# REASONING OF CONFLICTING SCIENCE INFORMATION

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# Introduction

- With the development of information technologies, different opinions, standpoints or controversial information about scientific facts or science-related public issues have become easily accessible through the Internet.
- Being a citizen in the information era, it is critical to have the ability to justify science-related information
- A big challenge for science educators today is how to provide learning environments that can help to promote the habits of making justification when students receive various information from outside-school sources
- The first thing we need to do is to know more of students' reasoning behaviors and find out the factors influencing their behaviors

# Problems to be discussed

- When receiving conflicting science information
  - What would people get from the reading of the conflicting information?
  - Is there any interaction between information taken by the readers and their reasoning behaviors?

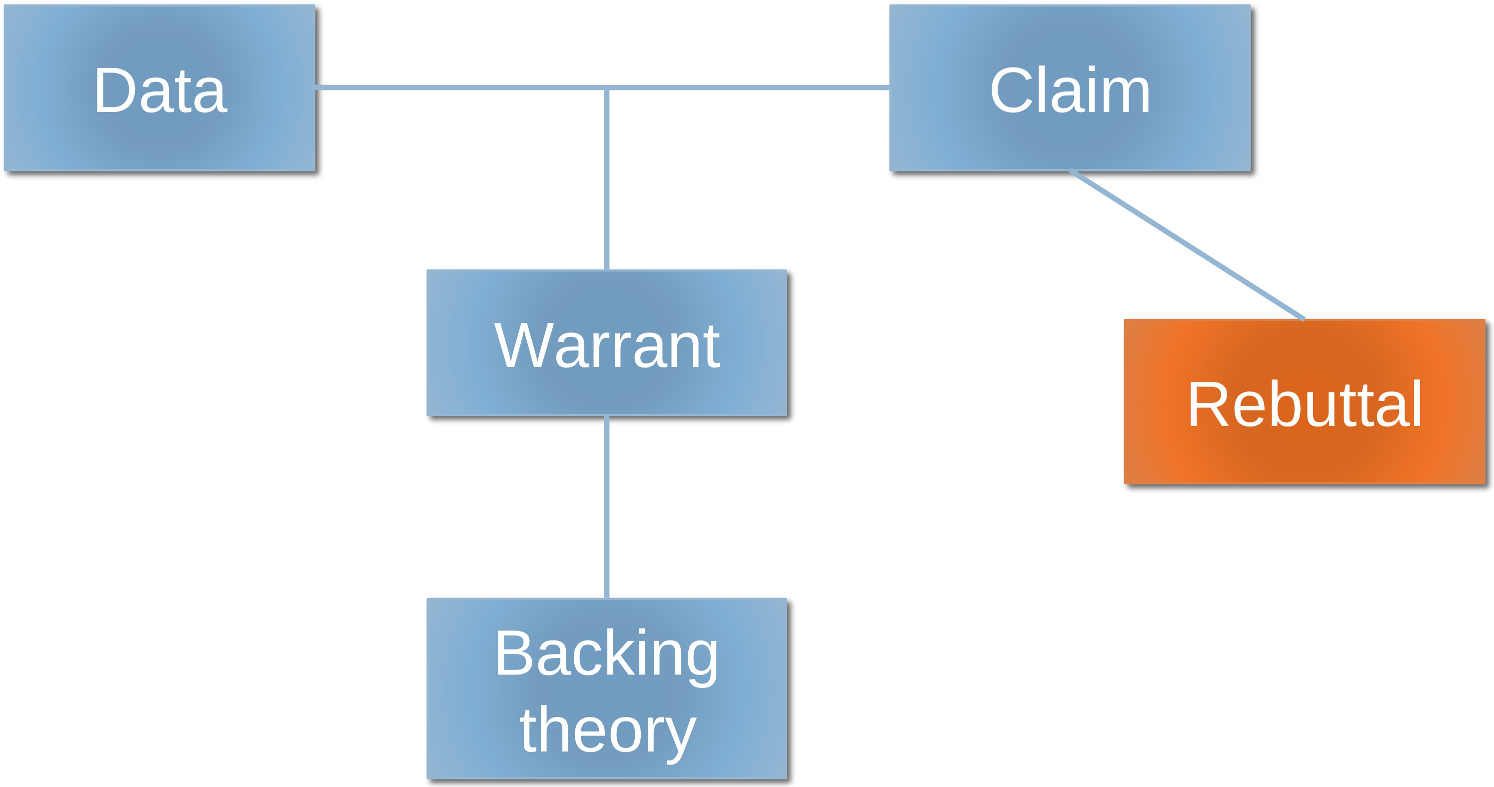
# Objective of the study

- The main goal of this study was to investigate how students' reading of conflicting science information was affecting their scientific reasoning behaviors

# Scientific reasoning and argumentation

- The ability to justify science-related information is related to scientific reasoning and argumentation
  - As argued by Duschl and Osborne (2002), the rationality of science is founded on the ability to construct convincing arguments that relate explanative theories to observable evidence
  - In Science, scientific argumentation is regarded as the core process of scientific reasoning
  - In the problem contexts involving uncertain information related to science, scientific reasoning takes the form of informal reasoning (Sadler, 2004)

# Toulmin’s model argument



# Reasoning and problem solving

- From the cognitive perspective, a person thinks and reasons when he/she encounters a problem
- The theory of problem solving states that a problem is solved through three stages, **namely representing the problem** by examining the task environment**, forming a problem space**, and **finding the problem solution** through effective searching in the problem space (Newell & Simon, 1972).
- Accordingly, how people think and reason out problems or issues is related to their understanding of the relevant information that they can access

# Reasoning and information processing

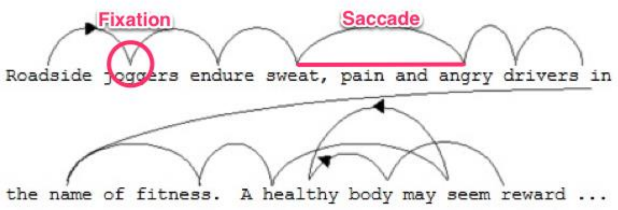
- In sum, when individuals are engaged in problem solving, thinking or reasoning, they will experience the process of information processing (**an attempt to represent the problem**).
- Hence, analyzing how the task-related information is processed will help us gain further insights into problem solving or reasoning behaviors.
- However, while science educators make use of various materials to encourage the practices of scientific reasoning skills, little is known about how the materials are read and processed and how the information processing may affect the performance of scientific reasoning

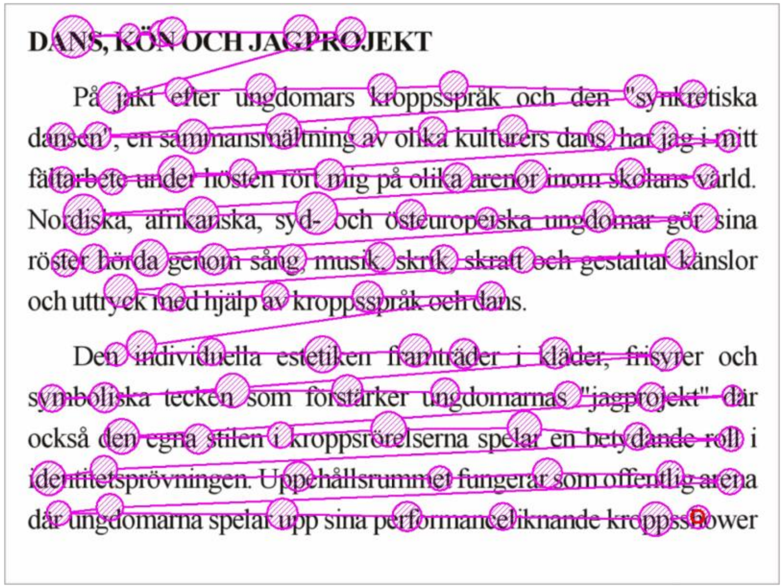
# Exploring the process of reading

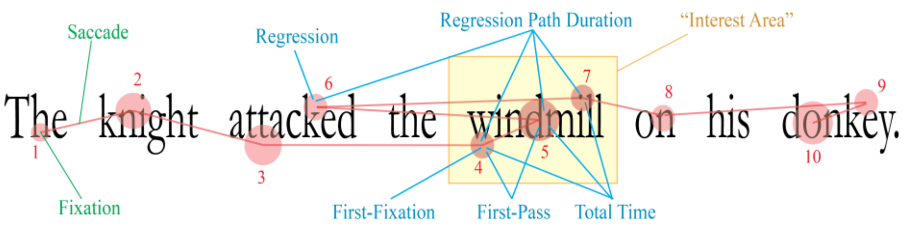
- In the reading and information processing research, the **eye tracking technology**, which is used to disclose cognitive mechanisms and map cognitive processes, has been extensively applied for decades
- The theoretical ground for the eye tracking method is the eye-mind assumption
  - There is a close relationship between what the eyes are looking at and what the mind is engaging with (Just & Carpenter, 1980)
  - Where there is fixated is processed
- Based on the eye-mind assumption, the eye tracking method was developed. By the method, reading psychologists have identified many eye movement measures revealing various cognitive processes

# The basic eye movement patterns and variations

- Fixation
  - Information processing
- Saccade
  - No information processing
- With time of fixation,  saccade length and directions, and positions of attention, various eye movement measures can be generated



# Use of eye tracking method in educational research

- Although the development of the eye tracking technology is quite mature, its use in educational research has increased more rapidly only in the past few years (Lai et al., 2013)
- By combining the eye tracking method and an interview procedure that probes reasoning behavior, the association between the online process of science reading and offline behavior of scientific reasoning can be examined

# Research questions

1. When encountering the disputed issue of the prediction of earthquakes, how do students perform the scientific reasoning skills in terms of coordinating theory and evidence, rebutting, and identifying supporting evidence?
2. When reading conflicting information regarding earthquake predictions, how do students distribute their visual attention (in terms of the eye movement patterns presented in the next section) to the text?
3. Do students of different background knowledge show different reasoning performances?
4. Do students of different background knowledge show different visual attention distributions on the text?
5. How do students' visual attention patterns interact with their reasoning performances?

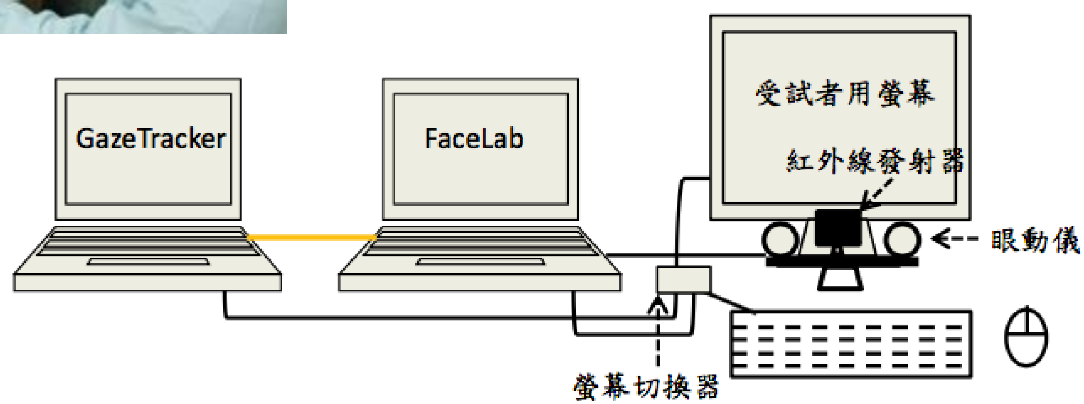
# Subjects

- A total of 25 university students, 14 females and 11 males aged from 21 to 24 years old from various science departments in a national university in Taiwan voluntarily participated in the study
- Given that the topic in discussion is “earthquake,” 13 of the participants who were majoring in earth science were assigned to the “relevant background knowledge” (RBK) group, while the remaining participants belonged to the “irrelevant background knowledge” (IBK) group

# Apparatus

- FaceLAB 4.6 eye tracking system with 60Hz sampling rate
  - A non-intrusive and fully automated eye and head tracking system

- The identification of fixation is determined by the analytic software, GazeTracker.
  - According to psychological studies the average fixation duration is about 200 to 250 ms (Rayner, 2009)
    - This study adopted 200 ms as a fixation standard



# Definitions for the eye movement measures
## (e.g., Rayner, 1998; 2009; Underwood, 1998)

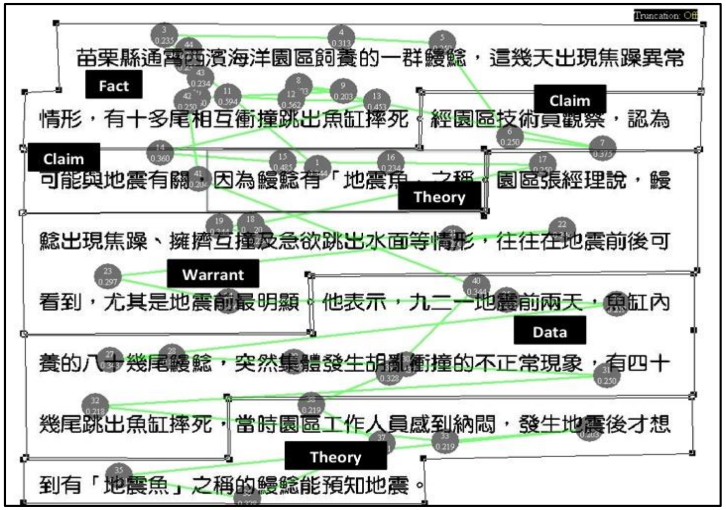
| Eye-movement measure | Definition | Indication |
|---|---|---|
| Total fixation duration (TFD) | Sum of durations of all fixation points on a page or text area | Time needed to processing information on a page, indicating cognitive attention to the page of text areas |
| Percentage of time fixated related to total fixation duration (PTFTFD) | Fixation duration in a text area divided by total fixation duration | Attention distributions (i.e., proportions of fixation durations) for different text areas. In general, the higher PTFTFD, the more difficult the text area. |
| First-pass reading time (FPRT) | Sum of all fixation durations after entering and before leaving a text area. This measure shows the first time that a reader looks at a text area | The initial time used to decode or recognize information in a text area. This measure indicates text uncertainty and early cognitive efforts. |
| Regression | Sum of all backward fixations in a text area | Difficulty of integrating information encountered in the later processing stage |
| Average fixation duration (AFD) | Average duration of a fixation point | The overall cognitive effort in decoding information suggesting text difficulty |

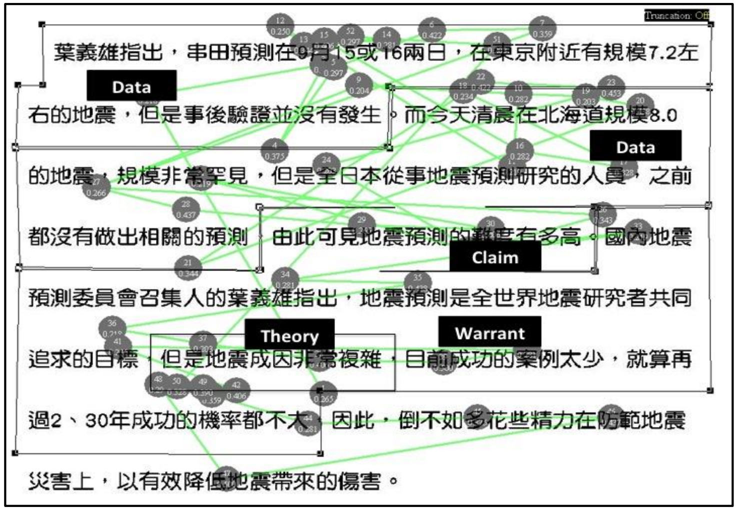
# Reading material

- Two news reports concerning whether earthquakes can be predicted were selected from the database of a renowned news source in Taiwan. The two reports give contrary viewpoints held by different expert groups about the possibility of making earthquake predictions
  - One group of experts claimed that a certain kind of fish could predict earthquakes (*referred to as the fish report*).
  - The other group who investigated the electrical discharges in clouds argued that prediction is nearly possible (*referred to as the cloud report*). The cloud report contain an unfamiliar scientific experiment
  - Both groups provided data and explanations for their arguments.

# Areas of Interest (AOIs)

- To analyze readers’ visual attention, each text page was divided into several text areas of interest (AOIs) for analysis
  - Including descriptions of data, claims, facts, warrants and theories,
    - These AOIs have been identified as key components of scientific argumentation (Toulmin, 1958).



# Interview for scientific reasoning

- Participants were interviewed after the eye-movement investigation. They were asked to respond to three questions. These questions aimed to reveal the students' abilities to coordinate theory and evidence, to rebut, and to identify evidence
  - "*Which report do you believe more? Why*?"
    - Coordination of theory and evidence
  - "*Why don't you believe the other report*?"
    - Rebuttal
  - "*What can the expert group in the report that you don't believe do to make you believe their claim*?"
    - Identifying supporting evidence

# Data analysis

- Eye movement measures were abstracted by GazeTracker to indicate the time and cognitive attention needed to process the text information
  - Total reading time in an AOI (TTZ), total fixation duration in an AOI (TFDZ), first-pass reading time (FPRT), and average fixation duration (AFD), regression
- Students' interview responses underwent content analysis
  - Kuhn's analyses of scientific reasoning (Kuhn, 1988, 1991) provide the basis of the coding scheme
  - Three reasoning skills were coded, including the coordination of theory and evidence, rebuttal, and identifying evidence

# Data analysis

- Descriptive statistics were used to present the overall trends of the students' eye movement patterns and reasoning performance.
- Comparisons between different text areas were analyzed by t tests.
- Associations between eye movements and reasoning were analyzed by Chi-square analysis and ANOVA.

# Procedure

- The reading material as introduced previously was displayed on a 17-inch computer screen with 1,024x768 resolution. The eye tracking system, placed about 60cm away from the seats
- Every participant had to perform the eye tracker calibration before the reading task. Those who passed the calibration could then proceed to the reading task.
- The participants read the fish report first and then the cloud report. They read the material at their own pace. The eye tracker concurrently recorded their eye movements while reading
- After the eye tracking experiment, the participants were interviewed to probe their reasoning performance

# Performance of scientific reasoning

| Reasoning skills | Category | N (%) |
|---|---|---|
| Coordination of theory and evidence | State clearly one's claim and also point out specifically the supporting evidence for their idea | 12 (48%) |
| | Did not state personal claim or did not point out the supporting evidence for one's claims | 13 (52%) |
| Identifying evidence | Specify direct evidence that can link the cause and the outcome | 11 (44%) |
| | Give additional factors that are not directly related to the correlation between the cause and outcome but still support the existence of the cause and outcome | 6 (24%) |
| | Give no evidence or evidence unconnected to theory | 8 (20%) |
| Rebuttal | Clearly point out the problems of the other study and also provide alternative or counter arguments | 5 (20%) |
| | Point out the problem of the other study but do not provide any alternative or counter arguments | 13 (52%) |
| | Give no or unrelated arguments about the study | 7 (28%) |

# Interactions between reasoning skills and the effect of background

- Chi-square analyses
  - Those who were able to coordinate theory and evidence showed a higher chance of identifying the supporting evidence for personal claims (Pearson $\chi^2 = 9.26$, $p = 0.01$)
  - Those who were able to provide clearer rebuttals could pinpoint better the supporting evidence (Pearson $\chi^2 = 11.27$, $p = 0.024$)
  - Relevant background (RBK) students tended to better coordinate the theory and evidence (Pearson $\chi^2 = 3.22$, $p = 0.081$)

# Eye movement patterns in different AOIs (Table 1)

| Area of interest | Number of characters | | TTZ Sec. (per character ms) | | TFDZ Sec. (per character ms) | | FPRT Sec. (per character ms) | | PTFTFD %. (per character ms) | | Number of Regressions | | AFD (ms) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *(AOI)* | *Fish* | *Cloud* | *Fish* | *Cloud* | *Fish* | *Cloud* | *Fish* | *Cloud* | *Fish* | *Cloud* | *Fish* | *Cloud* | *Fish* | *Cloud* |
| *Fact* | *43* | *15* | 4.37 | 1.37 | 2.51 | 0.84 | 1.79 | 0.63 | 23.34 | 5.37 | 0.48 | 0.32 | 289 | 265 |
| | | | (101.0) | (91.6) | (61.7) | (56.3) | (41.4) | (42.4) | (0.54) | (0.36) | | | | |
| *Claim* | *61* | *45* | 4.87 | 5.04 | 2.12 | 2.91 | 1.54 | 1.44 | 12.38 | 14.45 | 0.28 | 0.35 | 269 | 278 |
| | | | (82.7) | (112.1) | (**47.6***) | (64.6) | (26.2) | (32.0) | (0.41) | (0.64) | | | | |
| *Data* | *96* | *156* | 8.42 | 17.01 | 5.05 | 10.06 | 1.29 | 5.91 | 23.46 | 29.24 | 0.34 | 0.63 | 298 | 286 |
| | | | (87.7) | (109.0) | (**52.6***) | (64.5) | (**13.8***) | (***37.9+***) | (0.49) | (0.56) | | | | |
| *Warrant* | *123* | *70* | 12.43 | 6.50 | 7.59 | 3.89 | 2.67 | 2.03 | 21.61 | 32.75 | 0.42 | NA | 284 | 289 |
| | | | (**101.0***) | (92.8) | (**61.7***) | (55.6) | (37.5) | (29.0) | (0.53) | (0.47) | | | | |
| *Backing theory* | *73* | *54* | 6.78 | 7.64 | 3.79 | 4.51 | 1.85 | 1.86 | 34.37 | 34.37 | 0.60 | NA | 297 | 280 |
| | | | (92.9) | (**141.4***) | (51.9) | (**83.6***) | (26.2) | (34.4) | (0.47) | (**0.64***) | | | | |

Notes:

(1) TTZ = Total time in LZ; TFDZ = Total fixation duration in the AOI (s); FPRT = First-pass reading time; PTFTFD = Percentage of time fixated related to total fixation duration; AFD = Average Fixation Duration;

(2) *indicates that the eye movement measure in a particular AOI is statistically significant compared to that in other AOIs.

(3) + $p < 0.1$

# Summary of Table 1

- The subjects spent more time processing (reading) facts and warrants when reading the ***fish*** report, while more processing time was allocated to claims, data, and backing theories in the ***cloud*** report
- Participants felt more uncertain about the cloud study (indicated by FPRT, a measure of early processing)
- Students tended to go back more to the backing theory for the fish report while going back more to the data for the cloud report

# T test analysis

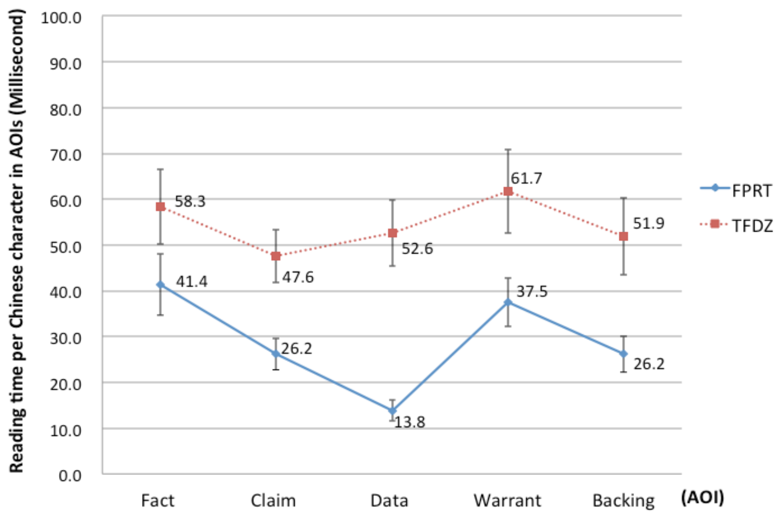
- When reading the fish report
  - The total reading time (TTZ) and total fixation duration on warrants (TFDZ) were significantly higher than those for data and claims (i.e., time needed to comprehend warrant is higher than the time for data and claims)
    - $t(25) = 2.34$ and $2.16$, $p < 0.05$ respectively for TTZ; $t(25) = 2.09$, $p < 0.05$ and $t(25) = 6.31$ $p < 0.01$, respectively for TFDZ
  - No significant differences in attention distribution (PTFTFD) were found among different text areas
  - In the early stage of reading (FPRT), the reading of the data required significantly less cognitive effort than did the reading of either facts or warrants
    - $t(25) = -4.16$ and $-4.51$, respectively, $p < 0.01$
  - Students went back more to the backing theory, suggesting that they might have had difficulty integrating theory with the other text components

# T test analysis

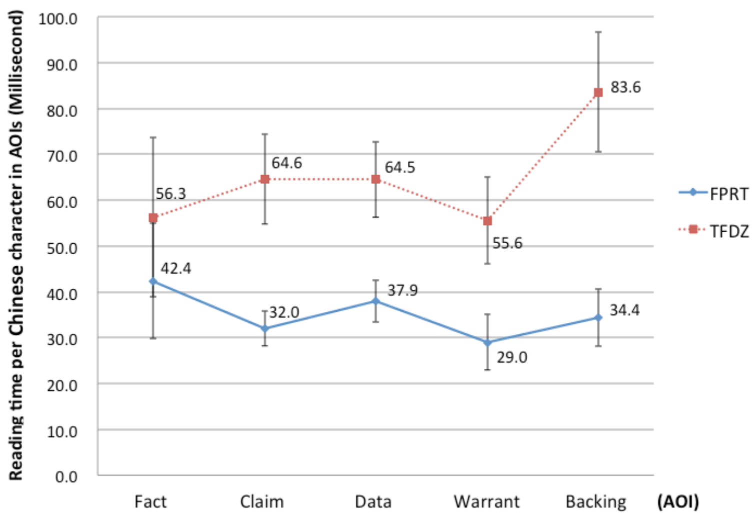
- When reading the cloud report
  - Reading time (TTZ) for backing theory was statistically higher than that for the areas of fact, data and warrants
    - $t(25) = 2.39, 2.78$ ($p < 0.05$) and 3.97 ( $p < 0.01$), respectively
  - Subjects' attention distribution (PTFTFD) on backing theory was significantly higher compared to warrants and fact,
    - $t(25) = 2.49$ ($p < 0.05$) and $t = 2.89$ ($p < 0.01$), respectively
  - Early stage of reading (FPRT) on data was slightly higher than that on warrants, indicating higher cognitive efforts needed for data
    - $t(25) = 1.77$, $p < 0.1$
  - The number of regressions was higher for data

# Influence of context on reading

- The context effect was evident on eye movement patterns




Fish




Cloud

# Background knowledge and eye movement patterns

| Context | Eye movement measures | Background difference in the area of Interest (AOI) |
|---|---|---|
| Fish report | TTZ | **Fact**: RBK > IBK, F(1, 23)=4.15, p=0.053 |
| | TFDZ | **Fact**: RBK > IBK, F(1, 23)= 6.00, p=0.022<br>**Claim**: RBK > IBK, F(1, 23)=3.28, p=0.083<br>**Backing**: RBK > IBK, F(1, 23)=3.92, p=0.060 |
| | PTFTD | **Backing**: RBK > IBK, F(1, 23) =3.08, p=0.093 |
| | AFD | **Claim**: *IBK > RBK*, F(1, 23)=3.91, p=0.061<br>**Data**: *IBK > RBK*, F(1, 23) = 4.07, p=0.056<br>**Warrant**: *IBK > RBK*, F(1, 23)=5.31, p=0.031 |
| Cloud report | TTZ | **Fact**: RBK > IBK, F(1, 23)=3.87, p=0.061<br>**Data**: RBK > IBK, F(1, 23)=4.79, p=0.039 |
| | TFD | **Fact**: RBK > IBK, F(1, 23)=4.88, p=0.037<br>**Claim**: RBK > IBK, F(1, 23)=3.44, p = 0.076<br>**Data**: RBK > IBK, F(1, 23)=6.14, p=0.021 |
| | PTFTD | **Fact**: RBK > IBK, F(1, 23)=6.23, p=0.020 |
| | AFD | **Warrant**: *IBK > RBK*, F(1, 23)=3.76, p=0.065 |

# Reasoning performance and eye movement measures (The fish report)

| Reasoning skills (Categories) | Eye movement measures | Difference in the area of interest |
|---|---|---|
| Coordination of theory and evidence (Able and unable) | TTZ | Claim: Able > Unable, $F(1, 23) = 4.084$, $p = 0.055$<br>Data: Able > unable, $F(1, 23) = 4.077$, $p = 0.055$<br>Warrant: Able > Unable, $F(1, 23) =3.47$, $p = 0.075$<br>Backing: Able > Unable, $F(1, 23) = 3.45$, $p = 0.075$ |
| | TFDZ | Claim: Able > Unable, $F(1, 23) = 5.00$, $p = 0.035$<br>Data: Able > unable, $F(1, 23) = 3.85$, $p = 0.062$<br>Warrant: Able > Unable, $F(1, 23) =3.52$, $p = 0.073$<br>Backing: Able > Unable, $F(1, 23) = 2.95$, $p = 0.099$ |
| Rebuttal (Full, partial and no) | FPRT | Fact: Full > Partial & No, $F(2, 22) = 4.07$, $p = 0.031$<br>Data: Full > Partial & No, $F(2, 22) = 2.58$, $p = 0.098$<br>Backing: Full > Partial , $F(2, 22) = 2.75$, $p = 0.086$ |
| Identifying valid evidence (Genuine, external and non) | PTFTFD | Warrant: Genuine > External,<br>$F(2, 22) = 3.20$, $p = 0.060$ |
| | AFD | Warrant: Genuine > Non $F(2, 22) = 3.46$, $p = 0.050$ |

# Reasoning performance and eye movement measures (The cloud report)

| Reasoning skills (Categories) | Eye movement measures | Difference in the area of interest |
|---|---|---|
| Coordination of theory and evidence (Able and unable) | TTZ | Claim: Able > less able, $F(1, 23)=5.32$, $p=0.030$<br>Data: Able > Less able, $F(1,23) = 3.05$, $p = 0.094$<br>Warrant: Able > Less able, $F(1, 23)=6.83$, $p=0.016$ |
| | TFD | Claim: Able > Less able, $F(1, 23)=3.90$, $p=0.060$<br>Warrant: Able > Less able, $F(1, 23)=4.69$, $p=0.041$ |
| | FPRT | Backing: Able > Less able, $F(1, 23)=4.67$, $p=0.041$ |
| Identifying valid evidence (Genuine, external and non) | TTZ | Backing: Genuine > External, $F(2, 22)=4.05$, $p=0.032$, |
| | TFD | Backing: Genuine > External, $F(2, 22)=3.25$, $p=0.058$ |
| | PTFTFD | Backing: Genuine > External, $F(2, 22)=7.08$, $p=0.004$ |
| | FPRT | Backing: Genuine > External & Non, $F(2, 22)=3.64$, $p=0.043$ |

# Discussion

- The percentages for performing the skills were low
  - Most of the participating subjects had not developed a mature reasoning competence that could help them make rational judgments of conflicting information
- The Chi-square analyses found that these different argument skills interact explicitly with each other
  - The argumentation skills might have been developing as a whole system

# Discussion

- The skill of coordinating theory and evidence was found to interact marginally with students' academic background
  - Students' background knowledge had a certain but limited impact on their reasoning performance
  - It suggests that the practice of scientific reasoning skills as explored in this study is not necessarily related to domain training
  - Alternatively, it was possible that the reading material contains information that is either indirectly related to earth science (the fish irritation) or unfamiliar to learners in the field of earth science

# Discussion

- The eye movement data showed that students did not distribute their attention equally to different text components classified as the four basic elements of scientific argumentation
- When reading the cloud report containing a complicated or unfamiliar research design, the readers displayed higher uncertainty (FPRT) about the meanings of the data and backing theories, but less uncertainty on warrants. The trend was just the opposite for the reading of the fish report
  - The higher initial cognitive effort on data might suggest the reader's difficulty in building a mental representation of data that can be linked to the making of valid arguments

# Discussion

- The findings of FPRT suggest that the initial decoding of the meanings of data and backing theories is crucial for understanding the scientific reports.
- Analysis of the students' backgrounds indicated that the background effect was in general more evident for the reading of information regarding facts and claims in the fish context, while in the cloud context, the background effect extended to the reading of the data
  - The effect of background knowledge on science reading was affected by the context factor
- The finding that no effect of background knowledge was found on the reading of warrants implies that understanding the causal or rational relationships between claims/assertions and evidence/data could have involved more of the domain-general ability to make causal inference

# Discussion - Cross analysis for eye movement patterns and performance of scientific reasoning

- Those who attributed higher cognitive attention to all four basic elements of scientific argumentation better performed the coordination of theory and evidence, regardless of the report context
- Relations between eye movements and rebuttals as well as identifying evidence are not consistent across different reports
- Rebuttals seemed to relate more or less to how much cognitive effort was placed initially on reading the data
  - The higher initial cognitive effort on data might suggest the reader’s difficulty in building a mental representation of data that can be linked to the making of valid arguments

# Discussion

- in the cloud context, with its unfamiliar research design, attention and early cognitive efforts spent on the backing theory were instead linked to better performance in terms of identifying evidence
  - According to Kuhn’s scientific revolution (Kuhn, 1970), theory as a paradigm, better understanding of the backing theory should lead to better performance of identif guides the design of scientific method and thus defines evidence.
- The associations between eye movement patterns and reasoning modes suggest that understanding the rational relationship between claim and data (warrants) is more important for identifying valid evidence.
- Some uncertainty in the text might encourage rebuttals when the issue is familiar or less complicated in research design

# Discussion

- Understanding the backing theory helps the selection of valid evidence when a complicated research design is involved in the to-be-discussed issue
  - Since warrants are justified by backing theory (Toulmin, 1958), the understanding of backing theory should support the understanding of warrants

# Conclusion

- When university students were asked to read and reason conflicting science information their performance of scientific reasoning corresponded to their attention distributions as well as to the early cognitive efforts paid to the text areas
- As suggested by the study findings, background knowledge, understanding of the nature of data in scientific investigation, and practices of making causal relationships together contribute to the development of scientific reasoning

# Educational implications

- Our study found that those who paid more attention to the backing theory showed better ability to identify evidence when the study under discussion involved a sophisticated experimental design
  - Accordingly, when the issue to be read involves scientific experiments that students are not familiar with, learners' attention should be directed to the backing theories
- When reading an issue with a familiar or easily understood research design, instructional attention should be placed on helping students to build the causal relationship between claims and data
- To promote this skill of rebutting, students need to have in-depth understanding of the nature of data
  - Some discussion of the meanings of theory and evidence and their relationship will help learners to clarify the nature of data
- Teachers need to be aware that although domain-specific knowledge helps individuals to understand science-related information, it does not guarantee better performance of scientific reasoning.
  - Practices make perfect.