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A Longitudinal Evaluation of a GIS Laboratory in a Transportation Engineering Course

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ABSTRACT

This paper focuses on the potential impact of student-centered feedback for enhancing the learning experience of civil engineering students that used a Geographic Information System (GIS) based tutorial in a transportation engineering course. The tutorial was implemented in a laboratory environment developed as a self-guided activity supported by a web-based learning system. The formative research proposed in this study includes a series of four successive implementations of this laboratory. Students' performance, beliefs and perceptions were monitored using a mixed-methods design approach and weaknesses identified from the early implementations were addressed before the next implementation of the laboratory activity. We found that students' performance improved when the GIS web-based tutorial was complemented with an instructor-driven short introduction that anchored the laboratory activity in traffic safety. In addition, students' feedback in both quantitative and qualitative format indicated weaknesses related to the high difficulty of the laboratory and usability factors such as speed of data uploading. As these weaknesses were addressed, students' positive input regarding the overall GIS laboratory experience increased significantly. This positive input was fully backed up by students' feedback indicating major strengths of the GIS laboratory for professional growth and future career development in civil and transportation engineering. Finally, students' inputs in the latest implementations provided us with valuable suggestions for future potential improvements regarding how to better integrate the GIS laboratory in course-related activities such as term projects.

Keywords
Transportation Education and Training, Transportation Engineering, Geographic Information Systems, Traffic Safety

INTRODUCTION

The education and practice of transportation engineering has evolved over the past several decades. The task of educating transportation engineers, as stated by an Institute of Transportation Engineers (ITE) Committee (ITE Journal, 1990), is not only "*to train students in how to do various activities associated with current practice*", but also "*to provide students with the tools necessary to solve new problems that arise*". Previous studies, on the other hand, reveal the hourly requirement of transportation-related courses in the civil engineering curriculum offered for undergraduate students as decreasing (Lipinski & Wilson, 1992; Mason, 2003) and entry-level engineers lack significant exposure to transportation engineering methodologies (Lipinski & Wilson, 1992). In terms of practice, young graduates face a wide range of increasingly complex problems from growing congestion, *heightened awareness of traffic safety,* and worsening air quality (Handy, Weston, Song, & Lane, 2002).

In a survey (Handy et al., 2002) of 360 participants in transportation engineering and planning courses offered at US universities, while assessing the match between knowledge and the skills needed for current transportation planning jobs and those covered by their formal degree programs, respondents indicated that their degree programs did not provide enough exposure to any of the 20 skill areas surveyed. In the skills category, GIS received the lowest average rating for coverage. When the topic and skills most in need of additional attention were assessed for transportation planning education, again GIS was identified as one of the top

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priority skills. The study indicated a greater deficiency in the development of skills than in the coverage of topics in academic programs. This clearly presents the need for inclusion of GIS in civil engineering curriculum and even more for transportation professionals.

To address the above issues, the transportation engineering curriculum (both topics and teaching methods) should be more rigorous and technically focused to meet market needs (Liao, Liu, & Levinson, 2009). In recent years, web-based education has become a popular and effective way of complementing classroom instruction. Online learning tools bring a classroom laboratory right in front of a student on the computer. Web-based learning tools also offer the independence of location, and flexibility of usage. The learning tools can be accessed anytime and from anywhere around the world from computers with Internet access.

Smith and Cunningham (1987) describe the ideal learner as one who is active and is involved in the learning process by asking questions, teaching others, or participating in hands-on activities. They showed that these learners more often develop a comprehension of the ideas and concepts of the material being presented and do not just memorize the material being presented. They concluded that active learners are more often able to apply the skills learned to new situations. In this context, a study that conducted a survey of more than 4000 adult learners from a variety of backgrounds who participated in a training project, identified hands-on exercises as very useful and often described how much fun they had learning the material (Zacharia & Jennings, 1998).

RESEARCH CONTEXT AND GOALS

To address the above needs and following the formats and active learning environments, this research project focused on developing and implementing a web-based learning system to

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scaffold learning for civil engineering students (Luna et al., 2008). The project introduced a series of stand-alone GIS laboratories customized for specific areas in the civil engineering curriculum: Environmental, Geotechnical, Surveying, Transportation and Water Resources engineering. The model proposed is that of a distributed learning instruction using individual laboratories across several civil engineering complementary courses (Luna et al., 2008, 2010).

This learning model is intended to build GIS-related skills by contextualizing the software application in various related topics. Under this learning model, students will move from mere learning of the mechanics of use of GIS to a broader understanding of the capabilities and usefulness of this tool for various civil engineering applications. Learning of this tool will then become a cumulative result of this string of individual implementations of the GIS software. This tool provides a high level of detail and richness of content such as built-in videos that can be played in parallel as users conduct the learning exercises (Learn Civil GIS, 2010).

The main goal of the GIS laboratory presented in this paper was to introduce traffic safety using the ArcGIS software. In the initial implementation of the laboratory, students completed three major instructional tasks: 1) a self-paced multimedia tutorial that introduced the steps associated with the use of ArcGIS for each stage of the task at hand using a simplified highway crash dataset; 2) a transfer task that required students to use the steps described in the tutorial for a given field dataset; and 3) a synthesis task that required students to write a short report on their findings. This structure involved eight major tasks that included high-end issues in GIS software manipulation such as buffering and extensive data handling and exporting.

Previous research, however, on multimedia-based and e-Learning instruction showed that despite clear strengths of these learning contexts, not considering various aspects of students' perceptions engaged in multimedia instruction can reduce the effectiveness of their learning (e.g.

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Graff, 2006; Jackson & Helms, 2008; Mackey & Jinwon, 2008; Srinivasan & Crooks, 2005; Sun et.al., 2008). First, student-oriented web design factors such as usability, perceived usefulness or perceived difficulty proved important for improving students' learning experiences. For example, Mackey & Jinwon (2008) found that web usability factors such as speed of access to the online module and resistance to web environments can significantly reduce the effectiveness of student learning when additional web-based and face-to-face resources to address these issues are not deployed. In addition, learner perceived usefulness and ease of use of the online learning systems were positively correlated to perceived satisfaction with e-Learning experience (Sun et al., 2008). Second, when web-based modules are deployed as part of a hybrid-teaching environment, as is the case with the GIS laboratory analyzed in this research, the strengths associated with flexibility and self-pacing of online modules overlap with corresponding weaknesses of lack of instructor interaction and technological challenges (Jackson & Helms, 2008).

To address the goal of the above mentioned distributed learning model (Fiore & Salas, 2007), this paper focused on the above-mentioned student-driven factors that impact the contextual implementation of the GIS laboratory in Transportation Engineering, a mandatory first course in transportation for civil engineers. The focus of this research is a longitudinal analysis of students' performance and perceptions in successive implementations of the web-based laboratory introduced in this course.

RESEARCH QUESTIONS

The overall objective of this research was to evaluate from students' perspective to what degree the GIS laboratory was a useful learning tool for a civil engineer undergraduate engaged in a transportation engineering course and use these perspectives to improve the learning

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experience. The main research questions that address the overall objective and were followed throughout the longitudinal implementation of this laboratory are:

Q1. Is the GIS laboratory an effective tool for learning traffic safety?

Q2. Does anchoring instruction in the traffic safety context through instructor's introduction of GIS laboratory goals and major tasks produce better learning experiences?

Q3. Do the students perceive the GIS laboratory as a useful tool for their professional growth?

RESEARCH METHODOLOGY

Research Procedure

The research for this study was conducted in four phases that focused on the implementation of the GIS laboratory in various stages of the redesign of both the overall instructional activity and its main associated tool, the online self-paced tutorial.

In *Phase 1*, the GIS exercise was a stand-alone laboratory activity during the first week of semester, following the first lecture. The activity engaged 27 students in a self-guided experience with online support, and very limited assistance from graduate teaching assistants. Students had one week to complete the final report before submitting it at the beginning of the next laboratory. Procedural items implemented in this phase included:

1) An entry survey administered in classroom to measure student expected engagement, self-reported level of skills, which assessed their prior knowledge on basic transportation engineering topics;

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2) A quasi-experiment to test if an additional short introductory activity offered by the instructor will enhance students' learning experience (Brown, Collins & Duguid, 1989; CTGV, 1993), and

3) An unannounced exit survey administered online during the next laboratory after the instructor collected the final report. This exit survey measured student perceived engagement, academic self-efficacy (Midgley et al., 1998; 2000), overall experience with the GIS laboratory, and student retention of basic traffic safety issues from the implementation of GIS software. Details associated with these procedural items are available in a previous research paper by Bham et al. (2010).

For *Phase 2,* in Fall 2009, four procedural changes were made compared to first implementation described above. First, the laboratory was offered during the second week of November rather than as a first laboratory. Second, students engaged in this laboratory were enrolled in a lower-level civil engineering communication course. Of the 96 students enrolled in this course, 87 participated in the entry survey. Third, an anchoring short lecture similar with the one offered to the treatment group in Phase 1 was offered by the faculty member that coordinates the Transportation Engineering course during the lecture preceding the GIS laboratory. Fourth, based on the findings from Phase 1, both the online tutorial and the tasks associated with this activity were modified to reduce the length of the activity from three to a two-hour laboratory and teaching assistants took a more active role in helping students during the laboratory activity. Finally, students were required to complete the entire activity, including the final report during the allocated laboratory time. At the beginning of their next regular laboratory, students participated in an unannounced survey on their experience with the GIS laboratory. Of these, 76 were retained for the final analysis because they participated in both the entry and the exit surveys.

In *Phase 3,* implemented in Spring 2010, the participants and the structure of the tasks were similar to the one implemented in Phase 1 of the study with the observation that the online environment used by the students was the reviewed one, initially deployed in the second phase. Similar to *Phase 2*, the instructor introduced traffic safety and GIS issues in a short introductory lecture and the teaching assistants were more proactive in helping students during the laboratory activity. The major changes made were: 1) a realigned and shortened structure of the laboratory activity, 2) the duration of the laboratory was two-hours with the requirement to produce the final report during this time. The entry and exit surveys administered for this third phase were similar to the one administered in Phase 1.

Finally for *Phase 4*, the major goal was to test if a second implementation of the GIS laboratory adapted this time as part of a comprehensive semester-long activity produces better learning and perception outcomes. The same group of students that participated in Phase 3 were also engaged in this second implementation of the GIS laboratory. The major procedural changes were: 1) the laboratory was placed toward the end of the semester; 2) the dataset used was changed to meet the requirement of the highway design-project to which the laboratory was linked, and 3) the generic test questions administered after the laboratory during previous phases were eliminated as the performance outcomes were now part of the more comprehensive assessment strategy administered for the design project.

Participants

The target participants in this research were mostly juniors and some seniors enrolled in an introductory Transportation Engineering course and for Phase 2 were mainly sophomores. Table 1 summarizes participants' information for all research phases.

(*Insert Table 1 about here)*

The entry GPA for the three groups of students participated in all four phases of the research was analyzed using a one-way ANOVA, between-subject design. This analysis revealed a significant effect for the GPA (Table 2). Tukey's HSD test showed that students in the non-transportation group (Phase 2) had significantly higher GPA scores than students in transportation groups (Phases 1, 3). All effects were reported statistically significant at the .05 significance level.

(*Insert Table 2 about here*)

RESEARCH DESIGN, RESULTS AND INTERPRETATION

The research design used for this study followed a mixed-methods approach (e.g. Creswell, 2003; Tashakkori & Teddlie, 2003) that builds on the complementarities of quantitative and qualitative data analysis. The quantitative analysis includes two types of designs. For *Phase 1* only, a quasi-experimental design was used, where students could choose between: a) going directly to the laboratory (control), and b) going to a 20 minute lecture with the instructor before starting the actual laboratory activities (treatment). In addition, for all four phases of this study the research design used a formative analysis of performance, attitudinal, and perception quantitative data.

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The qualitative analysis for all four phases of this study used an "in-vivo analysis" (e.g. Morse & Richards, 2002) of students' answers to various reflective prompts that were related to issues such as strengths and weaknesses of GIS laboratory, the importance of GIS for civil and transportation engineers, and suggestions for improvement of this laboratory's experience.

Results from the Quantitative Analysis

Measures for the Quasi-Experimental Design in Phase 1

Three categories of variables used were:

a) *Control variables* used to test the homogeneity of the two experimental groups:
   - Aggregate prior knowledge score, resulted as a percentage of total score for the prior knowledge questions on basic math, physics, and surveying administered with the course entry survey;
   - Entry GPA score, self-reported by students and validated using the internal reporting resources available;

b) *Dependent variables* used to assess students' performance on seven traffic safety questions administered with the exit survey:
   - Raw assessment score, computed as percentage of sum of correct answers (0 for wrong answer and 1 for correct answer) to total possible points;
   - Adjusted assessment scores that included a penalty for students that answered wrong even if they could chose the "I don't know" option, and respectively a reward for students that when not sure chose that option; that is, the item was scored 0 for wrong answers, 1 for "I don't know" and 2 for a correct answer and

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then the percentage was computed similarly to the one for the raw assessment score;

c) *Independent variables*,

- Experimental groups (control and treatment);
- Only for Phase 1, where we offered an extension of the regular laboratory time to compensate for the lecture time for the treatment group, the self-reported time-to-finish on task was collected. The scale used for this measure had five options: 1–by the end of regular laboratory time; 2–by the end of extended laboratory time; 3–later in the day of the laboratory; 4–the week of the laboratory; and 5–the week following the laboratory before the report deadline;

Measures for the Formative Data Analysis in Phases 1 to 4

First, a set of 11 perception variables related to motivation, usefulness and difficulty, previously reported for the data collected in Phase 1 of this study (Bham et al., 2010), were used for the longitudinal dataset covering all four phases of this study. Because these three factors were developed on a conceptual rather than empirical foundation, we used exploratory factor analysis to discover which variables in this set form statistically coherent subsets that are relatively independent of one another. Variables that were correlated to each other were therefore combined into factors that are thought to reflect the underlying relationships that created the correlations among analyzed variables (e.g. Tabachnick & Fidell, 2001, p.582). *Facto*r analysis procedure in SPSS (v.18) statistical software package was used to conduct exploratory factor analysis for the longitudinal dataset covering all four phases of this study. Two independent

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factors, engagement and difficulty, that utilized nine of the initial eleven variables resulted from the exploratory factor analysis (Table 3).

(*Insert Table 3 about here*)

Each of these factors explained variances represented by eigenvalues higher than one, as recommended in the literature (e.g Tabachnick & Fidell, 2001, p.593). To account for the internal consistency of these factors, the squared multiple correlations of factor scores known as variable loads, were analyzed. Variables having load values of .70 or higher and therefore accounting for substantial variance in the factor scores were retained for the analysis (Tabachnick & Fidell, 2001, p.625). As shown in Table 3, the five variables included in the engagement factor had the lowest load of (.76) and the four variables included in the difficulty factor had the lowest load of (.74). Finally, the internal reliability of the two identified factors was measured using Cronbach's alpha. The internal reliability was strong for both factors with values of .90 for the engagement factor and .81 for the difficulty factor (see Table 3).

Second, students' self-efficacy beliefs measure was considered for this study. According to social learning theory (Bandura, 1977), people with high self-efficacy i.e., those who believe they can perform well - are more likely to view difficult tasks as something to be mastered rather than something to be avoided. Self-efficacy in a learning environment can then be considered an indicator of students' confidence in the effectiveness of one's learning. A scale adapted from Pintrich and De Groot (1990) was used to measure students' academic self-efficacy associated with the GIS laboratory.

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Results from Basic Statistical Data

The means, standard deviations and sample size for each of the four phases of this study are summarized in Table 4. For first three phases, the raw and adjusted assessment scores are provided as percentages of maximum possible score. They are based on the same pool of multiple-choices or fill-in-the-blanks while for the last phase the assessment was tied to a specific project in the course. Therefore, this final performance measure was not used as it had a different structure which made direct comparison with the previous performance data hard to sustain.

(*Insert Table 4 about here)*

For the first three phases, for which both the assessment items used and their administration were similar, the basic statistical data were combined and analyzed. The analysis of the combined data for these phases revealed that the raw assessment scores (in percentages) ranged from 59.2 to 67.4 while the adjusted assessment scores that gave some credit to those students recognizing that they cannot answer a specific question ranged from 64.8 to 72.6. Two major factors influenced the mean values for the assessment scores for the first three phases as presented in Table 4.

First, for the first three phases the GIS laboratory was introduced as a stand-alone, one-time instructional activity due to the restriction in the length of the instructional process and was not preceded or followed at that time by any traffic-safety explicit instruction. Second, students were not told that an assessment will be administered in one week and therefore there was no preparation for this assessment, as is the case for traditional assessment practices in higher education. In these conditions, to evaluate the significance of these mean scores, they need to be compared to the retention rates measured in memory retention experiments reported in the

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literature rather than to standard grading percentages used in classroom assessment. From this perspective, the mean percentage scores found, fall within the range of retention rates after one week that vary from 46% for more complex items such as fill-in-the blanks (e.g. Goshen-Gottstein & Kempinsky, 2001) to 75% for simple items such as multiple-choices (e.g. Christiaansen, 1980). This provides quantitative support for answers to Question 1.

An independent-samples t-test indicated that the mean adjusted assessment score for Phase 2, non-transportation students, was significantly lower than the mean adjusted assessment score for Phase 1, first group of transportation students, $t(104) = 2.0$, $p < .05$ (See Table 4 for the mean adjusted scores). However, we did not find statistically significant difference between mean adjusted assessment scores for Phase 2, non-transportation students, and Phase 3, the second group of transportation students. One reason may be that students in Phase 1 had one week to complete the final report and take the test while the students in other phases had to complete it during the laboratory time and take the test after one week. Further research is therefore needed to identify the full meaning of previously mentioned significant difference. That is, it needs to be studied to what degree the length of the instructional process (before testing) interacts with the students' interest due to the nature of the courses, transportation and respectively non-transportation.

A bivariate Pearson correlation coefficient was calculated and found to be statistically significant ($p < .05$) for the relation between the mean raw assessment scores and students' self efficacy, however, the value of coefficient was low ($r = .18$). Therefore, we found no meaningful additional support for research Question 1. The main reason for this result was the fact that the relatively short duration of the learning activity did not allow students to build a strong self-efficacy for this activity.

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Results from Experimental Data in Phase 1

An independent-sample t-test did not indicate statistically significant differences at entry for both the aggregate prior knowledge scores and the GPAs of the two experimental groups; control and respectively treatment groups. Based on these results, it can be concluded that the two experimental groups were homogeneous from a learner characteristics perspective.

To test the second research question (Q2), results were also analyzed using an independent-samples t-test (N=27). The analysis revealed a significant difference between mean levels of performance for both the raw mean assessment scores and the adjusted mean assessment scores (Table 5). All effects were reported statistically significant at the .05 significance level.

(*Insert Table 5 about here*)

These results support the positive impact of explicitly (instructor-stimulated awareness) grounding the laboratory activity on students' performance on traffic safety questions (Q2). However, no significant differences between the two experimental groups were found for the exit perception (engagement, difficulty) and belief (self-efficacy) variables. These findings support the initial expectation that the treatment (20 minutes introductory lecture) was too short to produce a significant difference on students' perceptions of and attitude toward the laboratory activity.

Results Interpretation and Changes in Instructional Activity

The results of this quasi-experiment in Phase 1 indicated that a short instructor-driven introduction of the context for the online-based instructional material can be beneficial for students' successful performance in this laboratory activity. Based on this finding, a short introductory presentation was developed and used in the next administrations of this laboratory

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activity. In addition, the analysis of time-to-completion reported by students indicated quite a large spectrum which included both students with low and high exit performance scores. To ensure that the task can be completed in the three-hours allocated for this laboratory activity, the instructor decided to eliminate the transfer task in the initial implementation in favor of a detailed one-step data analysis followed by a more consistent final report focusing on traffic safety. These changes were implemented in Phases 2 and 3 and the results are presented below from a formative perspective.

Comparing Phases 1 to 4

As mentioned in the research procedures section, the laboratory activity adjusted in the first phase of this study were initially deployed in a non-transportation class (Phase 2) as a stand-alone laboratory activity to test and fine-tune changes made. Then the refined laboratory activity was deployed to the target transportation students first at the beginning of the course as a stand-alone laboratory activity (Phase 3) and toward the end of the course as part of a semester-long design project, Phase 4. Therefore, the performance in this last phase was not comparable with the performance in the first three phases of the study. Findings for performance, perception and beliefs for these phases are presented below. All effects were reported statistically significant at the .05 significance level.

Analysis of Performance Scores for Phases 1 to 3

Results were analyzed using a one-way ANOVA, between-group design. This analysis failed to reveal a significant effect for the laboratory implementation phase on both mean raw assessment scores and adjusted mean assessment scores. The sample means and their standard

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deviations are presented in Table 4 and it shows similar performance outcomes with a slightly smaller value for the non-transportation group.

Analysis of Students' Perceptions for Phases 1 to 4

For engagement and difficulty, the two variables used to measure students' perceptions related to the GIS laboratory activity, results were analyzed using one-way ANOVA, between groups design. This analysis revealed a significant effect for the implementation phase for both perceived engagement and perceived difficulty (Table 6).

(*Insert Table 6 about here*)

For the perceived engagement, Tukey's HSD test showed that students in the non-transportation group (Phase 2) scored significantly lower on perceived engagement than did transportation students in similar implementations, Phase 1 and respectively Phase 3. No statistically significant difference was found between students' perceived engagement in the non-transportation group and students' perceived engagement in the project-related implementation for transportation group, Phase 4 (Figure 1).

(*Insert Figure 1 about here*)

For the perceived difficulty, Tukey's HSD test showed that students in the first transportation group (Phase 1) scored significantly higher than the non-transportation students, Phase 2, and transportation students in the project-related implementation, Phase 4. Therefore, the students in the first implementation of GIS laboratory perceived this activity as being significantly more difficult than students in the second and final implementation phases. There was no statistically significant difference in perceived difficulty between the transportation students in initial implementation (Phase 1) and respectively third implementation (Phase 3) of the GIS laboratory (see Figure 2).

(*Insert Figure 2 about here*)

Analysis of Students' Self-Efficacy for Phases 1 to 4

For students' academic self-efficacy, results were analyzed using a one-way ANOVA, between-group design. This analysis revealed a significant effect for the implementation phase (Table 6). Additionally, Tukey's HSD test showed that students in the project-related implementation (Phase 4) had a *statistically significant higher self-efficacy* than did students in all other implementations of the GIS laboratory (Figure 3). As *Phase 4* students were previously exposed to a non-project related GIS laboratory, further research is needed to analyze to what degree the increase in the students' self-efficacy is influenced by the repeated exposure to the same instructional environment and to what degree this increase is influenced by the level of anchoring of instructional activity in a larger project.

(*Insert Figure 3 about here*)

Results from the Qualitative Analysis

The main goal of this analysis was to identify changes in topics and themes associated with the reflective open-ended research questions that targeted students' perceptions on this laboratory. The qualitative analysis used an "in-vivo" coding of students' answers to four open-ended questions (e.g. Morse and Richards, 2002). First, students' overall opinion about the laboratory experiences targeted those factors that made the highest impact on students' perception of this laboratory. Next two questions targeted some more specific factors such as

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specific strengths and weaknesses of the laboratory, and the last question prompted the students for suggestions to improve the laboratory experience.

Students' Overall Perception about the GIS Laboratory

A positive trend in students' inputs from 58% in Phase 1 to a high of 82% for Phase 3 was observed. In addition, students engaged in Phase 3 of the GIS laboratory implementation indicated more learning-related positive factors such as helping understand data analysis, helping learn and apply concepts as exemplified below for each of the four phases. For *Phase 1,* 16 of the 27 participating students (58%) provided a positive input. In *Phase 2*, 58 of the 75 students (77%) that provided an answer had a positive input for this question. They described the GIS laboratory as: *good, interesting, important, practical, useful tool, good tutorial, hands-on activity, and a good learning experience* as exemplified below.

In *Phase 3* answers showed a strong positive trend with 23 of 28 students (82%) having a positive input. Participants in this implementation described the laboratory activity as: a *useful, valuable, beneficial tool*, *great software* for engineers, and *helpful for understanding concepts.* Finally, in *Phase 4*, 20 of the 27 students (74%) had positive inputs that presented the laboratory as: *useful, helpful, important, a good review, useful practice on software, and good application to learn.* Appendix 1 presents sample student answers that provide support for the above-summarized overall perception about GIS Laboratory for each of the four phases.

Considering the openness of students' answers, the increased trend of positive inputs found for this question is a strong support for the benefits of student-centered instructional improvements made for this laboratory activity.

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Perceived Strengths of the GIS Laboratory

When the reflective prompting was more focalized, students provided more specific and clear themes associated with the strengths of this laboratory activity. The identified themes shown below indicate both overlap with respect to the beneficial role of instructional videos and complementarities strengthened by an increased specificity of provided input when it comes to the potential role of this laboratory for professional activities. One clear difference among these groups of themes is the more detailed and complete structure of themes found in the two stand-alone instructional activities implemented with transportation students, Phase 1 and Phase 3. For these two implementations it was observed that the more generic themes such as “a lot of potential for real-world application” in Phase 1 changed in Phase 3 to more detailed descriptions of this laboratory’s topic for stronger communication skills and understanding of the big picture of traffic safety.

In *Phase 1,* student answers to this question covered following major themes: *motivational activity, provided helpful visual representations, real-world/hands-on activity,* and *helpful for highway design, monitoring and decision-making on traffic safety issues*. In *Phase 2,* themes revolved mainly around the role of the online tutorial: *helpful videos, step-by-step clear guidance* and respectively a*llowed self-pacing of learning* while the themes found in *Phase 3,* when the fully reviewed activity was implemented, are clearly more oriented toward the professional benefits of this laboratory. The major themes found in Phase 3 were: e*asy to use tutorial with helpful videos, can help improve traffic safety and traffic design, knowing GIS could be important for securing jobs, helps Civil Engineers working with Transportation Engineers in real world,* and *helps understanding the big picture of traffic safety.* Finally, in Phase 4, the main themes associated with GIS laboratory strengths were more concise: *helps analyze traffic data,*

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has a practical use, and *activity represents a real world situation.* Support for these themes in form of sample student answers are presented in Appendix 2.

All the above topics and themes identified in these first two reflective prompting questions provide strong qualitative support for the exploratory research questions (Q1 and Q3) related to overall perception of the GIS laboratory and its effectiveness as a scaffold for learning GIS-related issues useful for civil engineers.

Identified Weaknesses and Suggested Changes

If the strengths and positive inputs are good indicators of the quality of both first deployment and changes made to subsequent implementations, weaknesses and suggested improvement are the ones providing support for effective changes of the instructional environment. After the first deployment, Phase 1, most of the complaints focused on the length of the laboratory activity and frustrations linked to lack of clear explanations for required instructional tasks. Because the time allocated to this activity was reduced from three to two hours, the complains associated with time constrains were still an issue in the next two implementations, Phases 2 and 3. However, in Phase 3 the tone of time complains improved from "not enough time" to "lab was long". The same trend was found for instructional clarity that evolved from "lack of explanations" in Phase 1 to "lack of explicit link between tutorial and deliverables" in Phase 3. The examples below provide a synopsis of themes and inputs associated with the perceived weaknesses of GIS laboratory throughout all four implementation phases.

In *Phase 1,* the major themes associated with the weaknesses of the GIS laboratory were: *the lab was too long, lack of explanations on the role of various steps in the activity,* and *no* *strong real-world scenario to ground the required laboratory tasks.* For *Phase 2,* when first review of the activity was implemented themes changed slightly: *not enough time/ tutorial took too long, written instructions not clear* and *activity too impersonal.*

When in *Phase 3,* the fully reviewed activity was implemented as a stand-alone laboratory the major weaknesses shift the focus toward the coherence of the tasks and outcomes: *lack of explicit link between tutorial and application outcomes,* and respectively *software not user friendly.)* Finally, in *Phase 4* when the laboratory activity was adapted to be included as a final task in a semester-long design project, the major weakness indicated was that this activity: *does not go beyond data representation.* Students' sample answers to support these themes related to GIS Laboratory weaknesses can be found in Appendix 3.

The two major overall findings from this section were: a) students indicated very specific weaknesses of the GIS laboratory, and b) the strength of the perceived weaknesses strongly diminished from the first phase to the last two implementation phases. These findings both complement and reinforce the results on changes in perceived difficulty across the four phases, as reported in the quantitative analysis.

The above-mentioned weaknesses-related themes are nicely complemented by students' inputs on suggested improvements that could make the GIS laboratory a more powerful learning experience. As the time-constraint issues from Phases 1 and 2 were addressed, students' suggestions shifted focus in Phase 3 toward the clarity of link between laboratory deliverables and GIS software tutorial learning tasks. One suggestion that was found across all implementations was the need for more instructor-driven examples before the actual self-directed activity supported by the online tutorial. This might derive from the nature of the instructional context these students commonly engage in i.e., fully-face-to-face instructional activities.

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Finally, the suggestions provided by the same group of students after each of the two phases of implementation and need to be addressed in future implementations are: a c*learer differentiation between the tutorial and traffic safety tasks, more time for the lab deliverables, (Phase 3)* and respectively*, instructor-driven examples before the lab activities (Phase 4).*

DISCUSSION OF RESULTS

Both quantitative and qualitative findings provide an overall positive support for the three research questions followed throughout the longitudinal implementation of the GIS laboratory in the target Transportation Engineering course. First, the means of student performance raw scores measured one week after the conclusion of the laboratory activity indicated a memory retention rate ranging from 59% to 67%. Considering the relatively short duration of the instructional process, one laboratory session, and the fact that the test was not announced, these scores show support for the GIS laboratory as an effective tool for learning traffic safety (Q1) and GIS. This finding is clearly strengthened by the above and well-above the mean percentages of positive inputs on the open-ended question regarding the overall student perceptions, especially for the revised implementations of the laboratory activity.

Second, the findings from the quasi-experiment administered in the initial implementation of the laboratory activity (Phase 1) clearly supported the positive impact of anchoring the instructional process through an instructor-lead introduction of the laboratory overall goals and tasks (Q2). These experimental research findings were clearly complemented by the students' qualitative input on the open-ended questions related to laboratory weaknesses and suggested improvements. The themes found in students' answers for the two previously mentioned open-ended questions supported previous research findings showing that in hybrid learning environment the major weaknesses that can hinder the learning process are the lack of instructor interaction (Jackson & Helms, 2008) and students' resistance to online learning modules (Mackey & Jinwon, 2008). More important, as the stand-alone format of the laboratory was reviewed based on students' perspectives (Phases 1 to 3) students' complains about lack of and suggestions for more instructor interaction significantly decreased suggesting better instructor interaction in final implementation phases.

Third, students' answers to the open-ended question related to the strengths of the GIS laboratory for professional growth strongly supported the positive role of this learning activity for civil and transportation engineers' career development (Q3). As students' suggestions were implemented in the structure of laboratory tasks, the themes associated with the impact of the GIS laboratory on professional growth resulting from students' answers became clearer and stronger. This finding also supports previous research findings regarding the importance of providing student-oriented instructional scaffold for web-based tasks (e.g. Mackey & Jinwon, 2008).

CONCLUSIONS AND FUTURE RESEARCH

Overall, findings of this longitudinal implementation of the web-supported GIS laboratory in the Transportation Engineering course indicated that monitoring and addressing students' concerns and suggestions produces positive outcomes associated with the learning process reflected in both students' performance and perceptions. Both the quantitative and qualitative data collected indicated support for the research questions that motivated this study suggesting that:

a) Overall, the GIS laboratory supports learning of traffic safety issues associated with civil engineering,

b) Anchoring the learning activity in a traffic safety context produces both better learning outcomes and more positive student perception of this laboratory as a whole, and

c) Students engaged in this laboratory perceived it as hands-on activity with strong links to real-world activities of a civil and/or transportation engineer.

Future research will focus on the course-related implementation introduced in Phase 4 of this study. Based on the suggestions provided by the students in the later implementations the main instructional changes to be implemented and monitored will be: a) the inclusion of a more expanded instructor-driven introduction of the laboratory goals and requirements, and b) replacing the software-driven with a question-driven structure of the laboratory activity especially for the query building tasks.

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Table 1. *Characteristics of Population for each Research Phase*

Variable	Phase 1	Phase 2	Phases 3 & 4
Mean GPA*	3.0 (.47)	3.3 (.42)	3.1 (.39)
Min. GPA	1.9	2.4	2.3
Max. GPA	3.8	4.0	3.9
Freshman** [%]	NA	1.3 [79]	-
Sophomore** [%]	NA	83.5 [79]	3.6 [28]
Junior** [%]	NA	15.2 [79]	50.0 [28]
Senior** [%]	NA		46.4 [28]

Notes: * Standard Deviation within parentheses; ** Total number of participant within brackets

Table 2. *Analysis of Variance for Students' GPA*

Source	df	F	η^2	p
GPA	2	6.12**	.09	.88
Within Groups	130	(.18)		

Note: Values enclosed in parentheses represent mean square errors. **p < .01

Table 3. *Results of Exploratory Factor Analysis for Perception Items*

Engagement* (Cronbach's alpha = .90)		**Difficulty*** (Cronbach's alpha = .81)	
Variable	**Load**	**Variable**	**Load**
Boring/Interesting	.89	Easy/Hard	.88
Useless/Useful	.88	Simple/Complicated**	.88
Worthless/Valuable**	.88	Effortless/Labor Intensive**	.75
Dry/Motivational	.80	Painless/Painful	.74
Dull/Lively	.76		

Notes: *Differential semantic scale with 1 (left) to 9 (right); ** Reversed scale items;

Table 4. *Means and Standard Deviations for continuous variables*

	Phase 1 (N=27)		Phase 2 (N=75)		Phase 3 (N=28)		Phase 4 (N=28)	
	M	(SD)	M	SD	M	SD	M	SD
Raw Assessment Score ^{a}	67.4	(15.8)	59.2	(21.1)	64.3	(23.9)		
Adjusted Assessment Score ^{a}	72.6	(11.6)	64.8	(18.8)	67.9	(18.9)		
Perceived Engagement ^{b}	5.58	(.96)	3.84	(1.59)	5.12	(1.02)	4.39	(1.51)
Perceived Difficulty ^{b}	6.16	(1.55)	5.27	(1.40)	5.44	(1.23)	4.56	(1.45)
Self Efficacy ^{c}	3.38	(.61)	3.41	(.58)	3.42	(.59)	3.97	(.77)

Notes: ^{a} Percentages; ^{b} 0 to 9 scale; ^{c} 0 to 5 scale

Table 5. *Raw and Adjusted Means Assessment Scores for Control and Treatment Groups*

	Experimental Group			
	Control	**Treatment**	**t**	**df**
Raw Mean Assessment Scores	62.3 (16.0)	75.9 (16.3)	-2.14*	25
Adjusted Mean Assessment Scores	70.8 (9.3)	79.9 (11.7)	-2.15*	25

Note: Values enclosed in parentheses represent Standard Deviations. *p < .05

Table 6. *Analysis of Variance for Students' Perception of Engagement, Difficulty, and Self-Efficacy*

Source	**df**	**F**	η^2	**p**
Engagement	3	12.92**	.20	.99
Within Groups	157	(1.97)		
Difficulty	3	5.87**	.10	.95
Within Groups	154	(1.97)		
Self-Efficacy	3	5.95**	.10	.95
Within Groups	153	(.39)		

Note: Values enclosed in parentheses represent mean square errors. **p < .01

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Appendix 1

Students' Overall Perception about the GIS Laboratory - Selected Student Answers	
Student 5 (*Phase 1*)	I found the lab to be very useful and I was glad to have the opportunity to use programs that would possibly be useful after I graduate. It was extremely helpful having the GTAs to answer questions, especially when I was learning to use the query builder. I would enjoy the opportunity to use other programs that are actually used in the field of transportation engineering.
Student 64 (*Phase 2*)	GIS helped me understand how to design roads. It gives you data that you can build around. If there is a dangerous intersection in a city, it needs to be reconstructed for safety. I liked GIS software.
Student 73 (*Phase 2*)	I thought the lab was good. The lab showed many different factors involved in crashes. It showed how often a certain factor can cause a crash. I did not realize a lot of the stuff. For example, asphalt causes more crashes than concrete, but not by much. I never really realized that until I did this lab.
Student 16 (*Phase 3*)	I think that the GIS lab has a lot of potential… it did provide useful tools on how to utilize GIS in the future, and I liked that the internet instructions did not do everything for you. They just showed the concept and then we had to come up with how to answer the questions using the program….it was one of the better GIS labs that I have done here.
Student 10 (*Phase 4*)	I thought it was relatively easy, good application to learn before going into practice.
Student 25 (*Phase 4*)	I think the GIS lab is a very helpful lab. Sometime in the future I could see an employer wanting use to perform these kinds of tasks.

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Appendix 2

Perceived Strengths of the GIS Laboratory – Selected Student Answers	
Student 7 (*Phase 1*)	The GIS lab was very motivational to me. It made me wonder what a transportation engineer could do to decrease the amount of crashes on interstate highways and to make them safer. I am very interested in seeing what else it can do.
Student 24 (*Phase 1*)	This program has a lot of potential in real world activities both in the decision making process for highway safety and verification of highway safety improvements.
Student 73 (*Phase 2*)	The strength was that it really walked you through the steps. I used the web-based learning system for the whole lab. It was really helpful.
Student 14 (*Phase 3*)	The GIS shows a list of factors that were involved in the crash which is a correlation not a causation of the crash so the data is not perfect. An example of this was there were more crashes on concrete than asphalt, this lab does not allow you to know whether it was due because of construction flaws, or because concrete is simply easier to crash on. In terms of real world applicability GIS is very important to show areas that need improvement.
Student 16 (*Phase 4*)	I found that this lab was extremely useful in the crash analysis. The ability to use GIS was utilized in this lab, and I could see how it would be used elsewhere.

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Appendix 3

Identified Weaknesses of the GIS Laboratory - Selected Student Answers	
Student 4 (*Phase 1*)	This lab would have been beneficial if it wasn't so long. It needed to be broken up in to more than one lab time. When I got to about the halfway point I was very tired and frustrated. It was hard for me to do even with the step by step instructions…
Student 71 (*Phase 2*)	Weakness based on personal preference on learning environments: I don't like web based learning I think a person should be there to explain things if there happens to be questions.
Student 8 (*Phase 3*)	The instructions were not very clear. It had you go through an example, but did not tell you that it was an example and not the deliverable. That was really confusing during the whole lab. Also there were a couple of steps the TAs told us to skip which was also confusing.
Student 16 (*Phase 4*)	…However, I still do not know how to take data in the real world and put it into GIS to utilize this. I think that if I understood this, the application to GIS and real world application would be greatly enhanced

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Figure Captions List

Figure 1. *Tukey's HSD groups for Perceived Engagement*

Figure 2. *Tukey's HSD groups for Perceived Difficulty*

Figure 3. *Tukey's HSD groups for Self-Efficacy*

Figure 1

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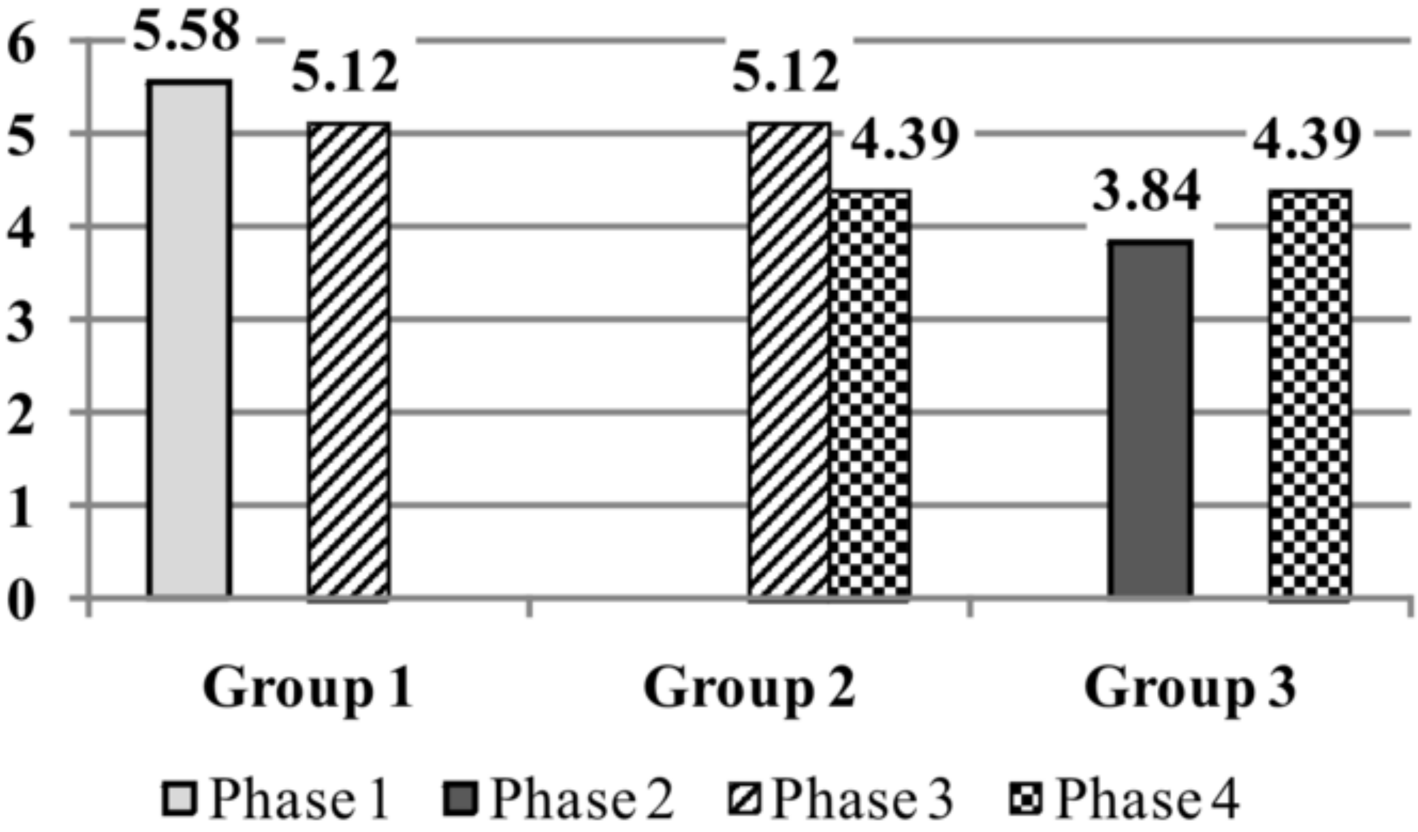

Figure 1. *Tukey's HSD groups for Perceived Engagement*

Figure 2

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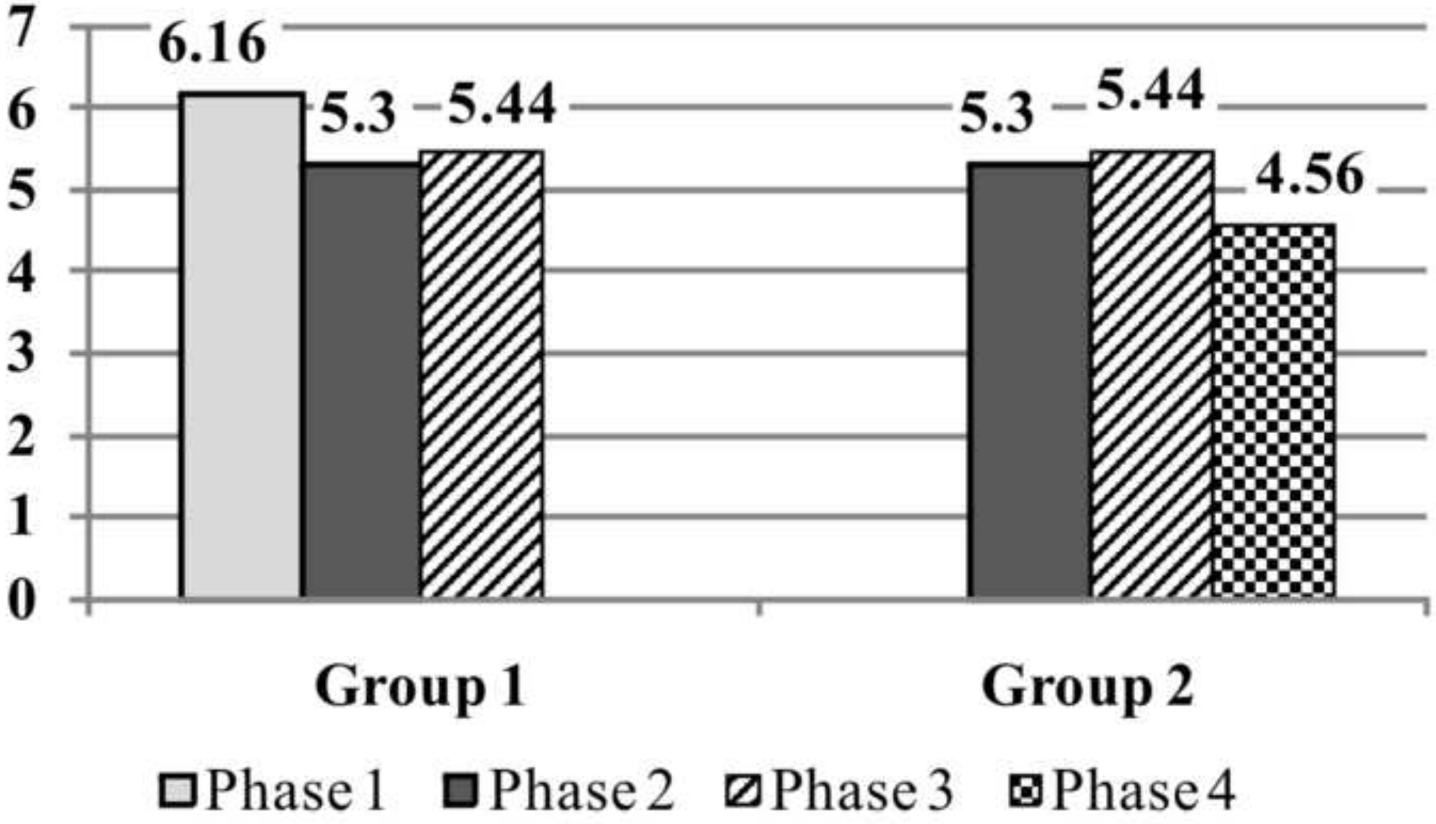

Figure 2. *Tukey's HSD groups for Perceived Difficulty*

Figure 3

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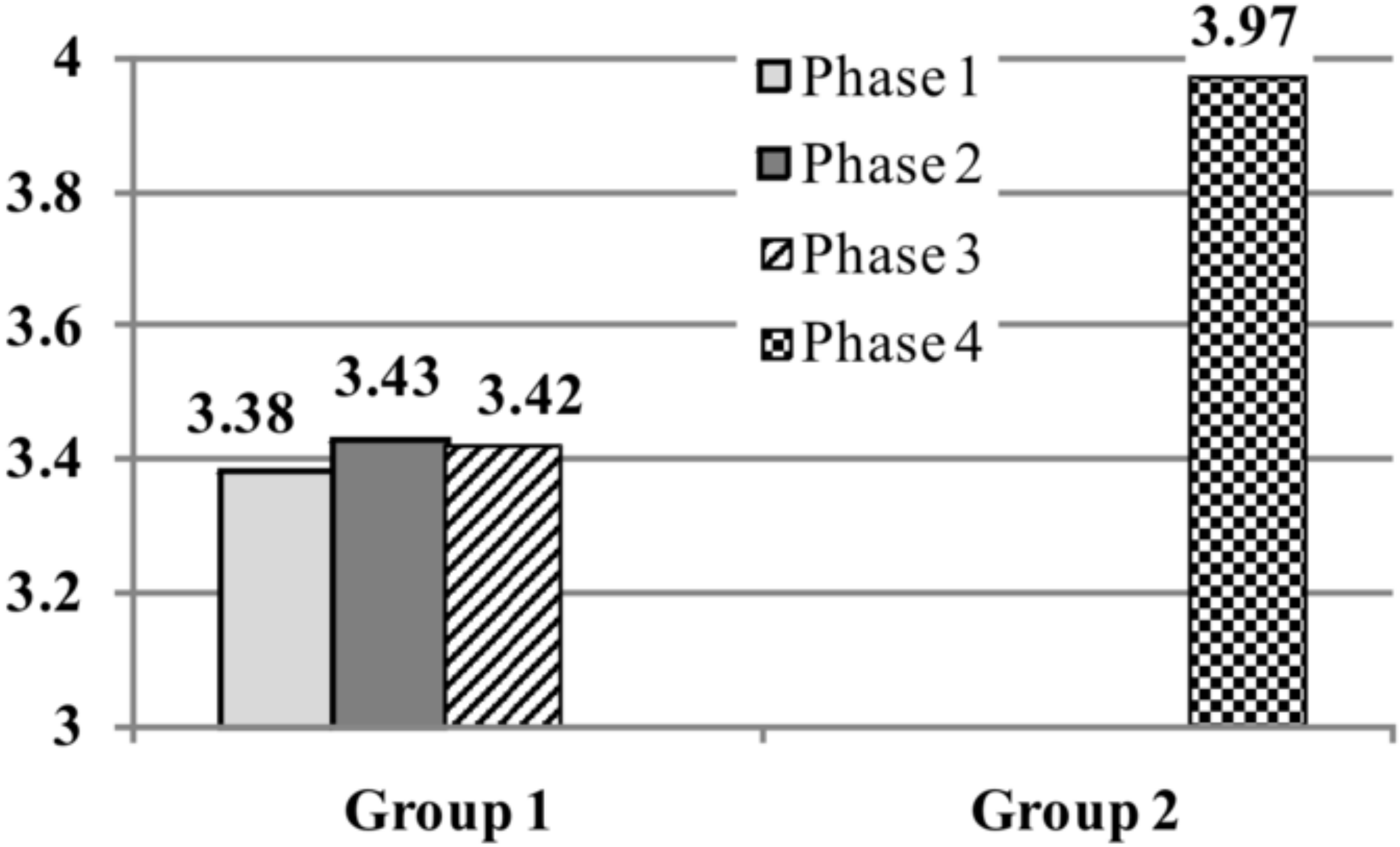

Figure 3. *Tukey's HSD groups for Self-Efficacy*