MIS Quarterly

RESEARCH NOTE

EXAMINING THE MEDIATING ROLES OF COGNITIVE LOAD AND PERFORMANCE OUTCOMES IN USER SATISFACTION WITH A WEBSITE: A FIELD QUASI-EXPERIMENT

Paul Jen-Hwa Hu
Department of Operations and Information Systems, David Eccles School of Business, University of Utah,
Salt Lake City, UT 84112 U.S.A. {paul.hu@eccles.utah.edu}

Han-fen Hu
Department of Management, Entrepreneurship, and Technology, Lee Business School, University of Nevada, Las Vegas,
Las Vegas, NV 89154 U.S.A. {han-fen.hu@unlv.edu}

Xiao Fang
Lerner College of Business and Economics, University of Delaware,
Newark, DE 19716 U.S.A. {xfang@udel.edu}

Appendix A

Representative Previous Research

Table A1. Representative Previous Research Examining Navigation Design or Navigability

	Research Question	Variables	Results
Cyr 2008 (Experiment)	How do website design features (navigation design, visual design, information design) affect users' trust and satisfaction? How do trust and satisfaction affect loyalty?	Determinant: • Navigation design • Visual design • Information design Dependent Variable: • Trust • Satisfaction • Loyalty	Navigation design affects users' satisfaction and trust toward a website; it also indirectly affects users' loyalty.
Katsanos et al. 2010 (Experiment)	How does information scent, a key attribute of navigability, influence users' behaviors while exploring a website (distribution of attention, confidence in choice of link, efficiency, effectiveness)?	Determinant: • Information scent Dependent Variable: • Distribution of attention • Confidence in choice of link • Efficiency • Effectiveness	For web pages with high navigability, the distraction users experience is low, while their confidence, effectiveness, and efficiency are high for completing information-seeking tasks.
Palmer 2002 (Survey)	Developing and validating website usability, design, and performance metrics.	Determinant: • Download delay • Navigability • Site content • Interactivity • Responsiveness Dependent Variable: • Likelihood of return • Frequency of use • Satisfaction	Website navigability is positively associated with users' perceived website success, in terms of likelihood of return, frequency of use, and satisfaction.
Webster and Ahuja 2006 (Experiment)	How do perceived disorientation, navigation, and engagement affect users' performance and future intentions to use a website?	Determinant: • Navigation systems • Perceived disorientation • Engagement Dependent Variable: • User performance • Future intention to use	Website navigability directly affects users' perceived disorientation and performance, in terms of accuracy and efficiency; it indirectly affects future intentions to use.

Table A2. Representative Previous Research Examining User Familiarity			
	Research Question	**Variables**	**Results**
Casaló et al. 2008 (Survey)	How do reputation, usability, satisfaction, and familiarity affect loyalty in an electronic commerce context?	Determinants: • Usability • Reputation • Familiarity • Satisfaction Dependent Variable: • Loyalty	Navigability, as part of usability, has a direct influence on user satisfaction. Users' familiarity moderates the influence of website usability on user loyalty.
Chen et al. 2011 (Experiment)	What are the interaction effects of familiarity, breadth, and media richness on users' perceptions and evaluations of a website?	Determinant: • Familiarity • Breadth • Media Dependent Variable: • Perceived disorientation • Engagement • Future intentions to use	User familiarity with a website is negatively associated with disorientation and positively associated with engagement and intentions to use the site in the future.
Galletta et al. 2006 (Experiment)	How do delay, familiarity, and site breadth interact to influence attitudes, performance, and behavioral intentions?	Determinant: • Familiarity • Delay • Breadth Dependent Variable: • Attitude • Behavioral intention • Performance	Familiarity affects users' attitudes and performance in their search for target information. Familiarity also dampens the negative effect of website delay on attitudes and performance.
Gefen 2000 (Survey)	What effects does user familiarity have on individual trust in a website?	Determinant: • Familiarity • Disposition of trust Dependent Variable: • Trust • Willingness to inquire • Willingness to purchase	Users' familiarity with the website increases willingness to inquire about products, willingness to purchase, and the level of trust.
Nadkarni and Gupta 2007 (Experiment)	Does complexity enhance or inhibit user experiences on a website?	Determinant: • Objective website complexity • Familiarity Dependent Variable: • Perceived website complexity	User familiarity moderates the positive association between objective and perceived website complexity.

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Appendix B

Data-Driven Navigability Metric and Applications to Assess Experimental Websites

We describe the formulation of the data-driven navigability metric, adapted from Fang et al. (2012), and detail its application to evaluate the navigability of the websites in our experiment. This metric is premised in the law of surfing (Huberman et al. 1998), which states that the probability $p(k)$ of surfing k hyperlinks in a session can be expressed as

$$p(k) = \sqrt{\frac{\beta}{2\pi k^3}} \exp\left[\frac{-\beta(k-\alpha)^2}{2\alpha^2 k}\right] \qquad k \text{ - } 1, 2, \ldots \tag{B1}$$

where the average number of hyperlinks surfed in a session is α, and the scale parameter β determines the shape of the probability distribution. Let $G(l)$ be the probability of surfing *at least* l hyperlinks during a session, which is the sum of $p(k)$, where $k \geq l$, such that

$$G(l) = \sum_{\forall k \geq l} p(k) \qquad l = 1, 2, \ldots \tag{B2}$$

The metric considers three fundamental dimensions of navigability: power, efficiency, and directness.

Power

Power reveals the probability that a visitor accurately locates target information by navigating through a website's hyperlink structure. Key access sequences, discovered from web logs, approximate visitors' information-seeking targets. A key access sequence refers to a sequence of content pages frequently accessed by users. Let U be a set of n key access sequences discovered from logs, $U = \{u_i\}$, $i = 1, 2, \ldots, n$, and $u_i = \langle p_{i,1}, p_{i,2}, \ldots, p_{i,m} \rangle$, where $p_{i,j}$ is the j^{th} visited content page in u_i, $j = 1, 2, \ldots, m$. For an information-seeking target approximated by a key access sequence u_i, *power* $R(u_i)$ can be measured as the probability of locating all content pages in u_i sequentially, from $p_{i,1}$ to $p_{i,m}$. Let p_s denote the start page in the search for u_i. If $p_s \neq p_{i,1}$, let $d(p_s, p_{i,1})$ be the distance from p_s to the first sought page $p_{i,1}$. Visitors willing to surf at least $d(p_s, p_{i,1})$ hyperlinks can locate $p_{i,1}$ from p_s. According to Equation B2, $G(l)$ is the probability of surfing at least l hyperlinks; therefore, the probability of surfing at least $d(p_s, p_{i,1})$ hyperlinks is $G(d(p_s, p_{i,1}))$. In turn, the probability of locating $p_{i,1}$ from p_s can be approximated as $G(d(p_s, p_{i,1}))$. After locating $p_{i,1}$, a visitor can continue to locate $p_{i,2}$, and the probability of locating $p_{i,j}$ from $p_{i,j-1}$ can be approximated as $G(d(p_{i,j-1}, p_{i,j}))$, where $2 \leq j \leq m$. If $p_s \neq p_{i,1}$, the power $R(u_i|p_s)$ of locating u_i becomes

$$R(u_i|p_s) = G\left(d\left(p_x, p_{i,1}\right)\right) \prod_{j=2}^{m} G\left(d\left(p_{i,j-1}, p_{i,j}\right)\right) \qquad \text{if } p_s \neq p_{i,1} \tag{B3}$$

Likewise, if $p_s = p_{i,1}$, we obtain

$$R\left(u_i | p_s\right) = \prod_{j=2}^{m} G\left(d\left(p_{i,j-1}, p_{i,j}\right)\right) \qquad \text{if } p_s = p_{i,1} \tag{B4}$$

Let P(start of seeking for $u_i = p_s$) be the probability of seeking u_i by starting from page p_s, which can be estimated from surfing data recorded in web logs. Accordingly, $R(u_i)$ is

$$R\left(u_i\right) = \sum_{\forall p_s} p\left(\text{start of seeking for } u_i = p_s\right) R\left(u_i | p_s\right) \tag{B5}$$

Not all key access sequences are equally important. Let $w(u_i)$ be the weight of u_i in U, calculated as

$$w\left(u_i\right) = \frac{v\left(u_i\right)}{\sum_{\forall u \in U} v\left(u\right)} \tag{B6}$$

where $v(u_i)$, is the frequency rate of visiting u_i. Therefore, the *power* $R(U)$ of a website can be measured as the weighted probability of achieving each information-seeking target in U on that site,

$$R\left(U\right) = \sum_{i=1}^{n} w\left(u_i\right) R\left(u_i\right) \tag{B7}$$

Power, $R(U)$, falls inclusively between 0 and 1. The higher its value, the more powerful a website's hyperlink structure design is for helping visitors locate target information on the site.

We illustrate the calculation of power with an example. In Figure B1, a sample website consists of nine pages (A, B, …, I) and has eight hyperlinks (l_B, l_C, …, l_I), pointing to web pages B, C, …, I.

The distance matrix for the site is in Table B1. For example, the distance from page A to page E is two clicks.

Let the key access sequences U identified from web logs be $U = \{u_1, u_2\}$, where $u_1 = \langle F,H \rangle$, with $v(u_1) = .15$; P(start of seeking for $u_1 = A$) = .8; and P(start of seeking for $u_1 = F$) = .2. In addition, $u_2 = \langle B,I \rangle$, with $v(u_2) = .1$; P(start of seeking for $u_2 = A$) = .9; and P(start of seeking for $u_2 = B$) = .1. Assume that $G(1) = 1$ and $G(2) = .8$, after the application of Equation B2. Then, applying Equation B3, we have

$R(u_1|A) = G(d(A,F))G(d(F,H)) = G(2)G(1) = 0.8$ by using the distance matrix in Table B1.

We apply Equation B4 and obtain

$R(u_1|F) = G(d(F,H))G(1) = 1$

Applying equation B5, we determine

$R(u_1) = P(\text{start of seeking for } u_1 = A)R(u_1|A) + P(\text{start of seeking for } u_1 = F)R(u_1|F) = 0.84$

Similarly, we can calculate $R(u_2)$:

$R(u_2|A) = G(d(A,B)G(d(B,I)) = G(1)G(2) = 0.8$;

$R(u_2|B) = G(d(B,I) = G(2) = 0.8$; and

$R(u_2) = P(\text{start of seeking for } u_2 = A)R(u_2|A) + P(\text{start of seeking for } u_2 = B)R(u_2|B) = 0.8$

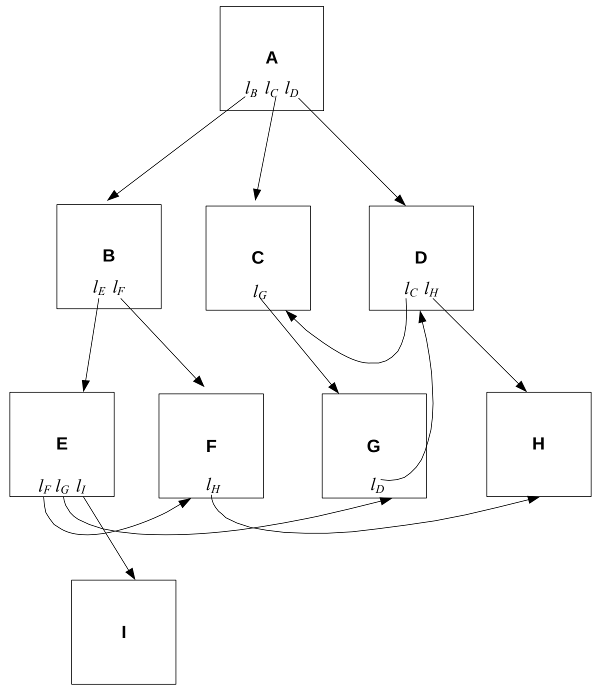

Figure B1. Sample Website

Table B1. Distance Matrix for Sample Website

	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*
A	0	1	1	1	2	2	2	2	3
B	∞	0	4	3	1	1	2	2	2
C	∞	∞	0	2	∞	∞	1	3	∞
D	∞	∞	1	0	∞	∞	2	1	∞
E	∞	∞	3	2	0	1	1	2	1
F	∞	∞	∞	∞	∞	0	∞	1	∞
G	∞	∞	2	1	∞	∞	0	2	∞
H	∞	∞	∞	∞	∞	∞	∞	0	∞
I	∞	∞	∞	∞	∞	∞	∞	∞	0

Finally, with Equation B7, we calculate the power of the website in Figure B1 as

$$R(U) = w(u_1)R(u_1) + w(u_2)R(u_2) = \frac{0.15}{0.1+0.15} \times 0.84 + \frac{0.1}{0.1+0.15} \times 0.8 = 0.82$$

Efficiency

Efficiency refers to the efficiency with which a visitor locates target information. The closer a page is to the current page, the more efficient it is to locate that page. For an information-seeking target approximated by a key access sequence $u_i = \langle p_{i,1}, p_{i,2}, \ldots, p_{i,m} \rangle$, given that seeking for u_i starts from page $p_s \neq p_{i,1}$, the *efficiency* $Q(u_i|p_s)$ of achieving the information-seeking target can be measured as

$d\left(p_s, p_{i,1}\right)\sum_{j=2}^{m} d\left(p_{i,j-1}, p_{i,j}\right)$ where $d(x, y)$ denotes the distance from page x to page y. By normalizing the efficiency metric onto [0,1], we obtain

$$Q(u_i|p_s) = \frac{m\gamma - \min\left(d\left(p_s, p_{i,1}\right)\right) + \left(\sum_{j=2}^{m} d\left(p_{i,j-1}, p_{i,j}\right), m\gamma\right)}{m(\gamma - 1)} \qquad \text{if } p_s \neq p_{i1} \tag{B8}$$

where m is the number of content pages in u_i; the function $\min(x, y)$ returns the smaller value between x and y; and $\gamma > 1$ is a constant. A page is most efficient to locate if it is one click away; it is least efficient if it is γ or more clicks away. Then γ can be set to an appropriate value, such that the probability of surfing γ or more clicks (i.e., $G(\gamma)$) becomes trivial. Similarly,

$$Q(u_i|p_s) = \frac{(m-1)\gamma - \min\left(d\left(p_s, p_{i,1}\right)\right) + \left(\sum_{j=2}^{m} d\left(p_{i,j-1}, p_{i,j}\right), (m-1)\gamma\right)}{(m-1)(\gamma - 1)} \qquad \text{if } p_s \neq p_{i1} \tag{B9}$$

Also, $Q(u_i)$ can be derived as follows:

$$Q(u_i) = \sum_{\forall p_s} P(\text{start of seeking for } u_i = p_s) Q(u_i|p_s) \tag{B10}$$

As a result, the *efficiency* $Q(U)$ of a website is measured as the weighted efficiency of locating each information-seeking target in U on the site. That is,

$$Q(U) = \sum_{i=1}^{n} w(u_i) Q(u_i) \tag{B11}$$

and $Q(U)$ falls inclusively between 0 and 1, where 0 indicates the least efficient (i.e., average distance to the visitor-sought content pages is γ or more clicks away) and 1 is most efficient (i.e., all visitor-sought content pages are only one click away). The higher the value of $Q(U)$, the more efficient it is for a visitor to locate the target information on a website.

We illustrate this calculation, using the sample website from Figure B1 and the key access sequences. We assume that the constant γ is 5. Applying Equation B8, we find

$$Q(u_i|A) = \frac{2\gamma - \min\left(d(A, F) + d(F, H), 2\gamma\right)}{2(\gamma - 1)} = \frac{2\gamma - (2+1)}{2(\gamma - 1)} = 0.88 \qquad \text{by using the distance in Table B1}$$

From Equation B9, 23 note

$$Q(u_1|F) = \frac{\gamma - \min\left(d(F, H), \gamma\right)}{\gamma - 1} = 1$$

Applying Equation B10, we obtain

$$Q(u_1) = P(\text{start of seeking for } u_1 = A)Q(u_1|A) + P(\text{start of seeking for } u_1 = F)Q(u_1|F) = 0.9$$

Applying Equation B11, we determine the efficiency of the sample website in Figure B1 as

$$Q(U) = w(u_1)Q(u_1) + w(u_2) = \frac{0.15}{0.1+0.15} \times 0.9 + \frac{0.1}{0.1+0.15} \times 0.86 = 0.89$$

Directness

Directness indicates the ease with which a visitor can decide where to move from the current page to the target information. People are likely to find target information with fewer clicks if more hyperlinks point to content pages on each page. At an extreme, efficiency *Q(U)* equals 1 when each page has hyperlinks pointing to all content pages on the site; that is, all content pages are only one click away from any page, which obviously is not a good design. Placing more hyperlinks on a page makes it increasingly difficult for visitors to decide on their next move. With an information-seeking target approximated by a key access sequence $u_i = \langle p_{i,1}, p_{i,2}, \ldots, p_{i,m} \rangle$ and assuming seeking for u_i starts from $p_s \neq p_{i,1}$, directness $L(u_i | p_s)$ can be measured as $N(p_s, p_{i,1}) + \sum_{j=2}^{m} N(p_{i,j-1}, p_{i,j})$, where $N(x,y)$ denotes the average number of hyperlinks on the pages located on the shortest path from x to y, and $N(x,y)$ is ∞ if there is no path from x to y. By normalizing the directness measure onto [0,1], we obtain

$$L(u_i|p_s) = \frac{m\delta - \min\left(N(p_s, p_{i,1}) + \sum_{j=2}^{m} N(p_{i,j-1}, p_{i,j}), m\delta \right)}{m(\delta - 1)} \quad \text{if } p_s \neq p_{i,1} \tag{B12}$$

where the function min(x, y) returns the smaller value between x and y, and δ is a constant, $\delta > 1$. Visitors have less difficultly deciding on their next move if the current page contains only one hyperlink but more difficultly if the current page contains δ or more hyperlinks. The value of δ can be user specified or set to an adequate constant, according to a generally accepted usability guideline. Similarly,

$$L(u_i|p_s) = \frac{(m-1)\delta - \min\left(N(p_s, p_{i,1}) + \sum_{j=2}^{m} N(p_{i,j-1}, p_{i,j}), (m-1)\delta \right)}{(m-1)(\delta - 1)} \quad \text{if } p_s = p_{i,1} \tag{B13}$$

Then $L(u_i)$ is derived as

$$L(u_i) = \sum_{\forall p_s} P(\text{start of seeking for } u_i = p_s) L(u_i|p_s) \tag{B14}$$

The directness $L(U)$ of a website can be calculated as the weighted directness of achieving each information-seeking target in U on the site:

$$L(U) = \sum_{i=1}^{n} w(u_i) L(u_i) \tag{B15}$$

In addition, directness $L(U)$ falls within [0,1], with 0 indicating the most difficulty and 1 the least. The higher the value of $L(U)$, the easier it is for a visitor to decide on the next move.

To illustrate this calculation, we again use the sample website in Figure B1 and the key access sequences, and we assume the constant δ is set to 5. For the key access sequence $u_1 = \langle F,H \rangle$, the shortest path from page A to F is A(3)→B(2)→F, and the shortest path from page F to H is F(1) →H. The number of hyperlinks on a page is indicated in parentheses after the annotation letter that denotes the page. Therefore, $N(A,F) = \frac{3+2}{2} = 2.5$, and $N(F,H) = 1$. By applying Equations B12–B14, we determine

$$L(u_1|A) = \frac{2\delta - \min(N(A,F) + N(F,H), 2\delta)}{2(\delta - 1)} = 0.81;$$

$$L(u_1|F) = \frac{\delta - \min(N(F,H), \delta)}{\delta - 1} = 1;$$

$$L(u_1) = P(\text{start of seeking for } u_1 = A)L(u_1|A) + P(\text{start of seeking for } u_1 = F)L(u_1|F) = 0.85$$

For $u_2 = \langle B,I \rangle$, the shortest path from pages A to B is A(3)→B, and the shortest path from pages B to I is B(2)→E(3)→I, so $N(A,B) = 3$ and $N(B,I) = 2.5$. Applying Equations B12–B14, we obtain

$$L(u_2|A) = \frac{2\delta - \min(N(A,B) + N(B,I), 2\delta)}{2(\delta - 1)} = 0.56;$$

$$L(u_2|B) = \frac{\delta - \min(N(B,I), \delta)}{\delta - 1} = 0.63;$$

$$L(u_2) = P(\text{start of seeking for } u_2 = A)L(u_2|A) + P(\text{start of seeking for } u_2 = B)L(u_2|B) = 0.57$$

We use Equation B15 to calculate the sample website's directness as

$$L(U) = w(u_1)L(u_1) + w(u_2)L(u_2) = \frac{0.15}{0.1 + 0.15} \times 0.85 + \frac{0.1}{0.1 + 0.15} \times 0.57 = 0.74$$

Navigability

Finally, by considering power, efficiency, and directness simultaneously, we obtain a single, holistic measure of navigability. Specifically, the navigability $Nav(U)$ of a website is the harmonic mean of power $R(U)$, efficiency $Q(U)$, and directness $L(U)$:

$$Nav(U) = \frac{3R(U)Q(U)L(U)}{Q(U)L(U) + R(U)L(U) + R(U)Q(U)} \tag{B16}$$

In this equation, $Nav(U)$ is bounded within [0,1]. The greater the value of $Nav(U)$, the better is the site's navigability. We used the data-driven navigability metric $Nav(U)$ to evaluate the navigability of the two experimental websites. When mining key access sequences from web logs, we set threshold values between .05% and .175%, in increments of .025%. Table B2 reports the metric scores for each site.

According to these metric scores, the navigability of Site A is better than that of Site B, across the range of threshold values. On average, the navigability score of Site A is 14.7% higher.

Table B2. Navigability Comparison of Experimental Websites		
Threshold Value	Navigability of Site A	Navigability of Site B
.05%	.62	.53
.075%	.62	.54
.1%	.62	.54
.125%	.62	.55
.15%	.63	.55
.175%	.63	.55

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Appendix C

Warm-Up Exercises and Experimental Tasks

Warm-Up Exercises

1: Find the location of the College of Business Administration and the dean's bio.
2: Find the university's president's name.
3: Find the page containing current campus news and then the page containing the information about the university (e.g., facts, history, etc.).

Experimental Tasks

1: Find the location and operating hours of the Campus Main Library.
2: Find the page containing the description of the University Athletics and then the page containing the description of the University Football team.
3: Find the location and hours of the Office of Academic Advising and then the Office of Career Services.
4: Find the page containing a list of current campus events.
5: Find the location and store hours of the Campus Bookstore.
6: Find parking permit rates and how to buy parking permits.
7: Find the contact information and operating hours of the Campus Medical Center.
8: Find the Academic Calendar and then the dates for this year's Spring break.
9: Find the current semester class schedule and then the location of a specific course offered in the semester.
10: Find the page containing Campus Directory and then the page containing Campus Map and Directions.
11: Find the page containing Campus Recreation Services and then the page containing Campus Sports Clubs.
12: Find the current semester Tuition and Rates and how to pay tuition.

Appendix D

Question Items

Computer Competence (CC; Shih 2006)
CC-1: How would you rate your general computer skills?
CC-2: How would you rate your overall competence for using Internet technology?
CC-3: How would you rate your general capability of browsing the Web?

Cognitive Load (CL; Hong et al. 2004; Nadkarni and Gupta 2007)
CL-1: I needed a lot of thinking when deciding how to navigate from a current page towards the target page/content on the experimental website.
CL-2: I often contemplated, among the hyperlinks on a current web page, which one to choose for my locating the target content.
CL-3: Generally speaking, my navigating the experimental website to locate a target page/content was cognitively demanding.

User Satisfaction (US; McKinney et al. 2002)
UST-1: Overall, I am satisfied with my using the experimental website to complete a search task.
UST-2: I am pleased with my use of the experimental website to locate target pages/content.

Self-Efficacy for Finding Information on Web (SE; Compeau and Higgins 1995)
SE-1: I can effectively navigate a website if I have seen someone else using that website before trying it myself.
SE-2: I am effective in navigating a website if I can contact someone for help if I got stuck.
SE-3: I can effectively navigate a website if someone else helps me get started.
SE-4: I can navigate a website effectively if I have just the online navigation information (available on that website) for assistance.
SE-5: I can effectively navigate a website for finding specific information if I have used similar websites before.

Verification Checks
Navigability: The experimental website provides precise structural information for guiding me to locate a target page/content effectively and efficiently (7-point Likert scale, 1 = “strongly disagree” and 7 = “strongly agree”).
User familiarity: How would you rate your overall familiarity with the experimental website? (7-point Likert scale, 1 = “not good at all” and 7 = “excellent”).

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