Leveraging Mobile Technology to Engage College Students in Scientific Research

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ABSTRACT
College students in the social sciences are required to learn quantitative research methods and statistics. Unfortunately, many fail to see the relevance of these courses, and are often anxious about them. In an effort to increase students' engagement in the research process, we developed Ruzo – a mobile scientific inquiry platform. Ruzo enables instructors and students to create research projects as custom mobile apps, collect data on the go, and visualize the data using a web-based interactive tool. Ruzo was designed based on five guidelines, derived from interviews with domain experts: guide students through all stages of research; reduce anxiousness; encourage active learning; connect to students' everyday lives; and adapt the system to the needs of the instructor. A user study showed that Ruzo was easy to use, and students expressed interest in research, thereby demonstrating the potential of mobile technology to scaffold scientific inquiry.

Author Keywords
Mobile Learning; Scientific Inquiry; Research Methods; Higher Education.

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (e.g., HCI): User Interfaces – *Prototyping*, *User-centered design*. K.3.1. Computer and Education: Computer Uses in Education.

INTRODUCTION
Anyone who taught a research methods or statistics course knows that engaging college students in the subject matter is not an easy task. These courses are a staple in many undergraduate and graduate programs in the social sciences [16]. Their main goals are developing students' critical thinking about research, and providing practical skills for designing and implementing empirical research [5,7]. Instructors must somehow clarify and exemplify the complex material, so that students new to the research process could understand and ultimately apply it. According to Earley [5], common techniques for teaching research methods include active learning ('learning by doing'), problem-based learning, cooperative learning and online learning. In addition, many instructors integrate an actual research project into the course.

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Unfortunately, students taking a methodological course often fail to see its relevance to their major and their lives. Moreover, they are typically anxious about the course and its difficulty, which may have debilitative effects on academic performance [5,11].

According to Chan and Ismail [4], incorporating technology into methodological courses could potentially reduce anxiousness and engage students in the research process, because it could: (1) make complex concepts and ideas more accessible; (2) mitigate the time and effort required to handle calculations when dealing with large data sets, leaving students more time to explore, analyze and interpret data; (3) enable multiple representations of data through visualization tools; (4) allow students to learn at their own pace, without limitations of time or place. Larwin and Larwin [9] conducted a meta-analysis to examine the impact of computer-assisted instruction in statistics education across four decades. Their findings indicated that it had a positive impact on students' achievements. Similarly, Boyle et al. [1] found that digital games, animations and simulations were a promising vehicle for learning research methods and statistics.

Mobile technology may be especially suitable to support learning. Modern smartphones are equipped with a growing number of sensors, which could be utilized to collect valuable data. In addition, smartphones offer computing, communication and storage resources, and they have become an integral part of everyday lives [3,8]. College students in particular seem to incorporate smartphones into their daily routines [10]. Therefore, leveraging smartphones for engaging students in the research process seems particularly promising.

In this paper we present the design, implementation, and evaluation of Ruzo – a mobile platform for engaging students in the research process. Ruzo enables instructors and students to create research projects, collaborate with others to collect data, and visualize the collected data. We suggest expert-based design guidelines, explain how they were implemented, and report findings from a user study. We conclude by discussing the benefits and risks of using mobile technology to engage students in scientific inquiry.

RELATED WORK

Previous systems demonstrated the utility of mobile technology for supporting college-level scientific inquiry. However, they were focused on a relatively narrow field, usually belonging to the natural sciences. For example, LillyPad [12] is a PDA-based learning application, used to make sense of ongoing observations when measuring the effects of different planting methods. Field studies with teams of students and environmental scientists demonstrated how the application supported switching between experiences of the physical environment and higher level abstractions. Similarly, GreenTouch [15] enables college students to take part in scientific inquiries in phenology. The system consists of three interfaces: a mobile interface for field data collection, a web application for automatic data curation, and a tabletop interface for exploratory data analysis in the lab. A series of user studies validated the feasibility and value of the system for helping college students learn complex concepts. Statisticum [6] is a tutorial for explaining statistical concepts through visual simulations. A dynamic version of the tutorial that enabled active manipulation of graphs was found to be preferable to a static version that only enabled passive observation.

Based on the lessons learned from this prior work, we coupled mobile technology for collecting data in the field with web technology for higher-level analysis, and enabled visual manipulation of data. Unlike prior educational systems, we focused on the social sciences, and created a flexible platform suitable for diverse subject areas.

SYSTEM DESIGN PROCESS

We set out to engage students from the social sciences in scientific inquiry, by turning research into a non-threatening process effortlessly integrated into everyday lives.

In order to design our system, we consulted domain experts – instructors who teach courses related to scientific inquiry.

Participants

Participants were five (4 females, 1 male) faculty members who teach methodological courses in the social sciences. All had taught in at least two institutes over the course of their career, usually both a research-oriented and a teaching-oriented university. See Table 1 for the specific characteristics of each participant.

Method

Participants were interviewed individually, either face to face or by phone, for approximately 20 minutes. All interviews were recorded. The recordings were later transcribed and independently analyzed by two researchers in order to identify emerging common themes.

Results

First, participants were asked regarding their main objective when teaching a methodological course. They were all in agreement that teaching students to independently conduct research from start to finish is most important.

"They should know how to conduct research, how to plan it, the stages of research, what to do in each stage".

Three participants added that they were less concerned with statistical formulas, as long as students understand the overall process.

"It is less important to me that they arrive at {significant} results or do statistics, it's more important to me that they know the stages of research".

While in agreement regarding the main objective, participants did differ from one another in the importance attributed to more specific aspects of research. For example, for one participant avoiding confounding was most important, whereas for another participant explaining the role of moderating variables was most important.

Expert ID	Years of Experience	Number of Institutes	Discipline(s)	Courses Taught	Course Level
1	23	4	Psychology	Statistics, Research seminar	Undergraduate
2	15	3	Communication	Research methods, Research seminar	Undergraduate Graduate
3	12	2	Communication	Research methods, Statistics, Research seminar	Undergraduate Graduate
4	6	4	Communication Psychology	Research methods, Statistics, Research seminar	Undergraduate
5	5	3	Communication Political Science	Research methods, Statistics, Research seminar	Undergraduate Graduate

Table 1. Characteristics of domain experts assisting in the system design process.

Secondly, participants were asked which difficulties students usually encounter during the research process. All agreed that students encounter difficulties in all or most stages of research.

"Everything is hard for them".

"I feel like I have to guide them very very closely through all stages of research".

In accordance with prior literature, three participants mentioned that students in the social sciences are often anxious regarding methodology and statistics.

"Teaching methodological courses requires me to be 50% psychologist and 50% instructor, because students arrive with great phobias regarding research methods and statistics. First you have to show them it's not so bad, only then they start listening and comprehending the material".

Next, participants were asked which techniques they employ to help students overcome difficulties. Two techniques were employed by all participants – repeating the material, and giving multiple examples.

"Repeating the material, and repeating the fact that {research} follows a systematic process".

"Lots and lots and lots of examples. Mainly examples that students themselves bring".

When asked to elaborate on the types of examples they give, participants explained that their initial examples are usually very simplistic and relatable, often derived from the physical world, so they would be easily understood. However, the examples quickly become more abstract and thus more representative of the social sciences.

"I always ground my concepts in {the students'} world, so they would be able to understand the abstract concepts".

Four participants mentioned active learning as a technique for teaching research methodology.

"I believe in practical experience. Until they do it themselves, things remain theoretical. Only when they actually do something it becomes real".

Lastly, participants were asked regarding current use of technology in class. While all use technology (mainly PowerPoint presentations and a course website), no one uses mobile technology.

Design Guidelines

Based on the interviews with experts, we formulated five design guidelines for a system aimed to engage students in the research process: (1) Guide students through all stages of research – students have great difficulties understanding both the overall process of research, and the specific requirements in each stage. They require constant guidance in order to proceed from one stage to the next. (2) Reduce students' "quantitative anxiousness" – students of social sciences are often anxious about statistics and research methods. They must overcome their fears to be able to focus on the material itself. (3) Encourage active learning – "learning by doing" helps students to better comprehend theoretical concepts. (4) Connect to students' everyday lives – students can better understand research when it is relevant to their own lives. (5) Adaptable to the specific needs of each instructor – different instructors highlight different aspects of research, therefore the system must be adaptable to their unique needs.

THE RUZO PLATFORM

Based on the design guidelines, we developed a mobile platform for engaging social sciences students in scientific inquiry. The platform is called Ruzo, named after "Robinson Crusoe" to symbolize exploration and discovery in one's surroundings. Intended for use during an introductory research methods course, Ruzo guides students through the various stages of a quantitative research project (design guideline 1). In order to reduce anxiousness, students are not required to perform statistical analysis, they use an interactive visualization tool. Furthermore, natural language has been used rather than technical terms (design guideline 2). Through Ruzo, students initiate or participate in actual research projects, promoting learning by doing (design guideline 3). The research projects take place in students' natural surroundings, and involve their social network, thus integrated with their daily lives (design guideline 4). The instructor of the course could either define the research question and measured variables, or instruct the students to do so independently (design guideline 5).

While commercial tools may offer similar capabilities to those offered by Ruzo, for example Tableau [14] offers data visualization, these tools were designed with business needs in mind, whereas Ruzo was designed with educational needs in mind. We aimed to scaffold the research process as a whole, and better connect it to students' daily lives. We did not aim to develop a generic tool for data analysis. Moreover, Ruzo was designed to support gradual progression, enabling students to begin with easy to understand concepts and analysis techniques, and gradually progress towards more complicated ones.

Using Ruzo

Through Ruzo, instructors and students can create research projects, collaborate with others to collect location-based data, and visualize the collected data.

Creating a Research Project

Users begin by creating a new research project, using a dynamic web-based form system. They are asked to fill in the project's name, data categories (equivalent of variables), and data items (equivalent of values). Figure 1 illustrates the creation of a study conducted during the ARS Electronica festival for art, technology and society, held in Linz, Austria during 2013. The project aimed to uncover relationships between artworks presented at the festival and visitors' subjective feelings. In the figure, the first category (type of artwork) has been defined, whereas the second category (feelings) has not yet been defined.

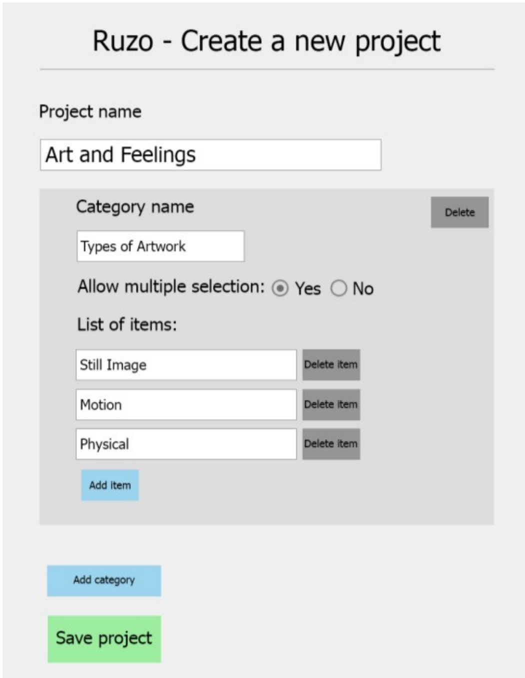

Figure 1. Web-based interface for creating research projects.

When users click the 'Save Project' button, the system automatically generates a cross-platform mobile web app for data collection. The system then sends users an email with two links – one for the data collection web app, and one for the web-based data visualization interface.

Collecting Data

The data collection interface can be accessed from any mobile device by clicking the link to the web app. The interface consists of a series of horizontal rows. Each row represents one category defined earlier by the project creator. Within each row, data items are represented by circles. Users press the circles in order to report the occurrence of the corresponding phenomena. Pressing a circle changes its color from gray to green, signifying this item has been selected. Pressing the circle again deselects the item. Figure 2 illustrates a report of feeling interested while looking at a still image.

When users press the 'Send' button, a report is sent to the server. All reports are anonymous to protect students' privacy. The report includes the selected data items as well as the GPS coordinates of the current location. The location is fetched using Google geolocation services. We chose to add location to each report for two reasons. First, location strongly links abstract concepts to real-life experiences, because it demands translation of abstract concepts into observable phenomena in a specific area. Second, location is a potential moderating variable. Including it in the data set could uncover unexpected differences between urban and rural areas, or between different neighborhoods in the same urban area.

Figure 2. Data collection interface. Circles appearing in green represent items reported by the user as currently occurring.

Visualizing Data

The web-based data visualization interface can be accessed from any computer by clicking the corresponding link. The screen is divided to three sections (see Figure 3). The left section displays the distribution of collected data on a map. Using a polygon tool, users select location-based sub-sets of the data. The selection can be easily modified using an eraser tool. The polygon tool enables users to define specific geographical regions of interest, so that only data originating from these regions will be included.

The right section of the screen displays an interactive visualization of statistical correlations between items in the selected data-set. Items are represented by circles, correlations by lines. When the mouse cursor is positioned on top of a line, the value of the correlation coefficient and its direction (positive or negative) are displayed. The bottom section of the screen enables users to set a strength threshold for displaying correlations. We chose to focus on correlation analysis because it is broad enough to suit multiple disciplines within the social sciences.

According to our interviews with domain experts, statistical calculations are of lower importance during an introductory research methods course, therefore the data visualization interface was not meant to serve as a statistical tool. It is only meant to facilitate intuitive data exploration and sense-making. Hopefully, using such a simple interface would help reduce students' anxiousness, and expose them to the joy of discovering something new or unexpected. In that sense, Ruzo serves as "training wheels" for novice social scientists, laying the foundations for using more sophisticated statistical software, for example SPSS [13].

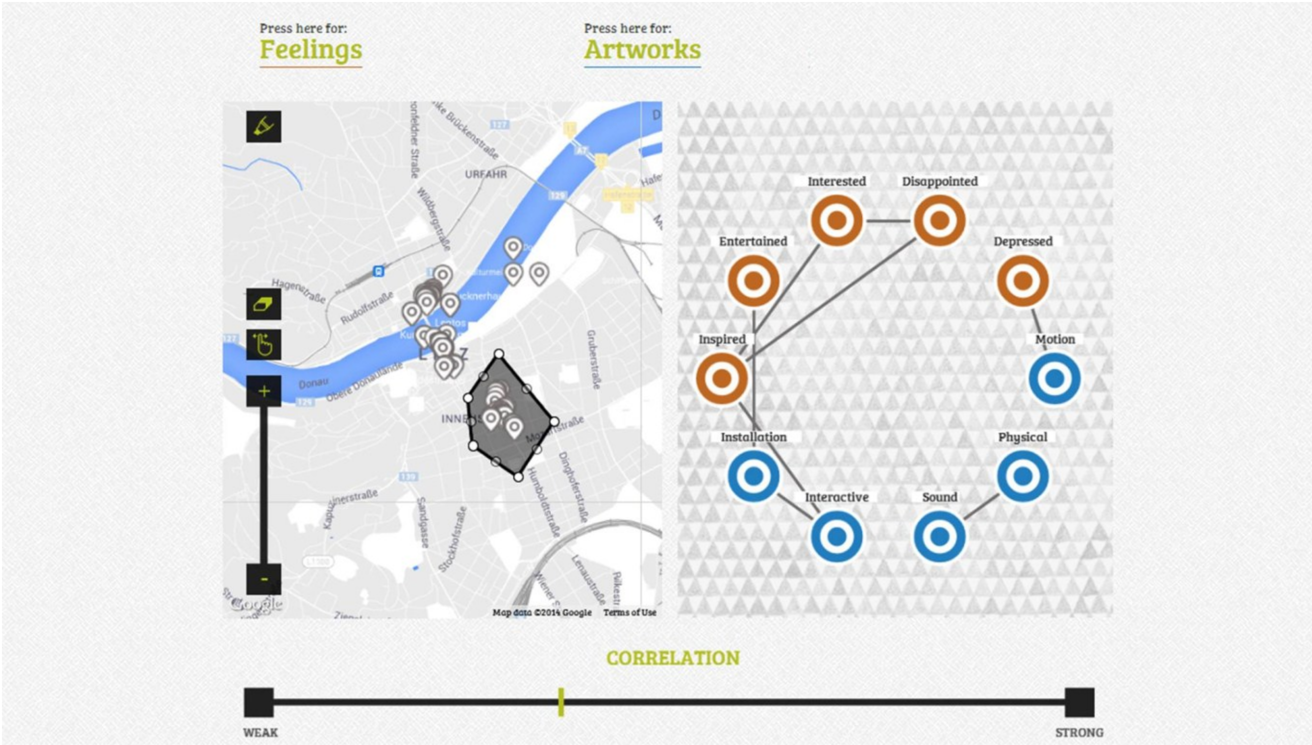

Figure 3. Data visualization interface. Left: Sub-sets of data are selected using a polygon tool. Right: Each data item is presented as a circle. Statistical correlations between items are presented as lines. Bottom: Selecting a strength threshold for correlations.

Technical Design

Ruzo consists of two main components: a web-based component and a mobile component.

Web-based Component

The web-based component enables the creation of research projects, inviting others to collect data, and visualizing the data. A Linux machine on cloud server is used with an Apache web server and the Kohana framework (http://kohanaframework.org), which wraps and extends PHP. The data is stored using MySQL. The correlations visualization interface was created using processing JS.

Mobile Component

The mobile component enables data collection with a web app. The web app was created using HTML5 and JavaScript.

Usage Scenarios

We imagine two different scenarios for using Ruzo. In the first scenario, the instructor creates the research project, and defines the categories and items. The instructor then sends the link for the web app to students, who begin collecting data using their mobile devices. At the end of the data collection stage, students are instructed to visit the data visualization interface in order to explore the data and formulate their own conclusions, or perhaps the instructor does that during class. The instructor could potentially create several research projects simultaneously, sending each one to a different group of students. In the second scenario, students create their own research projects, and share them with others. In both scenarios, instructors could focus on different stages or aspects of research, according to their current pedagogical objectives. Furthermore, students could participate in multiple projects simultaneously to better understand the research process through repetition.

USER STUDY

A two-week user study was conducted in order to examine the usability of Ruzo, and whether it can engage students in scientific inquiry. We opted to conduct an independent study and not evaluate Ruzo during an on-going research methods course, otherwise it would have been impossible to separate system-related variables from course-related variables (identity of the instructor, final grade in the course etc.). A within-course evaluation is a natural next step, however, an unconfounded evaluation of the core elements of Ruzo is an essential first step.

Participants

Ten representatives of the target audience – undergraduate social sciences students – participated in the study (4 females, 6 males). Their age ranged from 22 to 28 (M = 23.90, SD = 1.73). They volunteered to participate in exchange for extra credit in an interactive communication course. They all received the same credit, regardless of their actions during the study.

Procedure

Students were invited by email to participate in the study. The email included a link to an informed consent form and an initial background questionnaire. Participants then met with a research assistant, serving as the instructor, who explained how to use Ruzo. Since there are two usage scenarios for the system, half of the participants were asked to participate in a pre-defined project dedicated to urban phenomena (uncovering correlations between the number of visitors to a certain location and the existence of graffiti and trash there). The other half were asked to create their own project and recruit five additional data collectors. The role was randomly assigned. After one week, participants were instructed to switch roles – the first group created their own research projects, whereas the second group began collecting data for the pre-defined project. As they started working on the new project, participants were also instructed to stop working on the previous one. This ensured that an equal amount of time was dedicated to both projects. After two weeks, participants were invited to the lab, where each participant was asked to visualize the data collected in the pre-defined project. Afterwards, they were asked to fill out the System Usability Scale [2], and a 15-minutes semi-structured interview was conducted. Finally, participants were thanked and debriefed. The interviews were recorded with participants' consent. The recordings were later transcribed and independently analyzed by two researchers in order to identify emerging common themes.

Results

Participants found it relatively easy and rewarding to create research projects.

P1: *"{I like that} you can search for correlations between whatever comes to mind… People can produce a lot of positive conclusions, especially since it's a specific area, for example a country or a city"*.

P5: *"When you think of a project you need to invent relationships… all sorts of things that we think are one way, but are actually the other way around. It's creative so it's cool"*.

Most projects created by participants were dedicated to social phenomena, reflecting their social sciences background. Examples of projects created during the study include: the relationship between physical appearance and emotion; the relationship between gender, smoking and current company.

All participants were asked to visualize the findings from the pre-defined project because it had the largest data set. Though they were not given any specific instructions how to go about visualizing the data, all participants performed the following actions using the interactive tool: selecting to visualize the data set as a whole, as well as focusing on at least one sub-set of data, adding or removing items from the visualization, checking the value of the correlation coefficient between variables, changing the threshold for presenting correlations on screen. Participants seemed interested in uncovering relationships between seemingly unrelated phenomena, or identifying differences between geographical regions.

P1: *"It's very interesting to find out what's the answer to what you have been doing"*.

P3: *"I was really curious to see what's the strongest relationship in the northern vs. central region"*.

For example, participants found out that in a large city there was a positive correlation between graffiti and trash, whereas for a neighboring smaller city the correlation did not exist. This opened the door to discussing location as a moderating variable, and the effect of sample size on correlation coefficients.

Lastly, participants were then given the opportunity to visualize data from their own project. The motivation to do so was even higher.

P5: *"When it was my own project I felt a greater need to monitor it, and I was really interested in the results"*.

Usability

Ruzo was designed to be a non-threatening, easy to use system. To verify that, we evaluated its usability with the System Usability Scale [2]. The scale yields a single score, ranging from 0 to 100, representing a composite measure of overall usability. The average score was 78.21 (SD = 12.39, MIN = 60, MAX = 93). In addition, during the interview participants described Ruzo as easy to use.

P2: *"It's very friendly, anyone can understand it; you don't have to be an expert because it's very simple and convenient"*.

DISCUSSION

In an effort to engage college students in scientific inquiry, we developed Ruzo – a platform for creating research projects as mobile apps, collaborating with others to collect location-based data, and intuitively examining the data through interactive visualization. Ruzo aims to overcome students' anxiousness and lack of motivation because these appear to play a significant role in their reluctance to study methodological courses. To that end, Ruzo leverages mobile technology to redefine research as an effortless non-threatening process, which takes place in one's immediate surroundings.

A user study showed that social sciences students perceived Ruzo as user friendly. Moreover, they were motivated to create research projects and examine the collected data, thus providing initial validation for our design and implementation. These findings correspond to prior work, further demonstrating how mobile technology can connect field work to higher level abstractions [12], and how interactive visualization can be leveraged for teaching statistical concepts [6].

It is important to note that Ruzo was not meant to replace instructors or in-class discussions, only to enhance existing pedagogical practices. Introductory research methods courses are aimed at providing students with a basic understanding of the core scientific process. However, our interviews with experienced instructors revealed that this goal is not easily achieved. Active learning is perceived as a useful method for achieving this goal. We demonstrated how mobile devices can support active learning, as well as foster a positive attitude towards research.

The work reported in this paper has several limitations that should be addressed. Ruzo is only a prototype, and was evaluated with a limited number of students, out of context of a formal research methods course. Furthermore, we focused on user experience and usability rather than actual pedagogical gains. Further studies are required to examine the feasibility and effectiveness of Ruzo in real course settings. In addition, the platform itself could be further developed to better utilize mobile technology, supporting data collection through additional sensors. Lastly, we should acknowledge the fact that Ruzo transforms students' mobile device, typically used for communication and entertainment, into a work tool. Further research is required in order to verify that the use of a personal mobile device for academic assignments does not create a new source of stress for students.

Despite these limitations, our initial findings clearly show the potential of mobile technology to engage students in scientific inquiry, and better connect research to their everyday lives. A similar technique could be utilized to engage additional target audiences in location-based data collection, for example: tracking wildlife or hazards in a certain area. More broadly, our work can serve as inspiration for the mobile HCI community to explore potential practical implications of mobile technology. As we saw in our interviews with experienced instructors, it did not occur to them to integrate mobile technology into their course curriculum. We believe that mobile HCI researchers and practitioners, who have the most comprehensive knowledge of mobile technology, should be the ones leading the effort to leverage mobile capabilities for practical purposes, in education and beyond. Hopefully, the current paper could serve as a starting point in this direction.

CONCLUSION

In this paper we described the design, implementation, and evaluation of Ruzo – a mobile platform for engaging students in scientific inquiry. Our findings indicated that active learning with mobile technology fosters positive attitudes towards research. We encourage educators and designers to continue incorporating mobile technologies into existing curriculums for better scaffolding scientific inquiry. Mobile technology can equip students with tools to apply theoretical knowledge, as well as incorporate research into everyday lives.

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