Journal of the Korean Society of Mathematical Education Series D:
Research in Mathematical Education
Vol. 14, No. 3, September 2010, 249–262

韓國數學敎育學會誌 시리즈 D:
<數學敎育硏究>
제 14 권 제 3 호 2010 년 9 월, 249–262

Impact of Inquiry-Based Teaching on Student Attitude toward Mathematics[1]

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(Received August 10, 2010 Revised September 20, 2010 Accepted September 24, 2010)

Large Midwest university faculty members proposed the Science and Technology Enhancement Program Project (STEP) to improve students' learning in the secondary mathematics classroom using modules of inquiry-based teaching. The purpose of this study was to determine the impact of the STEP Project on students' attitude toward mathematics. Hierarchical linear models (HLM) were used to evaluate the impact of the STEP Project. The sample group for the study was 130 ninth grade students enrolled in Integrated Algebra I in a large urban school district. The school was one of eight secondary schools that participated in the STEP Project. The classes in the treatment group were three of five classes ordered in terms of the highest, middle, and lowest mean GPA. The control group consisted of two other middle GPA classes. The classes had an average of 25 students. Teachers who previously had been involved in the STEP Project taught all treatment and control classes. The inquiry-based teaching activities provided by the project were confined to the treatment classes. The survey measuring students' attitudes toward mathematics were obtained for both groups of students.

The inquiry-based teaching affected students' attitudes toward mathematics ($p < 0.07$, ES = 3.07). Especially, students who had preexisting low attitudes toward mathematics were significantly affected by treatment ($p < 0.02$, ES = 0.02), while the treatment positively affected African American students overall at $p < 0.08$ (ES = 0.58).

Keywords: student attitude, inquiry-based teaching, secondary mathematics
MESC Classification: B13, C23, D44.

[1] This paper will be presented at the International Session of the 45th National Meeting on Mathematics Education at Dongguk University - Gyeongju Campus, Gyeongju, Korea; October 8–10, 2010.

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MSC2010 Classification: 97B10, 97C20, 97D40

INTRODUCTION

The National Council of Teachers of Mathematics (NCTM, 2000) suggests that mathematics in academia should be conveyed and taught as a subject that improves one's logical thinking, analytical reasoning, and evaluating skills, all of which are essential to every career path. That such vital skills may be developed by learning mathematics makes the subject valuable to gaining a well-rounded education. There is a consensus that students need to understand mathematics, and that students do construct mathematical knowledge rather than infer it in finished form from the teacher. McNair (2000) concluded that traditional teacher-centered teaching methods, which are reliant on hierarchical transference of knowledge rather than on student-based knowledge construction, do not improve student's logical thinking, analytical, and evaluating skills. If traditional systems are not working, other instructional methods need to replace them. In the traditional form of classroom instruction, a teacher demonstrates procedures, then assigns homework, and later administers a test (Gersten, Taylor & Graves, 1999). A new type of teaching is needed to stimulate students' motivation and adjusts teachers' teaching styles to individual students' learning styles.

Promoting inquiry-based teaching as an ideal teaching method in our technology-centered world, the STEP Project encourages the development of modules based on real-world situations, hands-on activities, and the use of technology in teaching mathematics. Inquiry-based teaching in the STEP Project typically has the following characteristics. Lessons begin with collecting data. Then, students organize the information and identify relevant real-world situations. During this process, students are required to use technology and utilize critical thinking and logical reasoning skills to analyze the outcomes (Duffy & Cunningham, 1996; Grabinger, 1996). Compared to traditional teaching, students are more actively involved in learning while investigating the problem, designing solution strategies, and finding solutions (Slavin, Madden, Dolan & Wasik, 1994).

The relationship between teachers' instruction and students' learning has been the subject of much research for many years (Boaler, 1998; Portal & Sampson, 2001; Silver & Stein, 1996; Zahorik, 1996). Portal & Samson (2001) examined whether motivation was a factor in students' learning mathematics. The purpose of the study was to find the evidence that students' achievement in mathematics was related to motivation by analyzing teacher observations, student surveys, and students' grades. The participants were 1,460 high school students and 76 teachers from a suburb school in a middle class community of a large urban area. Portal and Samson suggested that instead of conventional teaching,

the instruction should consist of "Hands-On Math" with real life applications in order to increase students' motivation. Boaler (1998) inspected 3-year case studies of two secondary schools to examine student experience and understanding with different teaching approaches: traditional teaching and activity-oriented teaching. Data collection included the use of case studies, questionnaires, interviews, and student assessments. Both activity-related tests in real world situations and traditional test problems were given to students for the assessments. The researcher found that the two different teaching approaches affected students' achievement. Students in the traditional teaching were able to develop procedural knowledge, but were lacking in conceptual understanding, while the students in the activity oriented class achieved more at real-life situations.

Several studies investigated factors that are important to students' learning (Portal & Sampson, 2001; Silver & Stein, 1996; Veenman, 1984; Zahorik, 1996). Portal and Sampson (2001) found that motivation was an important factor in students' learning. They suggested that instead of conventional teaching, instruction should consist of "Hands-On Math" with real-life applications in order to increase students' motivation. They suggested that a way to improve mathematics teaching was to implement a new curriculum connecting life experiences to mathematics instruction. Veenman (1984) found that lack of student motivation was one of the greatest concerns of the teachers who were concerned with effective classroom management. Zahorik (1996) also noticed that lack of student motivation was great concern of teachers. In this research, he observed positive behaviors in the classroom and only a slight improvement in students' attitude towards mathematics after modifications of the curriculum. His research indicated that providing students with real-life examples to illustrate abstract ideas enhanced students' interaction and enabled them to better understand mathematic ideas.

However, Papanastasiou (2000) found that even though the students of Cyprus had lower scores on mathematics than American or Japanese students' test scores in the TIMSS study, the percentage of students in Cyprus with positive attitudes towards mathematics was higher than in the U.S. or Japan. The number of students in Japan with positive attitudes towards mathematics was also lower than the number of U.S. students, despite higher test scores among Japanese students.

Several studies reported ethnicity gaps in attitudes toward mathematics, affecting overall achievement in the mathematics classroom (Walker & McCoy, 1997; Tapia & Marsh, 2000). In their 1997 study, Walker *et al.* (1997) reported that most African American students did not expect to have mathematics-related careers. Tapia *et al.* (2002) also found that there was a relationship between ethnicity and attitude toward mathematics. However, Stanley & McCoy (2004) found no significant difference in attitude toward mathematics among students of different ethnicities or of different genders. The National Assessment of Educational Progress (NAEP, 2005) data also indicated the gap between

White and Black students among 4th grade in mathematics has narrowed from 32 of the scale score in 1990 to 26 in 2005. For 8th grade, the gap narrowed from 34 to 34 between 2003 and 2005.

The purpose of this study was to determine the effects of inquiry-based teaching on students' attitudes toward mathematics. The inquiry-based teaching can be a valuable tool to improve attitudes toward mathematics. If the inquiry-based teaching module were found to be successful, the findings would be of value to educators who seek an effective strategy to improve attitudes toward mathematics. Therefore, this study is significant to educators who seek to know more about how students' attitudes toward mathematics can be improved. This research is also important for helping teachers with their instructional design because it aids in the implementation of a teaching model that could be more effective for secondary students. The following questions guided the research effort:

1. Was there significant improvement in the students' attitudes toward mathematics after inquiry-based teaching?
    a. Was there significant improvement in the attitudes of the treatment group after inquiry- based teaching compared to those in the control group?
    b. Was there significant improvement in the attitudes of male and female students within the treatment group after inquiry-based teaching compared to those in the control group?
    c. Was there significant improvement in the attitudes of students in the treatment group after inquiry-based teaching compared to those in the control group, based on different levels of GPA?
    d. Was there significant improvement in the attitudes of different ethnic groups within the treatment group after inquiry-based teaching compared to those in the control group?

METHOD

Setting and Participants

Data were collected in ninth grade mathematics classes from one of eight secondary schools in a large urban school district that participated in the Science and Technology Enhancement Program (STEP). The sample group for the study was 130 ninth grade students enrolled in Integrated Algebra I. The participants were chosen because of their teachers' involvement in the STEP Project. The criteria for teachers' participating in STEP were a willingness to provide support for the graduate fellows, to guide the teaching framework according to school and State standards, and to be positive, motivating,

open, and flexible throughout the year. Due to the lack of randomization, this study was a quasi-experimental design that used a nonequivalent group design for comparison.

All participants were between ages 14 and 16; the groups included male and female students. Since the students were under 18 years old, students were allowed to participate in the STEP Project only with their parents' consent. At the beginning of the academic year, the fellows of the STEP Project collected consent forms, which had been approved by the University's Institutional Review Board. The school then assigned students to classes based on their grade point average (GPA). There were five different periods and the sizes of the groups were not the same.

Teachers who had been involved in the STEP Project taught all classes of the treatment and control groups. The students of both the treatment and control groups had five 50-minute classes per week. The inquiry-based teaching activities provided by the researcher were used with the treatment classes. In the control group classes, the teacher used lecture-oriented teaching methods: Asking students to read the textbook aloud, explaining the content, writing notes on the board, inviting students to answer questions, and requesting the completion of worksheets. Compared to the control group, the students of the treatment group had lessons with three main parts:

(1) The teacher's review of the previous lesson and introduction of the present lesson,
(2) Inquiry-based teaching and group activities, and
(3) The completion of a worksheet.

Instruments

The students' attitudes toward mathematics were measured using scores from the Mathematics Attitude Questionnaire. The Mathematics Attitude Questionnaire was a one-page paper-and-pencil questionnaire with 28 items consisting of 14 positive and 14 negative statements. The construct was adapted from separate attitude surveys by a STEP Project evaluation team that was developed from an instrument designed by Fennema and Sherman (1977) for a mathematics survey. The internal panel reviewed and finalized the items in order to validate that survey questions related to the research purpose. The scale ranged from highest score of 5, meaning strongly agree, to the lowest score of 1, meaning strongly disagree, with a neutral score of 3, meaning undecided. The values for negative questions were reversed. The researcher and the teacher administered the pre- and post-class surveys to the treatment group and the teacher conducted the pre- and post-class surveys in the control group. The same survey was given to students at the end of the fourth quarter. The reliability of the survey had the Cronbach's $\alpha = 0.98$ for the pre-class survey, and 0.96 for the post-class survey. However, the researcher did not use six items (#2, #8, #9, #11, #22 and #25) to analyze data, which were not relevant to the research questions. After conducting a factor analysis to measure the construct validity,

two items (#10 and #19) were not included in the data analysis because the loadings criteria of the two items were less than 0.3 (Hair, Anderson, Tatham & Black, 1998). The range of possible points for the pre- and post-surveys were from the maximum 100 to the minimum 20. After dropping two items, the first component accounted for 86.3% of the total variability for the pre-survey and 69.2 % for the post-survey. The validity and reliability analysis indicated that instruments were appropriate to interpret data.

At the beginning of the third academic quarter, the researcher gave a brief explanation to students enrolled in the Integrated Algebra I courses, and then asked the students to have the consent form signed by their parents in order to participate in the study. Only data from students who returned the consent form with their parents' signature were used in the study. The total participants were 128. At the beginning of the study, prior to any use of the inquiry-based teaching in the classroom, a survey was given to measure students' attitudes toward mathematics. Before the teaching began, the teacher checked the content to ensure that the lessons matched the students' present skills and followed the guidelines of the district academic content standards for mathematics. After a brief introduction, students were presented with the instructional activities. During the small group activities, the teacher observed and evaluated students' progress. After each class, the teacher collected and inspected the students' activity books and then evaluated students' activities following the rubric evaluation sheet, which was provided by the researcher. At the end of the quarter, a survey was given to students in order to measure students' attitudes toward mathematics.

Data Analysis

Besides descriptive statistics, *hierarchical linear models* (HLM) (Raudenbush & Byrk, 2002) were used to evaluate the effects of the inquiry-based teaching on the students' attitudes towards mathematics. HLM is a statistical linear model that analyzes hierarchical data like individual level within a classroom or within a school. Because students are grouped within classrooms, the errors from the observations are not independent of one another, and therefore there will be underestimation of standard errors. Traditional multivariate analysis of variance cannot handle this nested data structure. HLM was used as the analytical method in this research to address the problem of lack of independence among observations and the problem of cross-level relationships.

The dependent variables at level 1 were the attitude questionnaire scores from the post-survey. The covariates were the attitude questionnaire scores from the pre-survey, GPA, gender (male, female), and ethnicity (Caucasian, African American, Others). The independent variable at level 2 was the inquiry-based teaching versus the control method. The covariates of the level 2 were the average class GPA and class size. However, since there were valid data from only four students' data from the 'others' ethnicity category,

3.13% among the available data, only the data of Caucasian and African American students were used to perform the HLM analysis. The analyses were performed with one-tailed hypothesis testing because these studies were meant to find whether inquiry-based teaching method improved students' attitude toward mathematics.

Effect Size

In order to measure the practical significance of the effect, effect sizes were calculated. Effect size can be defined in terms of the standardized difference in group means (Tymms *et al.*, 1997). The effect size is consistent with Cohen's (1988) *d* with 0.2 indicating a small effect, 0.5 a medium effect, and 0.8 a large effect.

Definitions of Terms

For this study, definitions of the following terms were used:

Attitude towards mathematics: Positive or negative feelings in situations involving mathematics. It was simply defined as a personal preference for or dislike of mathematics (Papanastasiou, 2000).

Treatment group: Students who were presented with the inquiry-based teaching in the classroom during periods two, three, and five.

Control group: Students who were presented with traditional teaching methods in the classroom during periods one and four.

RESULTS

Missing Data

There were missing data in the data. 3.9 % of all participants did not take the pre-test and 7.0 % of subjects did not take the final. Because a group mean is the best estimate for the value on a given variable (Mertler & Vannatta, 2001), the mean values were filled in for missing data using the SPSS process. There were two outliers; after checking the raw data of the survey, two outliers were deleted because two subjects deliberately marked the same response from the beginning to the end of the test.

Descriptive Statistics

There was 45 male in the treatment group (62.5%), compared to 36 (64.3 %) in the control group. Thirty-five students (48.6%) in the treatment group were Caucasian, compared to 24 (42.9 %) of the control group (also see Table 1). To test the group equivalence on the demographic, as well as GPA, pre-survey score, an independent-sample *t* test was conducted to determine whether there was a difference in means between the

treatment and control groups, and a Chi-square test for categorical variables was used to evaluate group difference (see Table 1). All p values indicated that the difference between the treatment and control groups was not significant ($p > 0.05$) for any variables, except Mean GPA. The value of Mean GPA ($p < 0.05$) implied that two distributions differ significantly from each other. It is needed to be controlled in the data analysis. The treatment groups selected were three of the five classes: the high, middle and low GPA classes. The highest GPA, which of group 3, was 3.07. The lowest GPA, of group 5, was 1.11. The students who had a mid-level GPA of 2.13 were assigned to group 2. Meanwhile, the control group consisted of two classes with the following GPAs: 1.98 for group 1 and 1.12 for group 4 (see Table 1.)

Table 1. Descriptive Statistics

	Variables	Total (N = 128)	Treatment Group (N =72)	Control Group (N = 56)	Equivalence Test	
					Statistics	p
Gender					χ^2 (1)=0.01	0.95
	Male	81 (63.3%)	45 (62.5%)	36 (64.3%)		
	Female	47 (36.7%)	27 (37.5%)	20 (35.7%)		
Race					$\chi^2(1) = .95$	0.33
	White	59 (46.1%)	35 (48.6%)	24 (42.9%)		
	Black	64 (50.0%)	33 (45.8%)	31 (55.4%)		
	Others	5 (3.9%)	4 (5.6%)	1 (1.9%)		
Mean	GPA	128	2.10(SD =1.12)	1.62(SD =0.92)	t (126)= 2.33	0.02
Mean	Pre-survey	124	42.41(SD = 18.12)	44.68(SD = 17.14)	t (122)= -0.71	0.48

Figure 1 illustrates the group differences in the pre- and post-surveys. In the figure, the mean survey scores of the treatment group increased from 41.96 to 53.73, while the scores of the control group decreased from 46.84 to 42.61.

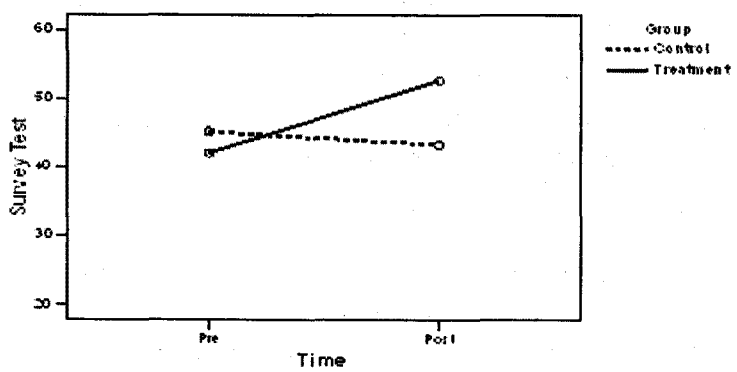

Figure 1. Group Difference from Pre-Survey to Post-Survey

Hierarchical Linear models

In order to know whether HLM should be used, the intra-class correlation was calculated using the unconditional model. The estimated variability in group was 39.1 % of the variance in survey scores, indicating a significant amount of variation between groups. Therefore, the HLM model was used and specified as follows:

Level-1 Model

$$Y = \beta_0 + \beta_1 * (\text{BLACK}) + \beta_2 * (\text{PRESURVEY}) + R$$

Level-2 Model

$$\beta_0 = \gamma_{00} + \gamma_{01} * (\text{MEANPRESURVEY}) + \gamma_{02} * (\text{TREATMENT}) + U_0$$
$$\beta_1 = \gamma_{10} + \gamma_{11} * (\text{MEANPRESURVEY}) + \gamma_{12} * (\text{TREATMENT})$$
$$\beta_2 = \gamma_{20} + \gamma_{21} * (\text{MEANPRESURVEY}) + \gamma_{22} * (\text{TREATMENT})$$

Where

Y = The outcome variable, *POSTSURVEY*

β_0 = The initial status.

β's = The level - 1 intercept coefficients.

BLACK: African American students

R = The level - 1 random error.

$\gamma's$ = The level - 2 coefficients.

U_0 = The level - 2 random errors.

PRESURVEY: The score of pre-survey.

MEANPRESURVEY: The mean score of pre-survey.

TREATMENT : The inquiry-based teaching class vs. control class.

Note that some other independent variables or covariates, for example, GPA, were not included in the HLM model above, because they were not significant predictors for the outcome in a preliminary analysis.

Table 2. Mean Scores on the Pre- & Post-Surveys Measuring Attitude

Group	Size (N)	MEAN GPA	Presurvey	SD	Post-survey	SD	Treatment/control
1	28	1.98	49.23	16.84	45.65	16.86	0
2	28	2.13	50.33	20.74	58.78	16.07	1
3	21	3.07	41.38	18.90	63.00	13.11	1
4	28	1.10	44.44	24.20	39.56	17.99	0
5	23	1.11	34.18	8.27	39.41	6.33	1

Table 3 shows the parameter estimates from the HLM analysis for the attitudes towards mathematics. In general, the effect of the treatment was marginally significant ($p = 0.7$) with a very large effect size (ES = 3.07). For Black students, the treatment also had a marginally significant effect ($p < 0.08$) on their attitudes toward mathematics with a medium effect size (ES = 0.58). In addition, all Black students in the sample significantly lowered on the post survey ($p < 0.01$, ES = 3.99); and Black students who expressed higher attitudes toward mathematics on the pre-survey scored significantly higher ($p < 0.01$, ES = 0.08) on the post-survey. The data also suggest that students who had lower pre-survey scores in the treatment group significantly improved their post-survey score ($p < 0.02$, ES = 0.02) although the effect size was small.

Table 3. Final Estimation of Fixed Effects for HLM 2

Fixed Effect	Coefficient	*SE*	*df*	*t*	*p*	*ES*
For INTRCPT1, β 0						
INTRCPT2, γ00	53.46	41.38	2	1.29	0.16	7.86
MEANPRESURVEY, γ 01	-0.99	0.87	2	-1.14	0.19	0.15
TREATMEN, γ 02	20.89	10.13	2	2.06†	0.07	3.07
For BLACK slope, β 1						
INTRCPT2, γ 10	-27.13	11.17	115	-2.43**	0.01	3.99
MEANPRESURVEY, γ 11	0.06	0.23	115	2.36*	0.01	0.08
TREATMEN, γ 12	3.92	2.75	115	1.43†	0.08	0.58
For PRESURVEY slope, β 2						
INTRCPT2, γ 20	-0.66	0.40	115	- 1.65†	0.05	0.10
MEANPRESURVEY, γ 21	0.03	0.01	115	3.66**	0.01	0.01
TREATMEN, γ 22	-0.16	0.08	115	-2.11*	0.02	0.02

* Significance level at p < .05 (One-tailed). ** Significance level at p < .01 (One-tailed).
† Significant at p < .10 (One-tailed).

DISCUSSION

The finding of this research showed that inquiry-based teaching significantly improved students' attitude toward mathematics. One of the important observations was that students who had lower pre-survey scores in the treatment group significantly improved their post survey score, indicating noticeable improvement of students' attitudes toward mathematics. This finding can be significant to educators who seek a proper teaching

method to improve students' attitude toward mathematics. Indeed, this result implied that researcher-developed inquiry-based teaching activities were effective teaching tools to improve students' attitude toward mathematics. The outcomes of this study support that inquiry-based teaching could be an effective teaching method with appropriate activities or teaching modules.

There was also improvement in the attitudes of black students in the treatment group after inquiry-based teaching, compared to those in the control group. Specifically, black students who had positive attitudes toward mathematics on the attitude pre-survey scored significantly higher on the post-survey than those who had less positive attitudes toward mathematics on the attitude pre-survey. This revealed inquiry-based teaching, making connections to real-life situation and using more technology oriented activities, made learning mathematics more interesting to Black students in urban areas.

However, there were no significantly different impacts on students of different genders. This result mirrored the national trend that there is no gender gap anymore (NAEP, 2005). Without any doubt, inquiry-based teaching provided not only an important element which students play an active role in their own education, but also increased students' attitude toward mathematics.

This present study has some limitations. First, the measurements of students' achievement were limited to one topic in the second semester. Examination of multiple topics studied over longer periods may result in different outcomes. A second limitation was the number of variables between treatment group and the control group that could affect the outcomes. The third limiting factor was students' consistent attendance in their classes. Absences from several mathematics classes could severely affect students' attitudes toward mathematics. The student absence rate and its effect on mathematics attitude were unknown and beyond the scope of the research. Finally, there was the teachers' participation factor: Since all teachers would not participate equally as voluntarily, the results from this study would apply only to teachers who had credentials comparable to those selected for the STEP project.

In the relation to other research, this study found that inquiry-based teaching positively affected the attitude of African American students, especially those who had pre-existing positive attitudes toward mathematics. Inquiry-based teaching may have affected the attitude towards mathematics of all Black students. The findings of Veenman (1984) and Zahorik (1996) were similar to the outcomes of this study: Modifications of the curriculum produced a slight improvement in students' attitude towards mathematics. However, the research indicated that simply providing students with real-life examples to illustrate abstract ideas enhanced students' interaction and enabled them to better understand mathematic ideas without lowering achievement. This complemented the findings of Portal and Sampson (2001) who suggested that a way to improve mathematics teach-

ing was to implement a new curriculum connecting life experiences to mathematics instruction. It is widely believed (Martin et al., 1997; NCTM, 1989, 1991, 2000) that with a proper lesson plan and activity, students can enjoy the mathematics class and at the same time improve their mathematics skills and their attitude toward mathematics. The result of this present research supported the suggestions of Portal and Sampson. There was clear evidence of improvement on students' attitudes of certain groups in this study. Previous studies indicated that inquiry-based teaching might be a good teaching strategy to improve the attitude of Black students who had a poor attitude toward mathematics (Walker & McCoy, 1997; Tapia & Marsh, 2000). In short, inquiry-based teaching may improve the attitude of Black students who had pre-existing positive attitudes toward mathematics.

In conclusion, the purpose of this study was to determine the effects of inquiry-based teaching on students' mathematics attitudes toward mathematics. The results indicated that inquiry-based teaching may have a positive affect on attitudes toward mathematics. By changing students' attitude towards mathematics, there may be increased numbers of students who choose to pursue science-related degrees, which was one of the goals of the STEP Project. This research found that inquiry-based teaching may be an effective teaching method to improve students' attitude toward mathematics. With proper instructional activities, inquiry-based teaching might be a valuable tool to improve their attitudes toward mathematics.

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