Transportation Engineering Education for Undergraduate Students: Competencies, Skills, Teaching-Learning, and Evaluation

Carlos Alberto Prado da Silva Jr.[1]; Heliana Barbosa Fontenele[2]; and Antônio Nélson Rodrigues da Silva[3]

Abstract: In general terms, engineering education at the undergraduate level should be based on at least three aspects: the definition of learning outcomes aligned not only with theoretical contents but also with competencies and skills; the specification of teaching-learning methods; and the evaluation of the learning outcomes. The purpose of this study was to analyze an approach that combines traditional lectures and active learning into one strategy to help in the development of competencies and skills demanded by the transportation engineering profession. The authors examined if the acquisition of the skills could be assessed through conventional evaluation techniques and concept maps. An experiment was conducted for the specific case of the course Planning and Analysis of Transport Systems, in three phases: (1) planning the teaching-learning process; (2) evaluating the teaching-learning process; and (3) evaluating the teaching-learning product. The results show that the use of a problem-identification methodology combined with conventional classroom activities is adequate in addressing the domains of the conceptual relationships and relational and attitudinal cognitive procedures, as presented in Bloom's taxonomy. The main conclusion refers to the use of concept maps as a strategy for learning evaluation. The results suggest that concept maps can serve as an additional assessment instrument, to assure an evaluation that is more precise and coherent with the learning outcomes desired for transportation engineering education. **DOI:** 10.1061/(ASCE)EI.1943-5541.0000220. *© 2014 American Society of Civil Engineers.*

Author keywords: Transportation engineering education; Competencies; Skills, teaching-learning; Assessment.

Introduction

In the current context of the profession, a small share of engineers practicing in transportation have graduate level education. Most of these professionals, however, have a bachelor's degree in civil engineering or architecture, with a predominance of the former. This is not surprising, given that civil engineering is largely encompassed by the broad field of transportation engineering, as highlighted by Khisty and Lall (2003). However, according to Sinha et al. (2002), the practical skills required by a transportation engineer cannot be obtained in civil engineering curricula with a generalist approach. The following issues were also raised by the same authors: (1) a transportation engineering curriculum should be more flexible and have a more specific approach in the first years of education, and (2) the project and management of transport systems is not fully covered by the literature available to the students.

An alternative strategy for complementing, at the undergraduate level, the development of civil engineers to work as transportation engineers is the Special Studies Program. In this case, the core of the study program is still maintained with the general focus (e.g., in civil engineering or production engineering), but it can be complemented by a selection of elective courses in a specific area of knowledge, such as transportation engineering. In the particular case of the University of São Paulo at São Carlos, Brazil, for example, the students who obtain a minimum number of elective course credits offered by the Department of Transportation Engineering are entitled to receive a certificate of special studies, in addition to the degree in civil engineering that those passing in all other courses will receive. However, courses in the field may not be enough to form fully competent transportation engineers if these courses follow only traditional teaching-learning approaches. In fact, the authors see these courses in the area, particularly the ones that are part of special studies programs, as opportunities to introduce more comprehensive approaches, in which competencies and skills can be developed along with theoretical contents.

Briefly, the development of professionals to work in transportation engineering can be done in at least three different ways at the undergraduate level: (1) through a complete formation provided by a specific curriculum; (2) through isolated courses focusing on topics of transportation engineering; and (3) through a special studies program. The first alternative would be a bachelor's degree in transportation engineering, mobility engineering, and the like. This is not common in most countries, although it exists in Brazil. The second alternative is the one adopted by most universities in Brazil, as discussed by Silva Junior and Rodrigues da Silva (2011a). The third alternative, a special studies program, is also not very common, even though it was successfully adopted by the University of São Paulo at São Carlos (EESC-USP) for the case of transport studies.

At least two important aspects have to be considered in the three alternatives. First, a set of courses that cover the main areas of knowledge in transportation engineering must be carefully selected in all cases. Second, special attention has to be given to

[1]Lecturer, State Univ. of Londrina, Rodovia Celso Garcia Cid, 380, 86051-990 Londrina, PR, Brazil. E-mail: carlos.junior@unioeste.br

[2]Lecturer, State Univ. of Londrina, Rodovia Celso Garcia Cid, 380, 86051-990 Londrina, PR, Brazil. E-mail: heliana@uel.br

[3]Associate Professor, Univ. of São Paulo, São Carlos School of Engineering, Av. Trabalhador São-carlense, 400, 13566-590 São Carlos, SP, Brazil (corresponding author). E-mail: anelson@sc.usp.br

Note. This manuscript was submitted on January 15, 2014; approved on June 5, 2014; published online on June 25, 2014. Discussion period open until November 25, 2014; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Professional Issues in Engineering Education & Practice***, © ASCE, ISSN 1052-3928/05014006(9)/$25.00.

the teaching-learning strategies adopted in these courses. This investigation focuses on the second aspect, with the particular perspective of helping to improve special studies programs like the one offered at EESC-USP. The study presented in this document covered the following aspects of the teaching-learning process: planning, evaluation of the process, and evaluation of the product. To accomplish this, a set of procedures adopted in the course Planning and Analysis of Transport Systems, which is designed to develop competencies and skills, was analyzed.

Engineering Education at the Undergraduate Level

In general, the teaching-learning process in engineering courses should include at least three steps: (1) the definition of learning outcomes aligned not only with theoretical contents, but also with competencies and skills; (2) the specification of teaching-learning methods and techniques; and (3) the evaluation of the learning outcomes. The first step must occur during the planning process. The second and third steps involve the evaluation of the teaching-learning process and of the teaching-learning product, respectively. Some of the basic concepts related to these topics are briefly discussed in this section as a theoretical background to the subsequent procedures and analyses.

Definition of Learning Outcomes

The definition of learning outcomes must be guided by a careful choice and also from the previous experiences of the educator (as discussed in ASCE 2008). The goal is to combine solid theoretical knowledge with the skills needed in the field. The entire process of selection and the ranking of the expected learning outcomes must be supported by the principles of a learning theory that the educator and the educational institution accept and agree with (Bloom et al. 1972). The learning objectives are statements that describe what is expected from the apprentice as a result of the teaching-learning process. According to Mager (1984), these statements are focused on the apprentice and on the sort of behavior that he/she is expected to demonstrate.

Specification of Teaching-Learning Methods and Techniques

Many of the early professionals working in transportation engineering were generalist engineers. After some time, though, the activities in the area became not only more diversified but also more complex. As a consequence, generalist engineers were not able to meet all the needs of the field. The broad range of skills and competencies required and the new tools available sometimes demand experts who are not always used to the peculiarities of transportation engineering. The distinction between specialist and generalist engineers has been reinforced by the educational strategies adopted in many universities. According to Sinha et al. (2002), although many universities had expanded their teaching programs, these are often becoming more theoretical. For Silvestre et al. (2010), the challenge is to find dynamic strategies for knowledge building that are able to show the students what they will meet in their professional lives. If that is the case, the best strategy can be a combination of conventional teaching methods with active learning, as discussed next.

Active Learning and Expositive Classes

Classroom activities in a more conventional setting often do not give opportunities for experimentation if based only on passive learning. Thus, students do not have the chance to test the alternatives they propose to solve the problems presented by the instructor. This process can result in loss of interest and discouragement (Felder and Silvermann 1988). For Hartman and Gindy (2010), the introduction of problem-solution activities in regular courses can be a strategy to put students in contact with practical issues that engineers have to face in the real world. They also stress that a problem-based learning approach based on unstructured and multidisciplinary questions can result in learning through discovery.

As discussed by Zhou et al. (2012), active learning can be a set of actions planned to guide the students to the knowledge, competencies, and skills needed altogether in the current professional context of engineering. Several methods can be used to support active learning, with positive results in engineering education, as discussed by Rodrigues da Silva et al. (2012) in the specific case of a transportation planning course. These methods include problem-based learning (PBL) and the problematization methodology. According to Berbel (1998), in PBL the problems are predefined by specialists and presented to the students in a structured way, whereas in the problematization methodology the students are led to identify problems in a certain context. The problem contexts can be presented to the students in many different ways (Loureiro 2008). For Domite (2001), in the problematization process, the attitudes of the instructor can broaden the social perception of the students regarding life and everyday problems. Therefore, the object of knowledge can be more or less internalized by the student according to his or her needs or interests.

In any case, in active learning, the focus of the process moves from teaching to learning (Leite and Esteves 2006). It does not mean, however, that active learning should necessarily replace the traditional teaching methods, as observed by Lambros (2004). The combination of PBL with conventional classes, for example, is perfectly possible, as shown by Barroso and Morgan (2009). The combination of conventional teaching techniques with active learning would then help to assure the acquisition of theoretical knowledge and development of skills. The challenge with this approach is the evaluation techniques. Specifically, are the conventional learning evaluation methods suitable to this new teaching-learning process?

Evaluation of the Learning Outcomes

In many cases, the evaluation of the learning outcomes has been transformed into a simple act of producing numerical records, which is essentially the definition of assessment found by the Accreditation Board for Engineering and Technology (ABET) (2012). These records are often used for ranking purposes, but are rarely used as part of a formative approach. From a formative perspective, the outcomes of the evaluation become subsidies for actions aiming at solving learning gaps or problems. However, if that is the case, different evaluation techniques may be needed. Among the existing alternatives to support formative evaluations are concept maps.

Concept maps have been proposed by John Novak in the 1970s as a pedagogical tool based on the theory of meaningful learning (Novak and Gowin 1984; Novak 2003). This theory, which has been published by David Ausubel, has been influenced by the studies of Piaget (Ausubel et al. 1978; Palmero 2004). In addition to a hierarchical structure, concept maps rely on two principles from the theory of meaningful learning: progressive differentiation and integrative reconciliation (Novak and Gowin 1984). If used as a tool for the evaluation of learning, a concept map can show valid or mistaken concepts and relationships about a certain piece of knowledge. As a consequence, it serves not only for static evaluations, but it allows the establishment of a dynamic continuous learning evaluation process. These characteristics can make it a powerful complement to the conventional learning evaluation techniques, with a clear potential for application in transportation engineering education. This was the basic assumption in designing the experiment presented in this study.

Method

A direct involvement in a teaching-learning environment was a necessary condition for the development of this study. This was done in a transportation planning course regularly offered to civil engineering undergraduate students at EESC-USP, titled Planning and Analysis of Transport Systems. The activity involved 30 students, the lecturer, and a researcher, who also acted as a tutor in the activities of the problematization methodology adopted [following Berbel (1998), as discussed in the previous section]. In this methodology, students are led to identify problems in a certain context. The study was organized in three phases: (1) planning the teaching-learning process; (2) evaluating the teaching-learning process; and (3) evaluating the teaching-learning product. The combination of the three steps allowed the analysis of the approach combining traditional lectures and active learning, which was the focus of this investigation. Details of the three phases are described next.

Planning the Teaching-Learning Process

In general terms, the purpose of this phase must be the identification of (1) advance organizers; (2) learning preferences of all individuals involved in the course; (3) personality styles of the students; and (4) expected learning outcomes. In the case studied, the following resources were used:

1. The computer program IHMC—Cmaps Tools, for the construction of the concept maps (in this phase, only the first version) (Novak 2003; Ausubel et al. 1978);
2. The Index of Learning Styles (ILS) inventory (Felder and Soloman 2004);
3. The Keirsey Temperament Sorter (KTS) (Keirsey and Bates 1984); and
4. Bloom's Taxonomy (Bloom et al. 1972).

All activities previously described are regularly conducted in the course. Advance organizers and learning preferences serve as references for the preparation of expositive classes and other course activities. The personality types are taken into account during the selection of students for teamwork to create groups as heterogeneous as possible and not necessarily based on preexisting personal relationships. Additional comments concerning items 2 and 4 appear in the next section.

Evaluating the Teaching-Learning Process

The main purpose of this phase was to evaluate the procedures adopted during the course activities. The following attitudes were stimulated in the students: the improvement of the specific conceptual basis, the establishment of relationships between concepts, the identification of relevant data, the development of qualitative judgment skills, and decision-making. The latest three attitudes are directly related to the problem-solving process, but decision-making initiatives, in particular, are part of a higher-order cognitive process. The phase involved the following activities: (1) application of teaching-learning resources in the classroom; (2) identification of the teaching styles predominantly adopted by the lecturer; (3) use of active learning resources, in particular, the problematization methodology; and (4) construction of the second and third versions of the concept maps. Details of these activities are described next.

Resources Applied in the Classroom

Several resources were explored in the classroom for improving the teaching-learning process, such as minute papers, constant questioning of the students, and problem resolution by small, two-student teams. The researcher monitored and registered all activities, tasks, and resources explored by the lecturer in the classes. These records provide the elements for the results discussed subsequently.

Teaching Styles

The purpose of this activity was to characterize the predominant teaching style used in the classes and to compare it with the students' learning preferences found with the ILS, as previously mentioned in item 2 of "Planning the Teaching-Learning Process." The aim of the comparison was to align the expositive classes with the learning preferences of most students in the class. The characterization of the teaching styles was done five times within the academic term with the instrument developed by Silva Junior et al. (2013), always referring to a set of classroom hours.

Active Learning

The problematization methodology was used for the improvement of competencies and skills, as suggested by Berbel (1998). The approach was partially developed online in the learning management system (LMS) *TIDIA Ae* (http://tidia ae.usp.br), which was also later evaluated by the students.

Evaluating the Teaching-Learning Product

In this phase, the acquisition of competencies and skills by the students regarding the course topics was assessed. The concept maps built in the phases described previously were analyzed. The results provided elements for identifying advances in conceptual and procedural knowledge. The knowledge of conceptual relationships was also assessed. All this was done through the analysis of the following elements:

- Common characteristics found in the different map versions (CCM);
- Recurrent problems (RPB);
- Concepts introduced (COI);
- Importance of the concepts introduced (ICOI);
- Evolution in the three map versions (ETMV);
- Difficulties for building the maps (DBM);
- Concepts preserved in all map versions (CPMV); and
- Relationship between the quantitative assessments of the concept maps and the final course grades (RCMFG).

Results

The results of the study are presented in this section, following the same sequence of the phases described in the method.

Planning the Teaching-Learning Process

Two of the four items mentioned previously were effectively used in planning the activities for the case studied: the identification of the learning preferences and of the personality types (items 2 and 3). The identification of advance organizers and of the expected learning outcomes (items 1 and 4) were also done, but the results will not be discussed in this section. In the case of item 1, as the concept maps were used for monitoring the progress in the teaching-learning process, the results will be discussed subsequently.

J. Prof. Issues Eng. Educ. Pract., 2015, 141(3): 05014006

In the case of item 4, the expected learning outcomes will not be treated in this study, because they were already discussed elsewhere (Silva Junior and Rodrigues da Silva 2011a, b).

Index of Learning Styles

The ILS (Felder and Soloman 2004) was used to identify the learning styles (or preferences) of the students. The individual results were used to obtain a general characterization of the entire class, as shown in Fig. 1. The values marked in the matrices represent the number of students matching a certain specific combination of learning preference and personality type. Although 16 matrices result from the combinations of learning preferences and personality types, only four of them are displayed in Fig. 1 as examples. The values distributed in the center of the rows (i.e., values 1 and 3) represent individuals with balanced preferences regarding the dimension of the learning style under consideration. According to Felder and Silvermann (1988), students in this condition can benefit from activities related to both styles covered by that dimension. The learning preferences of the students can also be classified as moderate (i.e., values 5 and 7) and strong (i.e., values 9 and 11). In the case of strong preferences, students clearly tend to favor one of the extremes of the dimension considered.

Keirsey Temperament Sorter

The KTS (Keirsey and Bates 1984) was used to identify the personality types of the students and was the basis for assembling the teams for the development of the problematization methodology. The teams were formed with a mix of personality types, replicating the dynamics of the professional world. The results of the classification are also shown in Fig. 1. The predominant combinations of personality types and learning preferences of the students were: active-extrovert (quadrant 1 of the matrix in the upper-left corner of Fig. 1), sensory-sensory (quadrant 1 of the matrix in the upper-right corner), visual-thinking (quadrant 1 of the matrix in the lower-left corner), and sequential/global-judging (quadrants 1 and 2 of the matrix in the lower-right corner).

Evaluating the Teaching-Learning Process

Although the results of item 4 in "Planning the Teaching-Learning Process" were obtained during the expositive classes, the discussion of the results of the three maps will be presented subsequently. This will be done in combination with the final grades resulting from exams and quizzes. All other results concerning the evaluation of the teaching learning process are presented next.

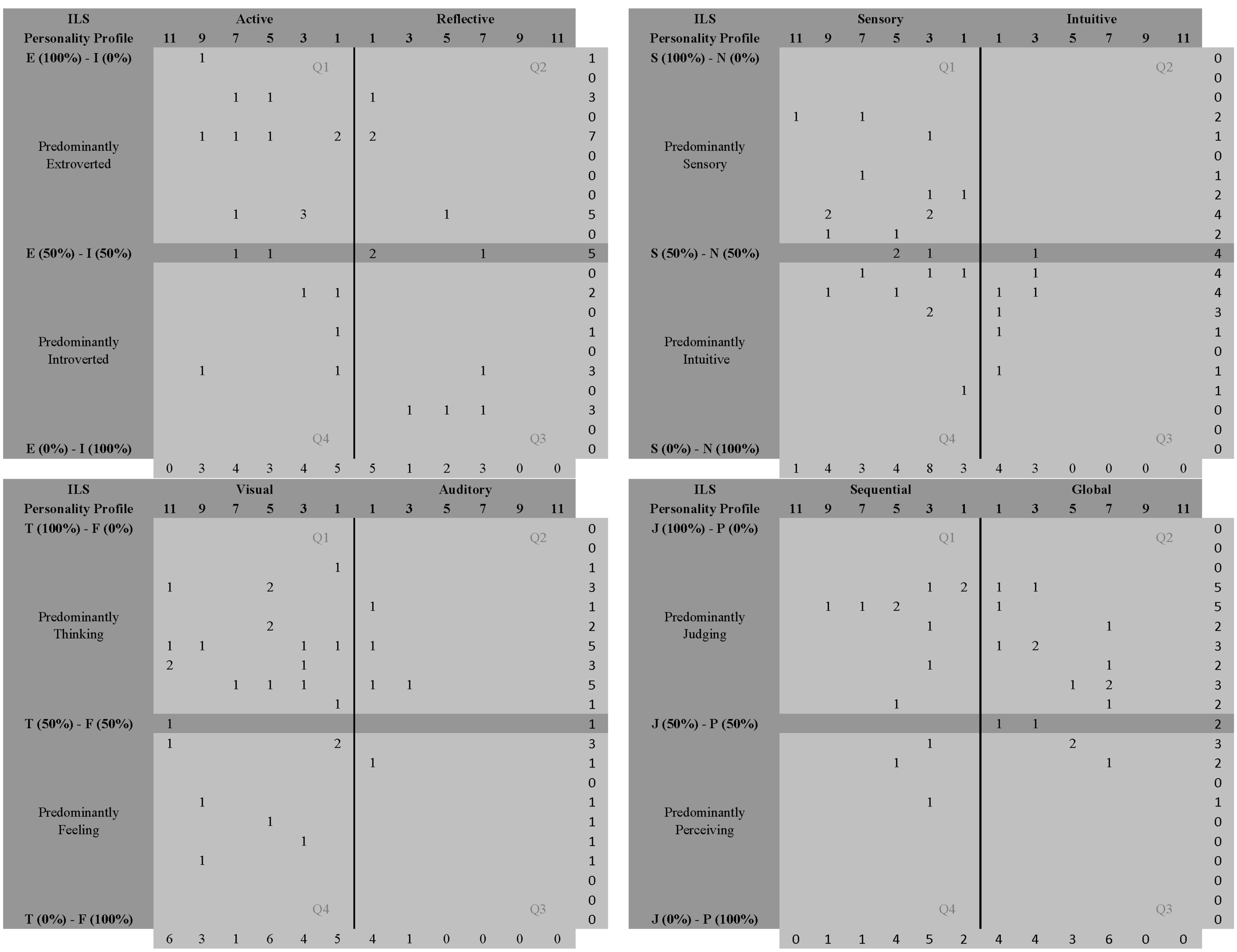

Fig. 1. Overview of the class based on the combined results of the *Index of Learning Styles* (Felder and Soloman 2004) and the *Keirsey Temperament Sorter* (Keirsey and Bates 1984)

Resources Applied in the Classroom

The following resources, which aim at the improvement of the teaching-learning process, were explored in the classroom:

- Expositive classes: The lecturer used conventional resources, such as oral presentations supported by slideshows and written explanations on the blackboard, and guided activities in a computer lab.
- Minute papers: The students were asked to register, immediately after the classes, the topics they have considered as useful or important and also those that were kept alive in the memory. The notes were analyzed and the most relevant points were brought back by the lecturer in subsequent classes.
- Constant questioning: The lecturer asked students to answer short and direct questions related to the topics discussed during the classes. The first student selected was then asked to select another student to answer the following question, and so on.
- Teamwork: Groups were formed to answer practical questions or to solve simple problems, such as the elaboration of graphs, the resolution of numerical exercises or the construction of simple mathematical models. The teams usually had only two students, who had approximately 5 to 10 min to finish the tasks assigned. Once they concluded the task, different students were always asked to present the results to the class.

The focus was to stimulate the participation of the students. The lecturer was always seeking interaction with the class. The students were constantly asked to express their perceptions, ideas, and comments about the topic presented to create a dynamic environment and helped to avoid boredom.

Teaching Style and Learning Preferences

The style of the classes was identified as proposed by Silva Junior et al. (2013). The purpose was to determine if the predominant teaching style used in the classes matched the students' learning preferences. The results are summarized in Fig. 2. In general,

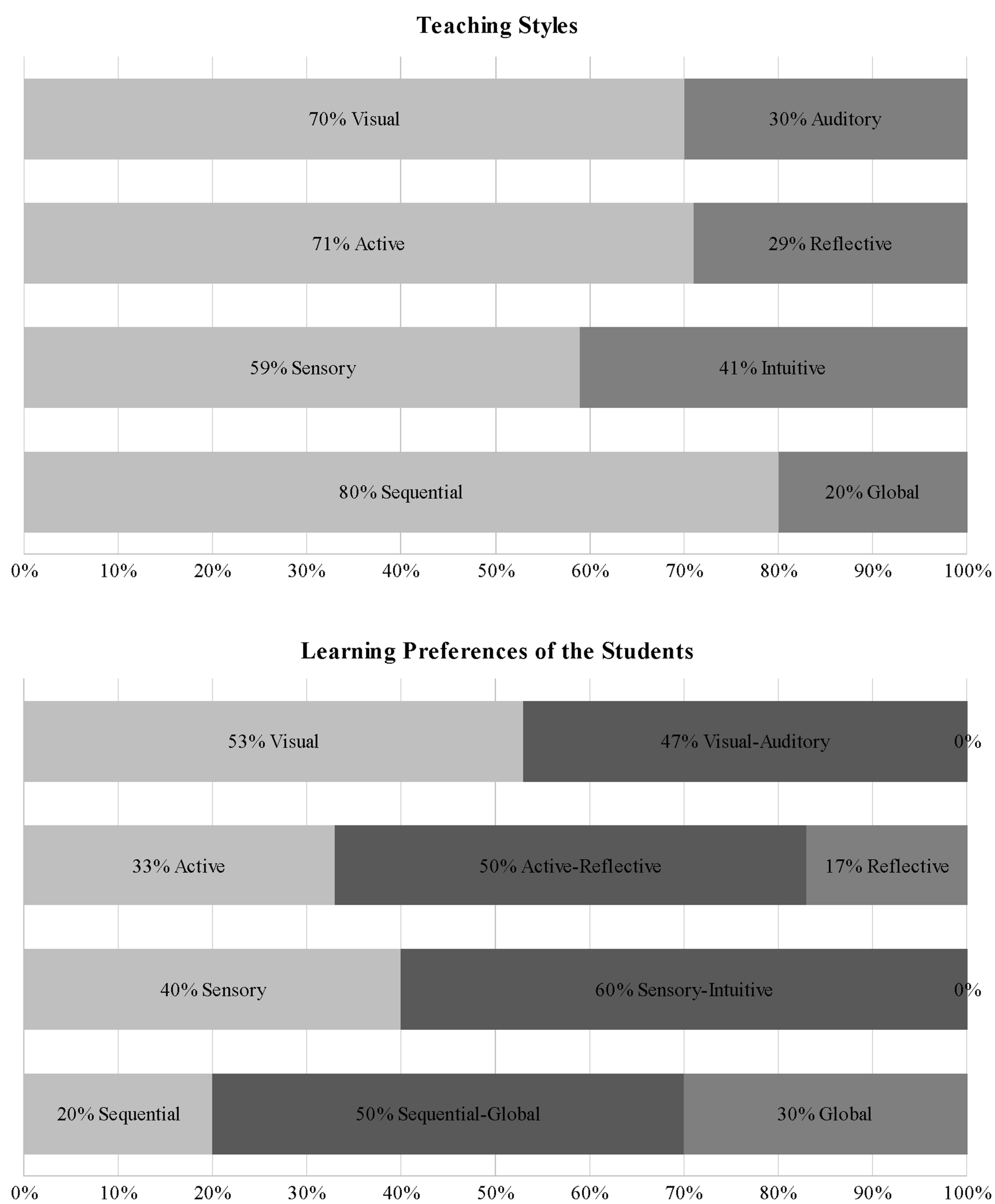

Fig. 2. Teaching styles in the classes and learning preferences of the students

the teaching style aligned most of the time with the learning preferences of the class, favoring the active participation of the students and the development of activities.

Problematization Methodology

In the course edition considered, the selected problem focused on pedestrian mobility and traffic calming possibilities around the university campus. A field survey carried out by the class of 2011 served as an initial reference. The procedures adopted in this phase involved teamwork, the use of the online LMS *TIDIA Ae*, the discussion of progress reports by the groups, and meetings of the groups with the lecturer and the associate researcher. The latter two activities will not be discussed in this paper. The following resources of *TIDIA Ae* were used for the problematization methodology: database storage and document sharing, discussion forums, message exchanger, and a report uploader.

Two online forums were organized with the students. Forum I had two parts. The first part was dedicated to the identification of the problem that the groups were expected to tackle. In the second part, the most viable courses of action were selected for further development. Immediately after the two parts of forum I were concluded, the teams started to look for ways to solve the selected problem. Forum II involved the analysis and evaluation of the data collected for developing alternatives for solutions. The data set from the previous year helped in the process.

Part of the evaluation of the online system *TIDIA Ae* done by the students is shown in Fig. 3. The results of Fig. 3(a) indicate that 40% of the students rated the LMS as good or excellent. Only 10% of the students found it bad or too bad, and 50% rated it as fair. The results displayed in Fig. 3(b) indicate that most of the students (86%) had never accessed the system before the course. This may have created some difficulties or even indifference in the use of the LMS. An overall evaluation of the course is also shown in Fig. 3(c). The fact that 93% of the students rated it as good or very good indicates that the approach adopted is a promising alternative for this course.

Evaluating the Teaching-Learning Product: The Use of Concept Maps

Concept maps were used to look for evidence of meaningful learning. All students have built three versions of concept maps about the general topic of the course throughout the semester. They were also asked to build maps about other topics, just to get used to the process and the computer package used. The first version of the three main maps was built in the very first class of the semester. The objective was to find out what the students already knew about planning and analysis of transport systems. The second version was built right before the beginning of the activities of the problematization methodology. The purpose was to check the evolution of the students regarding their knowledge of the concepts and their relationships up to that moment. The third and final version was built after the teams have presented their solutions to the selected problems with the problematization methodology. The analyses of the concept maps were based on the previously listed elements.

Overall Evaluation of the Concept Maps

The examination of concept maps has produced a more comprehensive evaluation and allowed an analysis of the evolution of the cognitive process. Aspects of the conceptual knowledge and of the knowledge of conceptual relationships were also assessed. Even considering that the analysis of the maps is essentially based on qualitative elements, the criteria allowed quantitative assessments. As a result, the concept maps presented evidence of meaningful learning, suggesting they can be used to support the learning evaluation process.

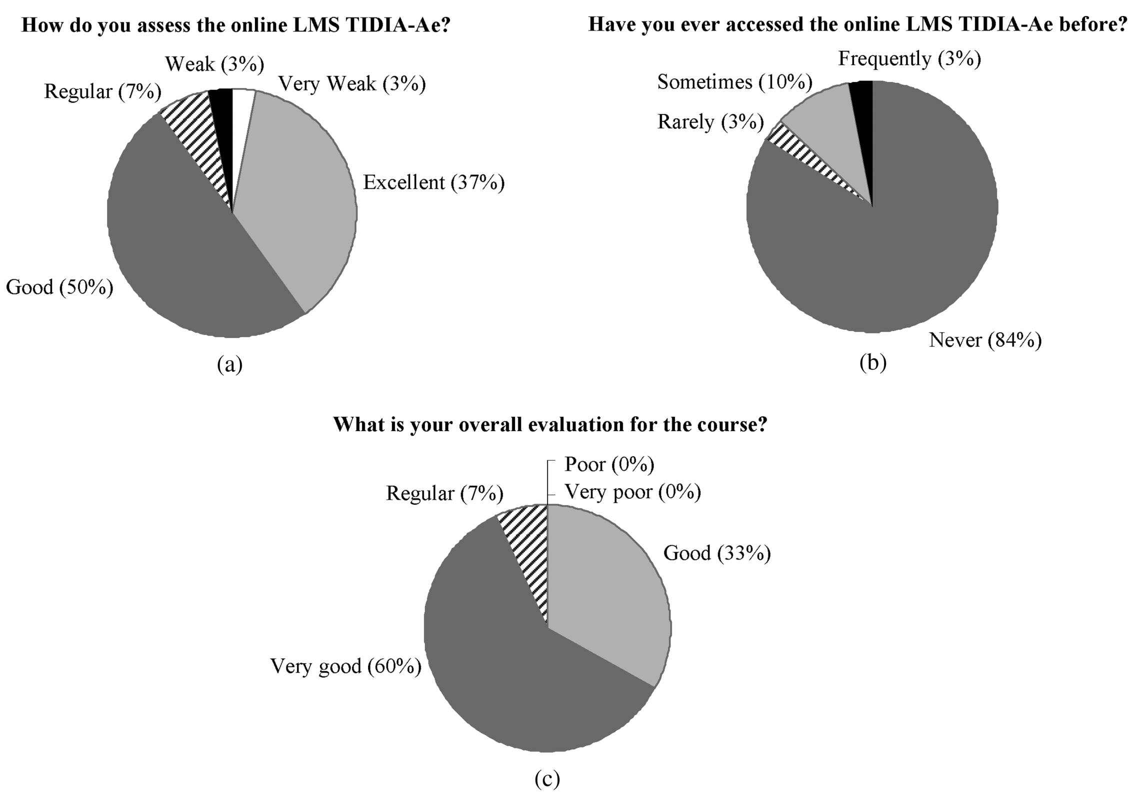

Fig. 3. Partial results of an evaluation by the students of the learning management system (*TIDIA Ae*) adopted and of the course

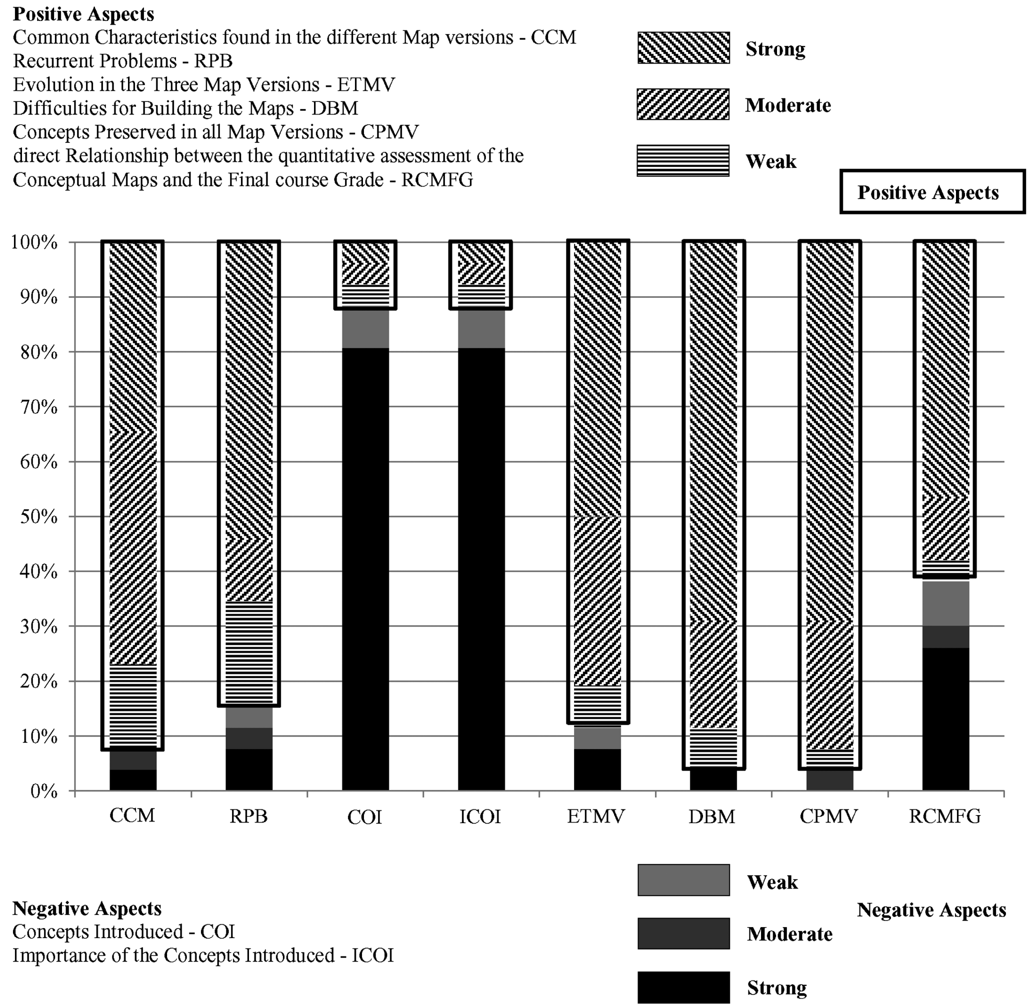

Fig. 4. General evaluation of the concept maps

A summary of the evaluation of the three main concept maps built by the students is presented in Fig. 4. In this case, the results of four students were not considered, because they did not produce the three maps. Fig. 4 contains two major divisions, which represent positive or negative evaluations. Positive evaluations are always placed on the top of the graph and marked by a black rectangle. Positive and negative evaluations are in both cases subdivided into three conditions: strong, moderate, or weak.

Most of the criteria had more positive than negative evaluations. Regarding the criterion ETMV, for example, approximately 88% of the students were positively evaluated. More important than the total number, however, is the fact that 50% had a strong improvement, approximately 31% had a moderate improvement, and only 7% of the students had a weak improvement in concept mapping. In addition, half of the students with moderate evolution built good maps since the first version. The same thing happened with the students with weak improvement. Some of those students had already taken elective transportation courses before, which likely explains the improvement in concept mapping.

More negative than positive aspects were found only for two criteria: COI and ICOI. This may be because the students were introduced to a limited number of elementary concepts.

In the case of the last criterion (RCMFG), however, the results are not very easy to interpret. The graph was built with the assumption that direct relationships would be positive; therefore, these are the cases on the top of the bar at the right side of the graph. The strength of the relationship, however, varied. The relationships were strong in approximately 46% of the cases, moderate in 12% of the cases, and weak in only 4%. The other 38% of the cases, in which inverse relationships were observed, were classified in the negative side of the graph (26% strong, 4% moderate, and 8% weak).

Part of the students classified in the negative side of the criterion RCMFG (i.e., 27% of the total) have built good maps, even though they did not have high grades in the conventional evaluations (i.e., maps and quizzes). The remaining 11% had high grades but built poor maps. These figures seem to indicate that the conventional instruments of evaluation were not able to capture all aspects of the learning process. Some of the learning outcomes may have been captured in the maps of those students with low grades and vice versa. This may be an indication that a combined evaluation strategy would have been more adequate in this case.

Conclusions

The purpose of this study was to analyze an approach that combines traditional lectures and active learning as a strategy to help in the development of some competencies and skills demanded by the transportation engineering profession. This was done in the specific case of the course Planning and Analysis of Transport Systems, which is offered to third-year civil engineering students at the University of São Paulo at São Carlos. The authors also tried to examine if the acquisition of the skills could be assessed through conventional evaluation techniques and concept maps. The conclusions drawn are presented in three parts. The first part refers to the planning process of the teaching-learning actions and phases, the second part to an evaluation of the process, and the third part to an evaluation of the product.

Regarding the proposed approach, the resources applied for planning the teaching-learning process for the course were quite useful and promising for supporting both the more conventional classroom activities and the problem-based methodology developed concurrently. This was confirmed by the favorable outcomes obtained in the classroom activities and in the teamwork projects, and also by the positive feedback given by the students when assessing the course. The resources used, however, were not limited to the identification of teaching styles and personality types described previously. The use of a knowledge table with clear learning outcomes, the regular application of minute papers, and the active participation of the students in the classroom tasks also played an important role.

This study was done, however, using only one semester of a single course. Other aspects should be considered if performed in multiple courses—both laterally across the curriculum and vertically through time. In that case, significant impact should be expected on planning issues due to the integrative nature required by the approach (planning and evaluation of teaching-learning processes and products), with much more time demanded by each step of the process. Several factors, such as time availability, institutional constraints or incentives, number of students per class, and students' profiles, can affect the results of the techniques proposed here and should be carefully taken into account in the implementation of the strategy and in the analyses of the results.

The use of a problem-identification methodology combined with conventional lecture-based activities was considered adequate for addressing the domains of the conceptual relationships, and relational and attitudinal cognitive procedures, as presented in Bloom's taxonomy. The evaluation phase, which involved the creation of concept maps, the resolution of exams and quizzes, and the active learning activity, i.e., the problem-solving part of the course, presented results that were consistent with the overall goal of the proposed strategy. The application of the learning management system *TIDIA Ae* was adequate for supporting the problem-resolution activities, as reported by the students in the course evaluation questionnaire.

The main conclusion of this study, however, concerns the use of concept maps as a strategy for student learning. This was confirmed by a comparative analysis of the three maps built by the students throughout the semester. The maps provided rich information about the domains explored by the students not only as a static snapshot, but also as a development process along the course. Another interesting outcome of this study was the comparison of the average of the grades obtained in the conventional evaluation activities with the average of the grades given to the concept maps. The results suggest that concept maps can serve as an additional evaluation instrument to assure an evaluation that is more precise and coherent with the learning outcomes desired for transportation engineering students. The use of concept maps, however, does not mean that other evaluation techniques should be eliminated, given this is not a matter of selecting a single evaluation tool. On the contrary, it shall be a search for a combination of tools and techniques that can make the evaluation process more comprehensive and effective.

Finally, returning to the case discussed in the introduction, a similar experiment should be developed with the set of integrated courses of the special studies program to look for evidence of meaningful learning in a more comprehensive and complex setting. In this case, the analysis of what was done with one course (Planning and Analysis of Transport Systems) could be taken as "proof of concept." which could then be scaled to evaluate the effectiveness of the overall special studies program in transportation engineering.

Acknowledgments

The authors would like to acknowledge the Brazilian agencies CAPES (Post-Graduate Federal Agency) and CNPq (Brazilian National Council for Scientific and Technological Development) for the financial support provided to this research.

References

Accreditation Board for Engineering, and Technology (ABET). (2012). "Criteria for accrediting engineering programs: Effective for reviews during the 2013–2014 accreditation cycle." ⟨http://www.abet.org/uploadedFiles/Accreditation/Accreditation_Step_by_Step/Accreditation_Documents/Current/2013_-_2014/eac-criteria-2013-2014.pdf⟩ (Apr. 24, 2014).

ASCE. (2008). *Civil engineering body of knowledge for the 21st century: Preparing the civil engineer for the future*, 2nd Ed., Reston, VA.

Ausubel, D. P., Novak, J. D., and Hanesian, H. (1978). *Educational psychology: A cognitive view*, Holt, Rinehart and Winston, New York.

Barroso, L. R., and Morgan, J. R. (2009). "Project enhanced learning: Addressing ABET outcomes and linking the curriculum." *J. Prof. Issues Eng. Educ. Pract.*, 10.1061/(ASCE)1052-3928(2009)135:1(11), 11–20.

Berbel, N. A. N. (1998). "A Problematização e a Aprendizagem Baseada em Problemas: Diferentes Termos ou Diferentes Caminhos?" *Interface—Comunicação, Saúde, Educação*, 2(2), 139–154 (in Portuguese).

Bloom, B. S., Engelhert, M. D., Furst, E. J., Hill, W. H., and Krathwohl, D. R. (1972). *Taxonomia de Objetivos Educacionais: Domínio Cognitivo*, Globo, Porto Alegre, Brazil (in Portuguese).

Domite, M. C. S. (2001). "Problem posing and problematization in the process of learning and teaching mathematics." *Adult Educ. Dev. J.*, 57, 27–31.

Felder, R. M., and Silvermann, L. K. (1988). "Learning and teaching styles in engineering education." *Eng. Educ.*, 78(7), 674–681.

Felder, R. M., and Soloman, B. A. (2004). "Index of learning styles (ILS)." ⟨http://www2.ncsu.edu/unity/lockers/users/f/felder/public/ILSpage.html⟩ (Apr. 22, 2012).

Hartman, D. J., and Gindy, M. (2010). "Comparison of lecture- and problem-based learning styles in an engineering laboratory." *Proc., 89nd Annual Meeting of the Transportation Research Board (CD-ROM)*, Transportation Research Board, Washington, DC.

Keirsey, D., and Bates, M. (1984). *Please understand me: Character & temperament types*, Prometheus Nemesis Book, Del Mar, CA.

Khisty, C. J., and Lall, B. K. (2003). *Transportation engineering—An introduction*, 3rd Ed., Prentice Hall, Upper Saddle River, NJ.

Lambros, A. (2004). *Problem based learning in middle and high school classrooms: A teacher's guide to implementation*, Thousand Oaks, Los Angeles, CA.

Leite, L., and Esteves, E. (2006). "Trabalho em Grupo e Aprendizagem Baseada na Resolução de Problemas: Um Estudo com Futuros Professores de Física e Química." *Actas do Congresso PBL 2006 (CD-ROM)*, Pontifícia Universidad Católica del Peru, Lima, Peru (in Portuguese).

Loureiro, I. M. G. (2008). "A Aprendizagem Baseada na Resolução de Problemas e a Formulação de Questões a partir de Contextos Problemáticos: Um estudo com Professores e Alunos de Física e Química." Master's thesis, Univ. of Minho, Institute of Education and Psychology, Minho, Portugal (in Portuguese).

Mager, R. F. (1984). “Writing learning objectives: Beginning with the end in mind.” ⟨http://www.oucom.ohiou.edu/fd/writingobjectives.pdf⟩ (Jul. 7, 2011).

Novak, J., and Gowin, D. (1984). *Learning how to learn*, Cambridge University Press, New York.

Novak, J. D. (2003). “The theory underlying concept maps and how to construct them.” Institute for Human and Machine Cognition (IHMC), Univ. of West Florida, ⟨http://cmap.coginst.uwf.edu⟩ (Apr. 12, 2013).

Palmero, M. L. R. (2004). “La Teoría del Aprendizaje Significativo.” *Proc., 1st Int. Conf. on Concept Mapping*, Vol. 1, Universidad Pública de Navarra, Pamplona, Spain, 535–544 (in Spanish).

Rodrigues da Silva, A. N., Kuri, N. P., and Casale, A. (2012). “PBL and B-learning for civil engineering students in a transportation course.” *J. Prof. Issues Eng. Educ. Pract.*, 10.1061/(ASCE)EI.1943-5541.0000115, 305–313.

Silva Junior, C. A. P., Fontenele, H. B., and Rodrigues da Silva, A. N. (2013). “Estilos de Ensino versus Estilos de Aprendizagem no Processo de Ensino-Aprendizagem—Uma Aplicação em Transportes.” *Transportes*, 21(2), 30–37 (in Portuguese).

Silva Junior, C. A. P., and Rodrigues da Silva, A. N. (2011a). “Graduação em Engenharia de Transportes: Objetivos Instrucionais e Diretrizes Curriculares Oficiais.” *Proc., 25th Annual Congress on Transport Research and Education*, National Association of Research and Education in Transportation, Rio de Janeiro, Vol. 1, 539–549 (in Portuguese).

Silva Junior, C. A. P., and Rodrigues da Silva, A. N. (2011b). “Problem/project/practice based learning and transportation engineering degrees.” *Proc., Int. Symp. on Project Approaches in Engineering Education (CD-ROM)*, Vol. 1, University of Minho, Braga, Portugal, 237–244.

Silvestre, V., Schunemann, A., Ordoñez, A., and Vaz, J. C. (2010). “PBL e Agenda 21—Problemas Socioambientais na Graduação de Gestão de Políticas Públicas para Sustentabilidade.” *Proc., PBL 2010 Int. Conf. Problem-Based Learning and Active Learning Methodologies (CD-ROM)*, University of São Paulo, São Paulo, Brazil (in Portuguese).

Sinha, K. C., et al. (2002). “Development of transportation engineering research, education, and practice in a changing civil engineering world.” *J. Transp. Eng.*, 10.1061/(ASCE)0733-947X(2002)128:4(301), 301–313.

Zhou, C., Kolmos, A., and Nielsen, J. D. (2012). “A problem and project-based learning (PBL) approach to motivate group creativity in engineering education.” *Int. J. Eng. Educ.*, 28(1), 3–16.