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Cognitive Styles, Demographic Attributes, Task Performance, and Affective Experiences: An Empirical Investigation into Astrophysics Data System (ADS) Core Users

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Abstract

As a primary digital library portal for astrophysics researchers, SAO/NASA ADS (Astrophysics Data System) 2.0 interface features several visualization tools such as Author Network and Metrics. This research study involves 20 ADS long term users who participated in a usability and eye tracking research session. Participants first completed a cognitive test, and then performed five tasks in ADS 2.0 where they explored its multiple visualization tools. Results show that over half of the participants were Imagers and half of the participants were Analytic. Cognitive styles were found to have significant impacts on several efficiency-based measures. Analytic-oriented participants were observed to spent shorter time on web pages and apps, made fewer web page changes than less-Analytic-driving participants in performing common tasks, whereas AI (Analytic-Imagery) participants also completed their five tasks faster than non-AI participants. Meanwhile, self-identified Imagery participants were found to be more efficient in their task completion through multiple measures including total time on task, number of mouse clicks, and number of query revisions made. Imagery scores were negatively associated with frequency of confusion and the observed counts of being surprised. Compared to those who did not claimed to be a visual person, self-identified Imagery participants were observed to have significantly less frequency in frustration and hesitation during their task performance. Both demographic variables and past user experiences were found to correlate with task performance; query revision also correlated with multiple time-based measurements. Considered as an indicator of efficiency, query revisions were found to correlate negatively with the rate of complete with ease, and positively with several time-based efficiency measures, rate of complete with some difficulty, and the frequency of frustration. These results provide rich insights into the cognitive styles of ADS' core users, the impact of such styles and demographic attributes on their task performance their affective and cognitive experiences, and their interaction behaviors while using the visualization component of ADS 2.0, and would subsequently contribute to the design of bibliographic retrieval systems for scientists.

Keywords: Cognitive Styles of Scientists; Task Performance; Demographic Attributes; Affective and Cognitive Experiences

1. Introduction

Funded by NASA, SAO/NASA Astrophysics Data System (ADS) is a "Digital Library portal for researchers in Astronomy and Physics, operated by the Smithsonian Astrophysical Observatory (SAO)." Claimed to be "a 'Disciplinary Repository' for bibliographic content in Astronomy and Physics," ADS holds "10 million

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bibliographic records, 60 million citations, and close to 3 million full-text documents, the world's most complete collection of scholarly content in the physical sciences" (SAO/NASA Astrophysics Data System, n.d., para. 2). Housed in the Harvard/Smithsonian Center for Astrophysics (CfA) and launched in 1993, ADS now has over 10 million users worldwide. There are two versions of the interface: ADS Classic and ADS Labs (currently referred to as ADS 2.0). According to ADS developers, "as a result of the massive technological and sociological changes in the field of scholarly communication, the ADS is now completing the most ambitious technological upgrade in its twenty-year history" (Accomazzi et al., 2014). In the ADS 2.0 interface, the results page features a number of visualization functions, including "Metrics," "Author Network," "Paper Network," and "Word Cloud." Figures 1 and 2 are screen shots of the Author Network and Metrics of ADS 2.0.

Over the years, the developers of ADS have made conscious improvement of the interface based in part on the three rounds of usability testing results conducted by students from School of Library and Information Science, Simmons College (Cressman, Singley, Perry, & Walsh, 2014; Danis, Corbett, & Kurahashi, 2011; Prentice & Guillette, 2012; von Eye, He, & Hileman, 2011). The tests were held on site at the CfA, but the participants were mainly graduate students. The core users of the system are long term ADS users who are scientists conducted years of research in the field of astronomy and astrophysics. These users are also users of ADS Classic, which is drastically different in its look and feel from ADS

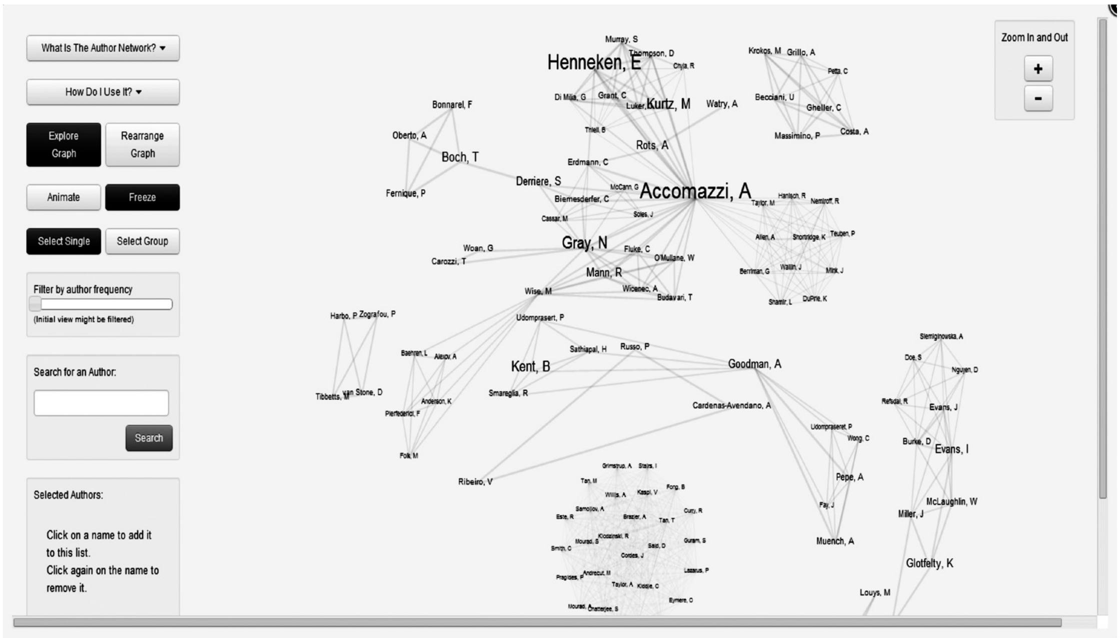

Figure 1. ADS 2.0 Author Network Visualization upon Searching "Accomazzi, Alberto"

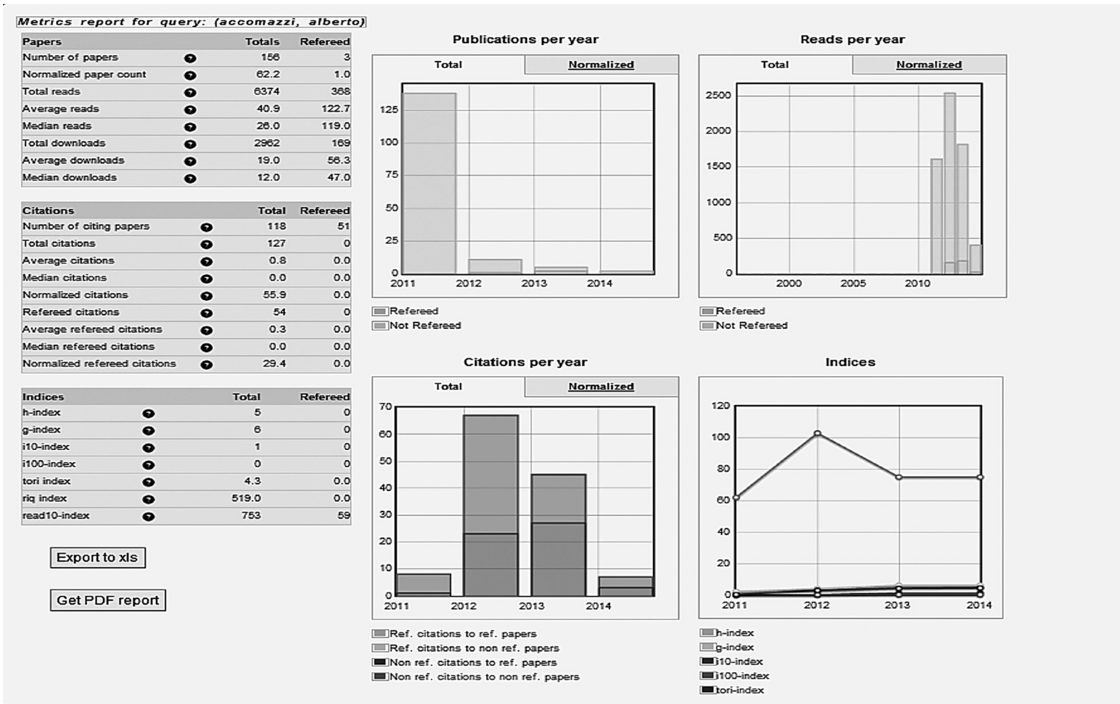

Figure 2. ADS 2.0 Metrics Display upon Searching "Accomazzi, Alberto"

2.0. Because ADS is built to serve its primary core users as well as other user segments, it is important to investigate how these users interact with new interface and whether their cognitive style might help facilitate the comprehension of ADS visualizations efficiently and effectively.

In the landscape of research investigations into cognitive patterns, there have been very limited research studies focused on cognitive styles of scientists in general and astrophysicists in particular. While a number of studies looked at cognitive traits of physical science students versus humanities students using the empathizing-systemizing (E-S) theory (e.g., Baron-Cohen, 2002, 2003; Baron-Cohen, Knickmeyer, & Belmonte, 2005; Billington, Baron-Cohen, & Wheelwright, 2007; Focquaert, Steven, Wolford, Colden, & Gazzaniga, 2007), the attention has been on either the gender and disciplinary differences of E and S in student populations, and it has seldom been on how the E-S balance manifests through expert scientists interacting with a bibliographic retrieval system with visualization capabilities.

The objectives of the study are:

(1) To uncover the typical cognitive style of astrophysics scientists that may impact on their interaction with ADS 2.0 and its visualization components;

(2) To investigate the relationship between **cognitive style**

a. and task performance

b. and ADS users' emotional and cognitive experiences;

(3) To investigate the relationship between **demographic attributes and past use experiences**

a. and cognitive style

b. and task performance

c. and ADS users' emotional and cognitive experiences.

For the purpose of understanding the core users' cognitive profile and their experiences with ADS 2.0, the present investigation incorporated a Verbal Imagery Cognitive Style Test (VICS) and an Extended Cognitive Style Analysis – Wholistic Analytic Test (Extended CSA-WA Test) (Peterson, 2005). Multiple studies of cognitive styles and information searching (Park & Black, 2007; Yuan & Liu, 2013) have revealed that cognitive styles influence users' task performance when interacting with a text-based system and a visualization system. In an attempt to create a profile for ADS users, the author hopes to further understand the effect of cognitive styles not only on user task performance but also on their interaction behavior, their query revision activities, and their affective experiences as they use ADS 2.0.

Following the VICS and Extended CSA-WA test, participants performed five tasks using ADS 2.0. Their interaction behavior and eye movements were captured through TechSmith's Morae software and Tobii eye tracker. The scope of this paper is defined as establishing ADS user cognitive style profile, and further examining the relationships among cognitive style, demographic attributes, task performance, and affective experiences.

2. Literature Review

In the fields of cognitive psychology and educational psychology, there is a magnitude of research on cognitive and learning styles. This review only examines literature pertaining directly to variables of interest to the current study.

2.1 Cognitive styles and VICS & Extended CSA-WA test

Cognitive styles can be defined as stable attitudes, preferences, or habitual strategies that determine an individual's modes of perceiving, remembering, thinking, and problem solving (Messick, 1976). In an attempt to understand individual differences in cognition, researchers in psychology and other fields have developed a variety of taxonomies describing cognitive styles such as locus of control (Rotter, 1966), concept articulation (Bieri, 1955; Messick, 1976), and field-dependency (Witkin, Moore, Goodenough, & Cox, 1977).

Field-dependency as a cognitive style construct was first introduced by Witkin et al. (1977). According to the authors, field-dependent (FD) people have global perceptions, while field-independents (FI) have a tendency to think Analytically. Later works by Riding and his colleagues (e.g., Riding & Rayner, 1998) argued that the FD/FI grouping holds much similarity to their Wholistic-Analytic style dimension.

Based on the results of a series of research studies on cognitive styles, Riding and Cheema (1991) proposed two major orthogonal cognitive style families: Wholistic-Analytic and Verbalizer-Imager. While the Wholistic-Analytic style dimension relates to "whether an individual tends to *process* information in wholes or parts," the

Verbalizer-Imagery style dimension pertains to "whether an individual is inclined to represent information during thinking verbally or in mental pictures" (Riding, 1997, p. 30).

Subsequently, Riding (1991) developed a computerized assessment to determine an individual's style, called Cognitive Style Analysis (CSA). In an attempt to improve the test-reliability and internal consistency of the automatic test, Peterson, Deary, and Austin (2003a, 2003b) and Peterson (2005) developed an extended version of the test, VICS and Extended CSA-WA test. The present study utilizes Peterson's VICS and Extended CSA-WA test software to assess participants' cognitive styles.

2.2 Cognitive traits of scientists

Cognitive traits were also measured in a series of empirical work conducted by researchers from Ghent University in Belgium through constructs of systemizing and empathizing. While empathizing is "defined as both the drive and ability to identify another's mental states and to respond to these with one of a range of emotions," systemizing is seen as "a drive and ability to analyse the rules underlying a system, in order to predict its behavior" (Billington et al., 2007, p. 261). In addition to confirming gender differences in cognitive traits with females being more empathetic-driven than males and males more systematic-driven than women, multiple studies (e.g., Billington et al., 2007; Focquaert et al., 2007) also uncovered that science students were more systemizing than humanities students, and the latter more empathetic than the former. Systemizing has been linked with a "field independent" cognitive style as per Billington et al. (2007), and it is "associated with a preference for local detail and an ability to ignore Gestalt perceptual distracters in a visual field" (p. 261). Based on this discussion, one may assume the core users of ADS 2.0 -- astrophysicists would have cognitive traits more towards systemizing, thus more towards Analytics style. One might further speculate that ADS core users might face some levels of difficulties in understanding visualizations as their attention would be in analyzing "the rules underlying" ADS 2.0 retrieval mechanism.

2.3 Impact of cognitive style and user search behavior

In the area of information science research, there are many empirical studies examining the effect of cognitive style on user search behavior. Researchers have applied a variety of categorizations of cognitive styles such as field dependent-independent (e.g., Kim & Allen, 2002; Leader & Klein, 1996; Palmquist & Kim, 2000; Yecan & Cagiltay, 2006), Imager-Verbalizer (Kinley & Tjondronegoro, 2010), or Analytic-Wholistic (Yuan & Liu, 2013; Yuan, Zhang, Chen, & Avery, 2011). In several cases, both Imager-Verbalizer and Analytic-Wholistic were investigated together in a setting (Graff, 2003; Uruchrutu, MacKinnon, & Rist, 2005).

Leader and Klein (1996) conducted a study to investigate the effects of search tool type and cognitive style on hypermedia database searches. They found that FI learners performed significantly better than FD learners under the index/find and map treatments. Palmquist and Kim (2000) examined the effect of cognitive styles (FD/FI) and search experience on web search performance. It was found that cognitive style significantly influenced the search performance of novice searchers. Among these searchers, participants who were FDs took significantly longer time to complete search tasks than those who were FIs. Yecan and Cagiltay (2006) compared FD and FI users through their eye gazing data on an instructional website. The study revealed that FD users spent longer time on average in their fixation duration than FI users.

In recent years, multiple studies (e.g., Kinley & Tjondronegoro, 2010; Yuan & Liu, 2013) have incorporated the Imager-Verbalizer or Analytic-Wholistic cognitive styles as their research variables. These studies have examined several aspects of information system interaction (e.g., performance, navigation style, and satisfaction) that were impacted by cognitive styles. For example, Graff (2003) compared task performance among participants of various cognitive styles and found Analytic users and Wholistic users outperformed Intermediate users on their online assessment. Another example is Kinley and Tjondronegoro's (2010) investigation into the differences between Imagers and Verbalizers in web searching. Their results showed that Verbalizers display sporadic navigation styles and adopt a scanning strategy to understand search result contents, whereas Imagers followed a structured navigational style and reading approach. Yuan et al. (2011) found that in a visualization system, Analytics found more correct answers than Wholistic participants. In addition, Wholistic users felt significantly more satisfied with their results than Analytics. In an extended version of the previous study, Analytics consistently manifested higher score on correct answers in a study by Yuan and Liu (2013).

In summary, existing research provides meaningful insights on users' cognitive styles and search behavior. Researchers using empathizing-systemizing theory discovered that science students were more systemizing-driving. However, because these empirical investigations had been relying on students of sciences, it is questionable whether this finding would be generalizable to ADS core users who are experienced astrophysics scientists. In addition, it is also uncertain what cognitive patterns that ADS core users would have when it comes to the visualization component of the ADS retrieval.

Furthermore, results describing the effect of cognitive styles on information searching have been inconsistent: Several studies showed significant differences among various styles, while findings from other studies did not support such differences. One of the limitations of previous research is that most studies relied on system-side performance measures (e.g., time, task success, and outcomes); very few focused on in-depth factors related to users (e.g., user's emotion or behavior). Yuan et al. (2011) and Yuan and Liu (2013) used emotional factors (preference and satisfaction) as part of their analysis, yet users' actual emotional reactions were not captured and hence their analysis was rather limited. Taking users affective/cognitive aspects into consideration will broaden the understanding of the empirical construct of cognitive style.

3. Research Questions and Hypotheses

The current research attempts to address the following research questions:

1. What constitutes a typical ADS core user profile including their cognitive style, research experience, and past user experience with ADS?
2. With regard to users' affective and cognitive experiences when performing tasks on ADS 2.0:
   a. What statistically significant differences in affective/cognitive experiences among ADS participants of different cognitive styles might be observed?
   b. What statistically significant correlations between various demographic attributes as well as past user experience with ADS and affective/cognitive experiences might be observed?
3. With regard to task performance:
   a. What statistically significant differences in efficiency and effectiveness of task performance among ADS participants of different cognitive styles might be observed?
   b. What statistically significant correlations between various demographic attributes as well as past user experience with ADS and task performance might be observed?

Based on the previous research, the following research hypotheses were developed:

1. There will be significantly more participants in Analytics category than participants in the Wholistic category.
2. Participants with different cognitive styles would have some significant variations in their task performance measures.
3. There are positive correlations between age and various performance measures: Younger participants would complete tasks faster and experience less difficulties when completing their tasks than older participants.

Since there is no prior research specifically investigated scientists' cognitive styles concerning processing of images (i.e., Imagers vs. Verbalizer), no hypotheses regarding the Imagery cognitive style dimension were established.

4. Research Variables and Measures

The present study included multiple sets of variables related to cognitive styles, task performance, demographic attributes and past user experiences, affective and cognitive reactions, and interaction behavior. See Table 1 for more details.

5. Methodology

A call for participation was sent to the CfA listserv by ADS program manager Dr. Alberto Accomazzi in April, 2014. A task scenario had been developed earlier by Dr. Michael Kurtz, an esteemed astrophysics scientist who has been on the ADS development team for over two decades. After securing an IRB approval from Simmons College, the license for VICS and Extended CSA-WA Test Software was obtained from Dr. Elizabeth Peterson in April 2014. A total of 20 usability test and eye tracking sessions took place at Harvard Wolbach Library between April 18 and May 8, 2014. With approximately 300 Smithsonian and Harvard scientists affiliated with CfA (Harvard-Smithsonian Center for Astrophysics, n.d.), the sample size of 20 participants is relatively small. However, with each participant performing 5 tasks and totaling behavior data of 100 tasks, the data collected provided a rich and comparable basis for non-parametric tests.

Table 1. Research Variables and Measures

Category	Variables and measures
Cognitive style	**Measures:** Imagery scores; Analytics scores **Groupings:** Imager versus non-Imagers; Analytic versus non-Analytic; Self-perceived Imagers versus Self-perceived non-Imagers; AI versus non-AI
Demographics and use experience	Age; Native English speakers versus Non-native English speakers; Research length; ADS use length; Used ADS 2.0 before or not
Task performance	**Efficiency measures[a]:** Time on task; Time spent on web pages; Time spent on applications; Average webpage changes; Mouse clicks; Mouse movement; Maximum time between inputs; Query revision **Effectiveness measures[b]:** Complete with ease; Complete with some difficulty; Complete with great difficulty
Affective and cognitive experiences[c]	Point of confusion; Point of frustration; Point of hesitation Point of thinking/learning Point of satisfaction; Point of surprise; Point of excitement

[a] Obtained by Morae automatic capture data.

[b] Coded by author and two research assistants, agreement ratio 96%.

[c] Coded by author and two research assistants, agreement ratio 69%.

5.1 Procedure

All participants came in for an individual session. Each first went through a 25-30 minute cognitive test. Following the test, a pre-session interview was conducted during which the participant was asked about their past user experience with ADS, the types of searches they conducted using ADS, and whether they considered themselves a visual or verbal person. After the pre-session interview, participants were asked to perform five tasks. The first two tasks focused on searching their own topics and their own publications. Tasks 3 through 5 were common standardized tasks for all participants. Table 2 outlines the details of the research session components and the five tasks in greater detail. Upon completing these tasks, participants were interviewed to discuss their likelihood of using individual visualization tools, what additional features they considered useful, and how they compared ADS 2.0 with ADS Classic.

Excluding the cognitive test time, each participant's session time averaged 67 minutes, with average performing task (for all five tasks) time being 35 minutes.

5.2 Data processing and analysis

Both pre-session and post-session interviews were transcribed. Data coding was performed using Morae Manager to record task starting and ending time and the levels of difficulty (complete with ease, complete with some difficulty, and

Table 2. Research Sessions and Tasks

Research session components			
Cognitive test	Pre-session interview	Task performance	Post-session interview

Tasks		
#	Task goals	Visualization used
1	Search your own topic	
2	Search your own (or your advisor) publications	Word cloud; Metrics; Author network
3	Identify common referees	Author network
4	Research productivity evaluation	Metrics
5	Michael Kurtz publications	Paper network

complete with great difficulty). The agreement ratio of coding among the author and two research assistants is 96%. Research sessions were further coded by various points of affective and cognitive reactions (points of confusion, hesitation, frustration, surprise, satisfaction, excitement, and points of thinking/learning). For example, one female participant discovered that clicking the "remove" button for one of the post-search filters removed two of her filters altogether, leading her to state with notable frustration: "Well that's backwards! " This point was coded as a point of frustration. One participant was unsure of which option to select after clicking on the "Apply" button; when he saw the options of "AND," "OR," and "Exclude," he hesitated, "Erh...let's do...OR." When the same participant later saw the Author Network visualization, he got very excited and commented "Cool!" The two affective reactions were coded as a "point of hesitation" and a "point of excitement" respectively.

Query revision was coded whenever the participant modified the initial query entered in the search box. Both the coding for query revision and affective/cognitive points were performed by two research assistants and the author, with the agreement ratio as 95.3% and 69.3% respectively.

Statistical testing methods performed include several nonparametric tests such as Spearman R correlations analyses, Mann Whitney U tests, Chi-square tests, and Krustal-Wallis tests.

6. Results

The results of this report are arranged according to the structure of research questions.

6.1 ADS core user profile

The study included 20 participants: 3 were female and 17 were male. Since there were very limited female participants in this study, no analysis on gender differences were performed. Participants' ages ranged from 26 to 64 years; average and median ages were 40 and 43 years, respectively (based on the answers of 19 participants). Half of the participants were native English speakers. Research length ranged from 5 to 40 years, with an average of 16 years. Both Dr.

Accomazzi and Dr. Kurtz confirmed that these participants were very representative of ADS core user group.

Among the 20 participants, 15 had used ADS Classic, and 14 participants had experimented with ADS 2.0 for a short duration. Although participants' average length of ADS usage was 14 years, individual lengths varied. One participant (a visiting scholar) had used the system for less than 2 years, whereas multiple other participants had been using ADS Classic since its launch in 1993. The average self-rating of familiarity and proficiency with ADS was 5.4 and 4.9 respectively, on a seven point scale where seven is the highest point of familiarity or proficiency.

A majority of participants claimed that they have been using ADS as their core research tool. One participant indicated:

I use ADS for all my bibliographic searches. It is my main source to look for papers on my field. I normally use it to look for all references on a particular source such as AGN or X-ray binaries. I also use ADS to follow the citations to my own papers. Also, probably one of my favorite functionalities is to get the bibtex code for all the papers I need to cite while writing papers.

Another participant listed how she uses ADS for her research:

(1) search for the articles relevant to my current topic of research;
(2) follow the references given in the articles to find other relevant publications;
(3) search for publications of the specific author, topic, object;
(4) find the catalogs of data which are relevant to my research and referenced in the publications.

Most participants have used ADS to perform known item searches for a specific paper, but participants also conducted subject searches of their topics. The most frequently mentioned search type was "author search," followed by "title search," "keyword search," and "subject search." Figure 3 illustrates the types of searches that participants typically conducted using ADS.

The VICS results showed that out of 20 people, 11 had the medium V/I ratios above 1.0 (with an inclination towards the Imager category), 8 participants were in between 0.8 and 1.0 (belonging to the Bimodal category) and 1 participant below 0.8 (an inclination towards the Verbalizer category). The Extended CSA-WA test results showed that while 9 participants' medium W/A ratios were between 0.97 and 1.25 (belonging to the Intermediate category), 10 participants' ratios were above 1.25 (inclined towards the Analytic category), and one participant below 0.97 (with an inclination towards the Wholistic category). Among 20 participants, there appeared a greater variability in their Analytic scores (range = 1.05, *SD* = .29) than in their Imagery scores (range = .68, *SD* = .19), although there was a significant positive correlations between two sets of scores (r_s = .53, *p* = .015). Table 3 summarizes the results of the cognitive tests as well as participants' self-perception of being a visual person or a verbal person.

Chi-square tests showed that there were not equal numbers of people in the categories of Analytics, Wholistics, and intermediatary (χ^2 = 7.2, *df* = 2, *p* = .026), nor in categories of Imagery, Verbalizer, and Bimodal (χ^2 = 7.9, *df* = 2, *p* = .019). However, when combining participants into categories of AI, IB, and others, there were

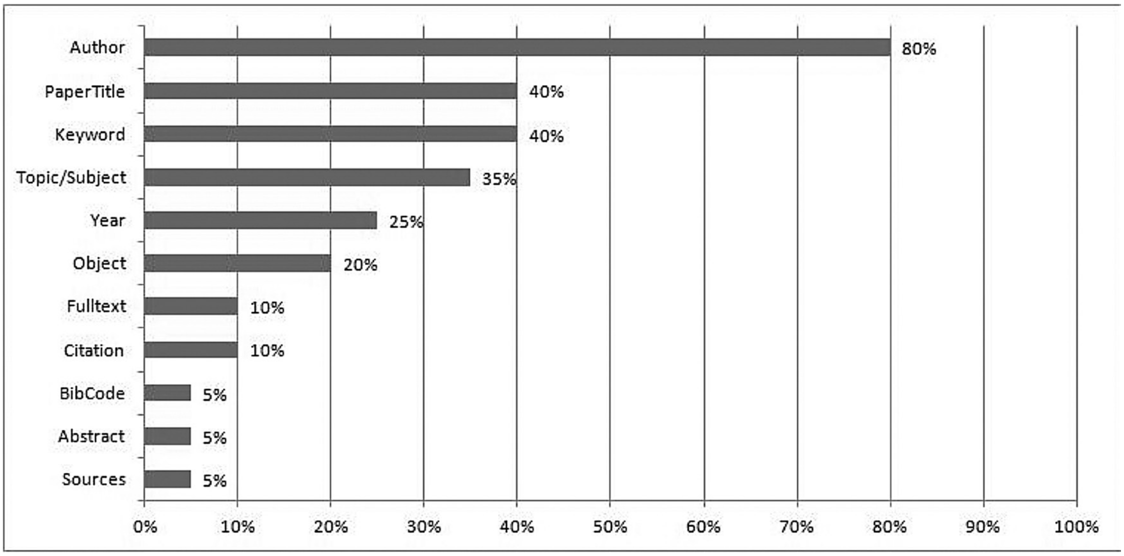

Figure 3. Types of Searches Performed by ADS Users

Table 3. Cognitive Style Test Results

	Test result	Self-perception
Imager vs. Verbalizer	Imager: $n = 11$; Bimodal: $n = 8$; Verbalizer: $n = 1$	Visual person: $n = 11$; Verbal person: $n = 1$; Balanced: $n = 4$; Don't know or depends: $n = 3$; Auditory: $n = 1$
	Consistent with self-report: $n = 9$; Not consistent with self-report: $n = 8$; Don't know: $n = 3$	
Analytic vs. Wholistic	Analytic: $n = 10$; Intermediate: $n = 9$; Wholistic: $n = 1$	
Cognitive dimensions	AI (Analytic Imager): $n = 8$; IB (Intermediate Bimodal): $n = 6$; II (Intermediate Imager): $n = 2$; AB: (Analytic Bimodal): $n = 2$; WI: (Wholistic Imager): $n = 1$; IV: (Intermediate Verbalizer): $n = 1$	

no significant differences among the number of people in each category. In other words, the results show that even though there were more Analytic people than Wholistic ones, there was also considerable number of participants who were in between Analytic and Wholistic. The results also showed that more than half the participants can be considered as an Imagery person, and there were significantly more Imagers than Verbalizers. Nevertheless, there was also a good portion of the participants who are Bimodal. Combining two dimensions together, 40% of the participants were AI ($n = 8$), 30% of the participants were IB ($n = 6$), where as the remaining 30% were in II, AB, WI, or IV.

In addition, no statistically significant differences were found in the VICS scores between self identified Imagers versus non-Imagers (U = 37.50, z = -.912, p = .36). Meanwhile, both age (r = -.55, p = .016) and research length (r = -.49, p = .041) were found to correlate negatively with the VICS scores. This means that in this participant group, Imagers tended to be younger and had less research experience. Self-identified Imagers were also significantly younger (U = 9.00, z = -2.95, p = .002), had shorter ADS use experience (U = 17.50, z = -2.44, p = .015) and research experience (U = 8.00, z = -2.851, p = .004) than those who self-identified as non-visual persons.

6.2 Affective and cognitive experiences

When performing their tasks, these 20 participants were most frequently involved in the mode of thinking (sum = 202), though they also got confused and frustrated quite often. They were least frequently happily surprised (sum = 42). Figure 4 shows the total occurrences of various affective and cognitive points across all participants.

Imager scores were found to be negatively correlated with the point of confusion (r_s = -.46, p = .04) and surprise (r_s = -.72, p = .00), whereas Analyzer scores were positively correlated with point of excitement (r_s = .48, p = .03). Participants with AI style were found to be less frequently surprised (U = 17.00, z = -2.44, p = .015) or pondered (U = 22.50, z = -1.98, p = .048) less frequently than non-AIs. Meanwhile, participants who claimed to be Imagers were found to get frustrated less frequently (U = 8.00, z = -3.17, p = .002) or hesitated less frequently (U = 16.50, z = -2.52, p = .012) than those who claimed not to be a visual person.

Non-native English speakers were found confused (U = 24.00, z = -1.97, p = .048) and thought (U = 23.50, z = -2.01, p = .044) more frequently than native English speakers. Age,

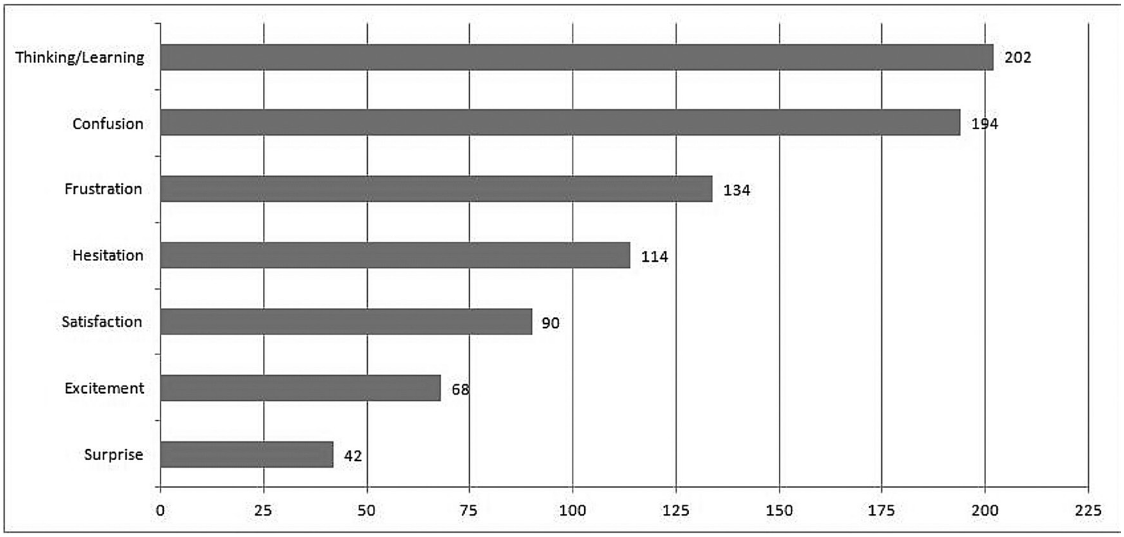

Figure 4. Total Occurrences of Affective & Cognitive Points

research length, and the length of previous ADS use were positively correlated significantly with the frequency of frustration (Age r_s = .62, p = .005; Research length r_s = .487, p = .04; ADS use length r_s = .450, p = .047) and thinking (Age r_s = .64, p = .003; Research length r_s = .64, p = .004; ADS use length r_s = .576, p = .008). Meanwhile, age was also found to correlate with the frequency of confusion (r_s = .585, p = .008), and the occurrence of hesitation (r_s = .461, p = .047). Meanwhile, participants who previously used ADS 2.0 experienced significantly fewer occasions of confusion than those who had not (U = 18.00, z = -1.99, p = .047). Furthermore, all three negative emotions (confusion, frustration, and hesitation), frequency of thinking, and query revisions (r_s = .53, p = .016) were negatively correlated with total time on task. Table 4 summarizes the significant results related to participants' cognitive and affective experiences.

6.3 Task performance

Task performance metrics include both efficiency measures (e.g., time on tasks, mouse clicks, web page changes, query revisions) and effectiveness measures (e.g., complete with ease). While Imagers scores were not significantly correlated with any performance indicators, analyzer scores were found to be negatively correlated with multiple efficiency measures such as average web page changes Tasks 3 through 5 (r_s = -.586, p = .008), time spent on web pages Tasks 3 through 5 (r_s = -.540, p = .017), time spent on apps Tasks 3 through 5 (r_s = -.540, p = .017), and time between inputs Tasks 3 through 5 (r_s = -.568,

Table 4. Impact on Affective & Cognitive Experiences

	Confusion	Frustration	Hesitation	Thinking	Excitement	Surprise
Imager scores	*r_s = -.46					**r_s = -.72
Analytic scores					*r_s = .48	
AI vs. non-AIs				*U = 22.50, z = -1.98		*U = 17.00, z = -2.44
Self-rated Imagers vs. non-Imagers		**U = 8.00, z = -3.17	*U = 16.50, z = -2.52			
Native English speaker vs. non-native English speaker		*U = 24.00, z = -1.97		*U = 23.50, z = -2.01		
Age	**r_s = .59	**r_s = .62	*r_s = .46	**r_s = .64		
Research length		*r_s = .49		**r_s = .64		
ADS use length		* r_s = .45		**r_s = .58		
Used ADS 2.0 before or not	*U = 18.00, z = -1.99					
Overall time on task	**r_s = .59	**r_s = .64	*r_s = .51	**r_s = .78		

* p < .05, ** p < .01.

p = .011). This suggests that Analytics tended to be more efficient on these common tasks than non-Analytics. Mann Whitney U tests confirmed that compared to non-Analytics, Analytic participants made significantly less web page changes (U = 18.50, z = -2.175, p = .030) and spent shorter time between inputs (U = 21.00, z = -1.960, p = .050). Mann Whitney U tests also showed that AI participants spent significantly less overall time on tasks than non-AI participants (U = 21.00, z = -2.083, p = .037).

In this study, the distinction between those participants who were self perceived as Imagers and those who did not perceived themselves as a visual person turned out to be a strong indicator for performance measures. Participants who self-identified as an Imagery person were also found overall to spend less time on tasks (U = 18.00, z = -2.39, p = .017), had less mouse clicks (U = 20.50, z = -2.038, p = .042), spent less time on apps (U = 19.00, z = -2.12, p = .034), spent less time between inputs (U = 15.00, z = -2.45, p = .014), and did less revisions to their queries (U = 19.50, z = -2.30, p = .022). Note that style related variables seemed to have significant results on efficiency measures, but none appeared to have significant impact on effectiveness.

With regard to demographic attributes, age, research length and ADS use length all positively correlated with a variety of efficiency measures, including Time on task (Age r_s = .795, p = .000; Research length r_s = .678, p = .002; ADS use length r_s = .654, p = .002), Mouse click (Age r_s = .723, p = .001; Research length r_s = .593, p = .010; ADS use length r_s = .703, p = .001), Time spent on web pages (Age r_s = .751, p = .000; Research length r_s = .655, p = .003; ADS use length r_s = .633, p = .004), Time spent on apps (Age r_s = .800, p = .000; Research length r_s = .711, p = .001; ADS use length r_s = .665, p = .002), and Time between inputs (Age r_s = .735, p = .001; Research length r_s = .700, p = .001; ADS use length r_s = .622, p = .004). In addition, age was found to negatively correlate with Complete with ease (r_s = -.508, p = .026), and positively associated with Complete with great difficulty (r_s = .614, p = .005). Research length was positively correlated with the frequency of query revisions Tasks 3 through 5 (r_s = .474, p = .047). This means people who were more senior, who used ADS longer or in the field longer were less efficient or effective in using ADS 2.0 than younger participants with less experience with the systems or in the field.

Meanwhile, participants who had used ADS 2.0 before experienced significantly more occasions of completing tasks with ease than people who didn't (U = 14.00, z = -2.318, p = .02). Those participants also experienced fewer occasions of completing tasks with some difficulty (U = 15.50, z = -2.201, p = .028). Table 5 summarizes results related to task performance.

The frequencies of query revisions were found to correlate significantly with multiple efficiency and effectiveness measures, and they also correlated positively with the frequency of frustration. Table 6 contains relevant statistics.

6.4 Post session evaluation

During the post session interview, participants described their overall impression and experiences of using ADS 2.0 during the research sessions and their likelihood of using various visualization tools in the future. Most participants appreciated

Table 5. Impact on Task Performance

	Efficiency measures		Effectiveness measures		
	Time on task	**Other efficiency measures**	**Complete w ease**	**Complete w some difficulty**	**Complete w great difficulty**
Analyzer scores		Avg webpage changes T3-5: ** r_s = -.59; Time spent on webpages T3-5: * r_s = -.54; Time spent on apps T3-5: * r_s = -.54; Time between inputs T3-5: * r_s = -.57			
Analytic vs. non-Analytics		Avg webpage changes T3-5: *U = 18.50, z = -2.175; Time between inputs T3-5: *U = 21.00, z = -1.96			
AI vs. non-AI	*U = 21.00, z = -2.083				
Self-rate Imagers vs. non-Imagers	*U = 18.00, z = -2.39	Mouse clicks: *U = 20.50, z = -2.038; Time spent apps: *U = 19.00, z = -2.12; Time spent between inputs *U = 15.00, z = -2.45; Query revisions: *U = 19.50, z = -2.30			
Age	** r_s = .795	Mouse click: **r_s = .72; Time spent on webpages **r_s = .75 ; Time spent on apps: **r_s = .80; Time between inputs : **r_s = .74	*r_s = -.51		** r_s = .61
Research length	** r_s = .678	Mouse click: *r_s = .59; Time spent on web pages: **r_s = .66; Time spent on apps: **r_s = .71; Time between inputs: **r_s = .70; Query revision T3-5: *r_s = .47			
ADS use length	** r_s = .654	Mouse click: **r_s = .70; Time spent on web pages: **r_s = .63; Time spent on apps: **r_s = .67; Time between inputs: **r_s = .62			
Used ADS 2.0 before vs. not			*U = 14.00, z = -2.32	*U = 15.50, z = -2.20	

* $p < .05$, ** $p < .01$.

Table 6. Query Revisions, Performance Measures and Affective Experiences

	Efficiency measures		Effectiveness measures		Affective experiences
	Time on task	Other efficiency measures	Complete w ease	Complete w some difficulty	Frustration
Query revisions	* r_s = .53	Time spent on webpages: * r_s = .49; Time between inputs: * r_s = .50	** r_s = -.72	** r_s = .71	** r_s = .60

* $p < .05$, ** $p < .01$.

ADS 2.0's graphics and visualization. They believed Metrics to be especially useful, and that its likelihood of being used in the future is high (M = 5.5 on a 7 points scale). Several long term users of ADS Classic commented on the learning curve of transitioning to ADS 2.0. Participants also articulated how to improve individual tools. For example, several participants wanted Metrics to have the flexibility to add authors to the chart. One participant suggested, "If you could load multiple authors, and compare them. Three authors together, for example." Another participant echoed this idea, saying "the whole point of Metrics is to compare. If you've got two people, you will need a button to bring in another person, to overlay on the same chart; that would obviously be quite useful."

Additional analyses were performed on participants' post session indication of their likelihood to use various visualization tools. It was found that participants who had used ADS 2.0 before were significantly more likely to use Word Cloud (U = 5.00, z = -3.143, p = .001). Participants who believed ADS 2.0 was better than ADS Classic had a significantly higher likelihood to use Author Network (Kruskal-Wallis Test χ^2 = 6.15, p = .046). Furthermore, the likelihood to use Word Cloud was found to correlate positively with "Complete with ease" (r_s = .541, p = .014), while correlate negatively with "Complete with some difficulty" (r_s = -.575, p = .008) and with the frequency of observed confusion (r_s = .516, p = .020). The likelihood to use Author Network is correlated positively with the occurrences of "excitement" (r_s = .447, p = .048), the likelihood to use Metrics is correlated with the frequency of mouse movement (r_s = .470, p = .049).

While a few participants had reservations of using ADS 2.0, most expressed their enthusiasm with the new interface. One participant commented, "I think it is great. I hope the problems can be resolved. All the suggestions can be implemented. I definitely like the interface a lot more than Classic." Another participant asked the researchers to "pass along the general kudos" to developers of ADS. He said, "Good work. ADS is sort of amazing how important and great it is."

It should be noted that all participants' comments and feedback regarding specific tools have been reported to ADS leaders. Some suggestions have already been adopted in the development of the new version of ADS.

7. Discussion

With regard to the research question concerning ADS core users' cognitive style, the results confirmed a strong showing of the Analytic style, which is close to the systemizing-driven style. It appears to be consistent with the results of previous research that there were more students of science that have the systemizing style than those in the humanities. On the other hand, an almost equal number of participants belonged to the Intermediate category. Even though there was only one participant that had more of a Wholistic tendency, the fact that there were a good portion of the participants that were in between Analytic and Wholistic suggests that the Analytic or Systemizing style is a common style in astrophysics scientists but not necessary a predominant style.

One of the significant contributions of this study is to uncover participants' cognitive traits with regard to visual processing. With more than half of the participants being Imagers, the study results might have provided counter evidence for the claim that scientists tended to resist visual distracters (Billington et al., 2007). However, the visualization functionality of the ADS system might have been perceived as part of the rules of a system, which could also be linked to the systemizing style. With only one participant as a Verbalizer, the scientists in this study showed a strong Imagery-oriented thinking ability, but there were also 40% of the participants who were Bimodal. Similar to the finding concerning participants' Analytic-Wholistic spectrum, the second majority of the participants had a middle ground style – Bimodal, making IB (Intermediate Biomodal) the second most popular cognitive dimension of this group.

When combining the style dimensions, the majority of the participants belonged to the AI (40%) or IB style (30%). It is interesting how astrophysicists involved in this study had a middle to high level Analytic style as well as a middle to high level Imagery style. Since the Analytic orientation seems to be part of physical scientists' characteristics, an Imagery-driven trait would enable ADS users to process visualization part of the retrieval rather comfortably. According to Riding and Rayner (1998), 16 year old AI pupils were better in their performance of scientific tasks than their peers who possessed different styles. In this study, with over half of the participants being Imagers, while exactly half were Analytics, ADS users appeared capable of thinking both in terms of diagrams and charts and focusing on specific details in scientific experimentations and observations.

In terms of the impact of cognitive style on task performance, it was shown that the style dimensions have some significant impacts on several efficiency measures. Analytic scores were correlated negatively with multiple time-based measurements, and people who had the AI style completed tasks in a shorter duration than non-AI participants. The self-identified Imagers performed more efficiently through multiple counts (e.g., time on task, mouse clicks, time spent on web pages, query revisions) than those who did not claim to be a visual person. However, in this study, all style variables did not uphold significant impacts on levels of difficulties that participants were experiencing.

The cognitive style seemed to have interesting correlations with participants' emotional and cognitive experiences. While the Imagery scores were negatively correlated with frequency of confusion and surprise, the Analytic scores were found to positively correlate with points of excitement. It appears reasonable that a visually-oriented person would be less confused or surprised at the visualization displays, one would assume an Analytic user would be more locally focused and more level-headed, rather than being more excited than non-Analytic users about the visual functionalities. It is, nevertheless, quite interesting to find out that Analytic users found visualization exciting.

When combining two style dimensions together, AI participants were found to be less frequently engaged in thinking or being surprised than non-AI participants. It might be the combined ability of focusing on details while seeing the full picture of the visualization display enabled them to have a quick understanding of the system for them to be greatly surprised or having to think further. It is also interesting that self-claimed Imagers were found to be less frustrated or hesitated when they interact with the search interface and its visualizations. In this study, there seemed some cognitive factor that associates the self-identified Imagery group, making them both performing more efficiently and experiencing less negative emotions than those who did not identify themselves as a visual person.

Previous user experience made a fairly remarkable impact on task performance with regard to levels of difficulty. Those who had used ADS 2.0 before had more tasks completed with ease and fewer tasks completed with some difficulty than participants who had not used ADS 2.0 before the research session. It is also seems sensible that participants who had used ADS 2.0 before were less confused than those who had not used it before. However, having used ADS 2.0 before did not have any impact on the efficiency measures of task performance, which is the opposite of the impact by the Analytic dimension of cognitive style or self-identified Imagery style. These cognitive styles had significant influences on efficiency but little on effectiveness.

In this study, demographic attributes such as age, research length, and the length of previous ADS use all positively correlated with time on task, mouse clicks and several other time-based efficiency measures. This confirms the first part of Hypothesis 3 which states that younger participants are faster performers. In addition, age was indeed found to correlate negatively with "complete with ease" and positively with "complete with great difficulty," which confirms the second part of Hypothesis 3.

A good number of demographic attributes were found to have significant results with mostly negative emotional experiences. The non-native English speakers had experienced more confusion and thought more frequently than native English speakers. Age, research length, and ADS previous use length all correlated positively with the frequency of frustration and points of thinking. What's more, age correlated positively with points of confusion and hesitation. The fact that age and length of experiences were associated with negative affective experiences might suggest that people who have used ADS earlier on from its Classic version to its new versions would have different mental models of the system structure and visualization functionality, and they needed more mental effort to learn about the new structure. Since age is negatively associated with "complete with ease," it is consistent that it had positive correlations with occurrences of all three negative emotional experiences.

8. Conclusion

Overall, results of the study helped uncover the cognitive style profile for astrophysicists who are core users of ADS. With the half of the participants having the Analytic style, which to some degree confirms with previous findings on science students' systemizing-orientation, the results also showed that over half of the participants were Imagery-driven and hence would be suitable to handle visualization-based retrieval displays. This is the one of the first studies that reveals that the majority of the astrophysics participants did not have the Verbalizer or Wholistic end of the style, and that they are either AI (Analytic Imagery) or IB (Intermediate Bimodal). Further studies are needed to confirm whether the distribution of cognitive style patterns detected from this study remain to be true with a larger sample as well as scientist from other fields beyond astrophysics. With a consistent finding regarding scientists' cognitive styles will inform future design of retrieval systems for scientific users.

In this particular study, cognitive styles including the self-claimed ones seemed to have impact only on the efficiency dimension of the task performance. Factors that impacted significantly on the effectiveness component of the task performance included demographic attributes such as age and past use experiences. It would be interesting to explore in the future research why cognitive patterns influence the efficiency but cast no substantial impact on the levels of difficulties for scientists.

Both cognitive styles and demographic attributes had some varying levels of connections with emotional and cognitive experiences. With Imagery scores negatively associated with points of confusion and surprise, and self-identified Imagers experienced fewer frustration and hesitations than those who did not consider themselves as an Imager, it would be worthwhile to expand the research to verify whether Imagery-oriented styles, be it objectively tested or self-claimed, indeed better facilitate the comfortable level when scientists interact with visualizations of a bibliographic retrieval system.

Overall, the discovery of ADS users' cognitive styles and their behavioral patterns has helped the future development of the ADS system. More importantly, this study has made the first step towards establishing a cognitive style profile for astrophysics scientists, exploring the correlation between users' cognitive style and their task performance and emotional experiences. Greater insights might be gained through examining the occurrences of affective/cognitive behaviors and their emerging contexts in more depth. Further qualitative-oriented analysis of participants' think-aloud comments and their nonverbal behaviors will help to provide a fuller, more contextual-based understanding of relationship patterns among cognitive styles, task performance, affective and cognitive experiences, and interaction behaviors as reported in this paper.

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認知風格、人口統計屬性、任務績效及情感體驗：一項關於天文物理資料系統核心使用者的實證研究

Cognitive Styles, Demographic Attributes, Task Performance, and Affective Experiences: An Empirical Investigation into Astrophysics Data System (ADS) Core Users

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摘　要

美國國家航空暨太空總署（NASA）與史密松天文台（SAO）同建的天文物理資料系統（ADS）是天文物理學者重點使用的數位資料庫。ADS的視覺介面包括作者引文網路、文章網路、文字雲及引文計量。本研究由20個ADS核心使用者參與可用性測試，測探認知風格與個人背景對任務績效和情感體驗的影響。研究結果揭示參與者多屬評析及圖像思維風格、過半的參與者自評為圖像思維者。評析傾向及自認圖像思維者，對於任務完成效率有統計學意義的影響。年齡及之前使用經驗對任務執行功效有顯著影響。圖像思維指數於困惑次數有負向關係，而自認圖像思維者比非自認參與者較少體驗到沮喪和猶豫。本研究對深度探討科學家使用者的思維型態和情感體驗有啟發，而對促進ADS視覺介面的改建有幫助。

關鍵字：科學家認知風格、任務績效、人口統計屬性、情感及思維體驗

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