test for the learning-style-feedback group. The fact that there is no significant difference in pre-test and post-test for the no-feedback group makes sense because this group did not receive any help between the tests. On the other hand, the textual-feedback group could have shown some improvement between their test scores but interestingly did not. Many factors could have contributed to this lack of improvement: small sample size, students did not read the feedback, students did not understand the feedback, etc. One of the most likely reasons is that, in general, high school students do not like to read, and the students in the evaluation study did confirm that by voicing their dislike about reading when they were asked to read the handouts and feedback carefully. For the learning-style-feedback group, the evaluation data shows that students who received the learning style feedback did realize learning gains after using the system. This result suggests that providing feedback in a student's preferred learning style is certainly worth the effort it takes to create it. It is also likely that students paid more attention to feedback in their preferred learning style.

In addition to the pre-test and post-test, the students who received any type of feedback were also given a Pedagogical Advisor evaluation questionnaire asking them specific questions about the feedback that they received from the ITS. The purpose of this questionnaire was to determine if the students found the feedback helpful in identifying their errors and in fixing these errors. Other reasons were to determine if the students liked the visual feedback and actually understood the information conveyed in the images / diagrams. The results of the survey showed that 90% of students read the advice, 72% found it helpful in identifying the error in their design, 71% found it helpful in correcting their errors, 65% liked the visual images and 69% understood the information conveyed in these images. Overall, 70% students liked the Pedagogical Advisor feedback.

7. Conclusions and Future Work

We described a general framework for providing pedagogical advice tailored to individual learning style, determined with a well-established learning style model and a validated instrument. We specified the overall architecture and the feedback selection and assembly algorithm for a pedagogical advisor, which provides both popup hints and extended multimedia lessons. Evaluation results with high-school students indicate that learning style based feedback helps students realize learning gains.

Because the learning style framework is general, we were able to develop a feedback maintenance tool that enables instructors to add/delete feedback to this framework without programming or developer hand-holding (<http://designfirstui.cse.lehigh.edu:8080/servlets-examples/servlet/GetAdminID>). Two computer science instructors have used this tool successfully, validating its effectiveness.

Our most obvious future work is to demonstrate further the generality of the learning style framework and maintenance tool by applying them to other ITS domains. With more data, it may be also useful to determine which learning style dimension has the largest impact on student learning gains and to adapt feedback accordingly. It might also be useful to inform a student of her learning style to see if she appreciates the feedback or wishes to adapt the feedback so that she can learn along alternative learning style dimensions.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grants No. EIA-0087977 and 0231768 and the Pennsylvania Infrastructure Technology Association (PITA). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

- [1] Blank, G., Parvez, S., Wei, F. and Moritz, S. (2005). A Web-based ITS for OO Design, *Proceedings of The 12th International Conference on Artificial Intelligence in Education*, Amsterdam. Online www.cse.lehigh.edu/~cimel/papers/AIEDworkshop-poster.pdf.
- [2] Brown, E.J, Brailsford, T. (2004). Integration of learning style theory in an adaptive educational hypermedia (AEH) system. Short paper presented at the *11th International Conference of the Association for Learning Technology (ALT-C)*, Exeter, 14-16.
- [3] Carver, C. A., Howard, R. A., Lane, W. D. (1999). Enhancing Student Learning through Hypermedia Courseware and Incorporation of Learning Styles. *IEEE Transactions on Education*, 42(1), 22-38.
- [4] Claxton, D. S., Murrell, P. (1987). Learning styles: Implications for improving educational practices. *ASHE-ERIC Higher Education Report No. 4*. Washington: Association for the Study of Higher Education.
- [5] Corbett, A., Koedinger, K., Anderson, J. (1992). LISP Intelligent Tutoring System: Research in Skill Acquisition. In J.H. Larkin & R.W. Chabay, (Eds.), *Computer-assisted Instruction and Intelligent Tutoring Systems: Shared Goals and Complementary Approaches*. Hillsdale, NJ: Erlbaum, pp. 73 – 109.
- [6] Dunn, R., Dunn, K. (1978). *Teaching students through their individual learning styles: A practical approach*. Reston, VA: Reston Publishing.
- [7] Felder, R. M., Silverman L. K., (1988). Learning and Teaching Styles. *Engineering Education*, 674-681, April 1988.
- [8] Felder, R. M., (1996). Matters of Style, *American Society of Engineering Education (ASEE) Prism*, 6(4), 18-23

- [9] Felder, R. M., Solomon, B. A. (2001). *Learning styles and strategies* [WWW document]. Online at www.ncsu.edu/effective_teaching/ILSdir/styles.htm, North Carolina State University.
- [10] Felder R.M., Spurlin J.E. (2005). Applications, Reliability, and Validity of the Index of Learning Styles, *Intl. J. Engr. Education*, 21(1), 103-112.
- [11] Gardner, H. (1983). *Frames of Mind*. New York: Basic Books.
- [12] Gertner, A., VanLehn, K. (2000). Andes: A Coached Problem Solving Environment for Physics. In G. Gauthier, C. Frasson & K. VanLehn, (Eds.). *Intelligent Tutoring Systems: 5th International Conference*. Berlin: Springer (Lecture Notes in Computer Science, Vol. 1839), pp. 133-142.
- [13] Gilbert, J. E., Han, C. Y. (1999). Adapting Instruction in search of 'a significant difference'. *Journal of Network and Computer Applications*, 22(3), 149-160.
- [14] Jonassen, D. H., Grabowski, B. L. (1993). *Handbook of Individual Differences, Learning and Instruction*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- [15] Kelly, D., and Tangney, B. (2002). Incorporating Learning Characteristics into an Intelligent Tutor. *Proc. of the Sixth International Conference on Intelligent Tutoring Systems, ITS'02*, Biarritz, France, 729-738.
- [16] Koedinger, K. (2001). Cognitive Tutors as Modeling Tools and Instructional Models. In Forbus, Kenneth and Feltovich, Paul (Eds.), *Smart Machines in Education (pp. 145-167)*. Cambridge, MA: AAAI Press/MIT Press.
- [17] Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall.
- [18] Kyparisia A., Papanikolaou, A. M, Bull, S., and Grigoriadou, M. (2006). Designing learner-controlled educational interactions based on learning/cognitive style and learner behaviour. *Interacting with Computers* 18(3): 356-384.
- [19] Litzinger T.A., Lee S.H., Wise J.C., Felder R.M. (2005). A Study of the Reliability and Validity of the Felder-Soloman Index of Learning Styles, *Proceedings, ASEE Annual Conference*.
- [20] Livesay, G., Dee, K., Felder, R. M., Hites, L., Nauman, E., O'Neal, E. (2002). Statistical evaluation of the index of learning styles. *Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition*, Montreal, Quebec, Canada.
- [21] Merrill D. C., Reiser B. J., Ranney M., Trafton J.G. (1992). Effective tutoring techniques: A comparison of human tutors and intelligent tutoring systems. *The Journal of the Learning Sciences*, 3(2):277-305.
- [22] Moritz, S., Blank, G. (2005). A Design-First Curriculum for Teaching Java in a CS1 Course, *SIGCSE Bulletin (inroads)*, June, 89-93.
- [23] Myers, I. B. (1976). *Introduction to Type*. Gainesville, Fla.: Center for the Application of Psychological Type.
- [24] Paredes, P., Rodriguez, P. (2002). Considering Learning Styles in Adaptive Web-based Education. *Proceedings of the 6th World Multiconference on Systemics, Cybernetics and Informatics*, Orlando, Florida, 481-485.
- [25] Specht, M., Oppermann, R. (1998). ACE: Adaptive CourseWare Environment. *New Review of HyperMedia and MultiMedia*, 4, 141-161.
- [26] Thomas, L., Ratcliffe, M., Woodbury, J., Jarman, E. (2002). Learning styles and performance in the introductory programming sequence, *Proceedings of the 33rd SIGCSE Technical Symposium on Computer Science Education* (pp. 33-37). Cincinnati, Kentucky: ACM Press.
- [27] Triantafillou, E., Pomportsis, A., Demetriadis, S. (2003). The design and the formative evaluation of an adaptive educational system based on cognitive styles. *Computers and Education*, 41, 87-103.
- [28] Van Zwanenberg, N., Wilkinson, L J., Anderson, A. (2000). Felder and Silverman's Index of Learning Styles and Honey and Mumford's Learning Styles Questionnaire: How do they compare and do they predict academic performance? *Educational Psychology*, Vol. 20 (3), 365-381.
- [29] Wei, F. & Blank, G.D. (2006). Student Modeling with Atomic Bayesian Networks, *Proceedings of the 8th International Conference on Intelligent Tutoring Systems, Intelligent Tutoring Systems 2006*, Taiwan (June), 491-502.
- [30] Wolf, C (2003). *iWeaver: Towards 'Learning Style'-based e-Learning in Computer Science Education, Australasian Computing Education Conference (ACE2003)*, Research and Practice in Information Technology, Vol. 20, 273-279.
- [31] Zywno, M.S. (2003). "A Contribution of Validation of Score Meaning for Felder-Soloman's Index of Learning Styles." *Proceedings of the 2003 Annual ASEE Conference*. Washington, DC.