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Tracking Student Propositions in an Inquiry System

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Abstract. We built software to support student reasoning about a phenomenon and development of hypotheses to explain it. The goal is to engage students in asking questions, generating hypotheses and testing predictions. Rashi, an intelligent tutor, tracks students' investigations (e.g., hypotheses, questions, data collection, and inferences) and helps articulate how evidence and theories are related. The tutor provides advice, such as recognizing when data does not support a hypothesis

Cases are presented in geology, biology or engineering, and students are scaffolded to use an inquiry-based approach to posit a theory to explain the situation. Generic and reusable structured tools guide students through exploration of ill-structured problem spaces, supporting student knowledge and scaffolding reasoning and diagnostic skills.

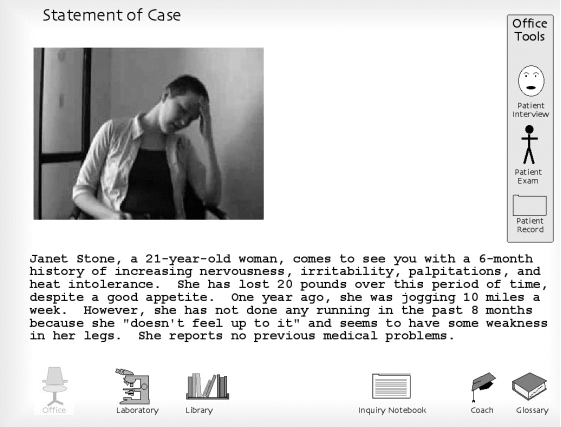
1. Inquiry Learning

Using computers to support inquiry learning presents many challenges, including how to involve students in generating new questions and support them to refine existing hypotheses, leading to further predictions and evidence gathering. Software should scaffold students to synthesize observations, request data to confirm or refute hypotheses and assess and trust the validity of their own hypotheses. The software must support observation of phenomenon and critical reflection. In the investigation of a fallen bridge, for example, students might deduce a chain of events from consequences. Biology students might diagnose a disease responsible for symptoms and confirm the diagnosis by running tests and interpreting results.

Table 1. Challenges faced by students in inquiry learning and how Rashi addresses these issues.

Challenges in Inquiry-based Learning	Issues Addressed by Rashi Inquiry Software,
Students need scaffolding to pose open ended and authentic questions.	Rashi provides multiple cases in which student diagnoses and interpretations are scaffolded (Section 3).
Students need to plan queries and do research. They should recognize salient data and distinguish known facts from questions which require further study.	Students identify data that is "known" or "should be studied" from a document library, an examination tool, a video interview (Figures 3,4, 7) and ultimately the Web.
Students need to become mindful of what they are doing and to monitor their own progress closely.	Rashi tracks students' observations, data and hypotheses. Students can move freely through activities (Inquiry Notebook, Figures 2, 5, 6).
Students should recognize when data does and does not support their hypothesis.	The coach helps student identify consistent data (Inquiry Diagram, Figure 5).

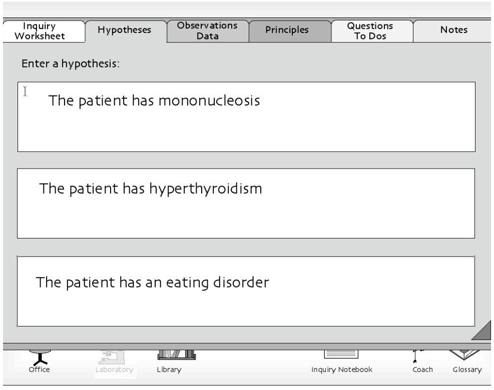
Teachers in traditional non inquiry-based classrooms ask 95% of the questions, mostly requiring short answers [1,2]. This pushes students further away from inquiry-oriented instruction. Similarly, computer-assisted teaching systems frequently deliver concepts, facts and findings, directing students to a single correct answer. Researchers have investigated inquiry learning and scientific reasoning with children and several computer tutors support inquiry learning [3-9]. Inquiry-oriented learning has proven effective in dedicated small-college settings such as Hampshire College [10-12], yet is labor intensive. Research shows that instructors using inquiry in the classroom devoted significantly more time to activities designed for the acquisition of inquiry skills and that these practices led to greater changes in students' inquiry skills and epistemologies [10,11].



Statement of Case

Janet Stone, a 21-year-old woman, comes to see you with a 6-month history of increasing nervousness, irritability, palpitations, and heat intolerance. She has lost 20 pounds over this period of time, despite a good appetite. One year ago, she was jogging 10 miles a week. However, she has not done any running in the past 8 months because she "doesn't feel up to it" and seems to have some weakness in her legs. She reports no previous medical problems.

Figure 1. Rashi presents a medical case. Icons on the bottom right are always available, providing access to the Inquiry Notebook, coach and glossary, and the latter two may be context sensitive. Icons on the bottom left are domain sensitive, available only in the medical domain. Icons on the top right represents resources available only in the "office."



Enter a hypothesis:

The patient has mononucleosis

The patient has hyperthyroidism

The patient has an eating disorder

Figure 2. Students enter hypotheses within the Inquiry Notebook on the hypothesis/data page. Tabs represent available tools and can be configured by the domain author. Navigation icons on the bottom are still available.

2. Challenges to Inquiry Learning and How the Software Addresses them

Table 1 lists some of the challenges faced by students who begin to use inquiry in the classroom and how Rashi,[1] the inquiry tutor we built, begins to meet those challenges. Facilitating inquiry-based learning is difficult for faculty, who may not know how to encourage students to work in teams, to ask their own questions, to refine them so they can be answered through analyzing evidence, and to plan to gather such evidence in the laboratory or library [10]. Students should observe a situation, formulate open questions about it, advance hypotheses and prove them by further observation or experimentation. These methods are difficult to convey via text or traditional lectures, yet conceptual understanding of process and causal effects is key to reasoning about science and the humanities. Rashi has the potential to engage students in long-term investigations and cognitive problem solving, allowing them to solve messy problems without nearby authoritative help in the form of an instructor.

This inquiry research has several goals and is unique for several reasons. The tutor helps students organize and qualify their knowledge in preparation for acquiring more

[1] Rashi was a biblical scholar who introduced inquiry methods in the eleventh century. He wrote extensive commentaries, produced queries, explanations, interpretations and discussions of each phrase and verse of the bible. Rashi's written commentary on the bible made it more comprehensible for everyday scholars. Today, these and other commentaries, assembled in the Talmud, have been extended to nearly 40 volumes and continue as a source of biblical law [13].

knowledge. To some extent, Rashi attempts to understand the reasoning behind students' hypotheses. The environment teaches investigation and problem solving skills, and elucidates the inquiry process in the process. This research is innovative in that it supports inquiry skills in three domains, civil engineering, biology and geology. The software will be evaluated with distinct student populations, and scalable to different sized post-secondary institutions (a community college, small liberal arts college and both a medium and large university) and a variety of teaching styles (traditional large lecture-based, small case-based classes). We have shown that a prototype of this infrastructure supports students' observations and interpretations in a single domain (geology) [14].

3. Brief Overview of the Inquiry Process and Rashi

Although there are many definitions of the inquiry process, it is generally characterized in terms of five phases, see Table 2. Inquiry is often described as a cycle, but it is not uncommon to find people moving opportunistically from one phase to a non-adjacent phase. Rashi does not enforce a specific order of the phases.

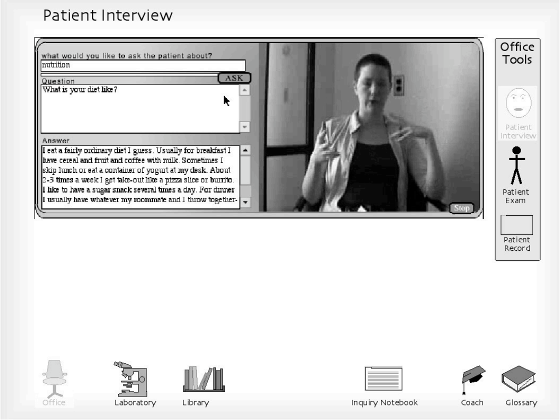
In the *Orientation and Observation Phase* students are presented with a case description and goal. In the biology module, a patient is presented with explicit symptoms, Figure 1. In this case, the patient complained of nervous symptoms, fatigue, weight loss and sweaty palms. Students try to diagnose the cause of these symptoms. In the geology case, students study photographs of a river, glacier or volcano and try to explain geological processes that might have caused the phenomenon. In civil engineering, students research a collapsed bridge and determine factors that might have contributed to its failure. Students extract whatever information is salient in the initial case description. It is important for them to recognize the difference between pure observation and inference, but both of these things may place.

In the medical case, the patient's complaint forms an initial set of symptoms from which the student begins the diagnostic process. In engineering, the collapsed bridge photo yields information about the state of the bridge after some events caused its destruction. The student sees clues in the pictures, such as abnormally high river waters.

Table 2. Five phases of the inquiry process.

Inquiry Phases	Student Activity
I	***Orientation*** to the environment. ***Observe*** what is ostensibly present without making an interpretation.
II	Form questions and propose ***hypotheses***.
III	***Collect data*** germane to the open questions and hypotheses.
IV	***Analyze data***.
V	***Communicate*** findings

The *Hypotheses Phase* scaffolds students to make predictions, provide explanations for the phenomenon, or form subgoals that might resolve some aspect of the problem, Figure 2. Often the student may think at various levels of abstraction; forming a hypothesis is very similar to forming a skeleton plan. An initial hypothesis might be quite vague such as "I think the weather caused the bridge to fail." Hypotheses of this sort will require further refinement. Alternatively, students might wish to act on intuition or experiential knowledge such as "I bet the patient has mono, because her symptoms sound exactly like my roommate's." Often new terminology must be researched and understood.



what would you like to ask the patient about?
nutrition

Question
What is your diet like?

Answer
I eat a fairly ordinary diet I guess. Usually for breakfast I have cereal and fruit and coffee with milk. Sometimes I skip lunch or eat a container of yogurt at my desk. About 2-3 times a week I get take-out like a pizza slice or burrito. I like to have a sugar snack several times a day. For dinner I usually have whatever my roommate and I throw together-

Figure 3. Students interview the patient through free text (e.g. “nutrition”) in the top field. The tutor responds suggesting possible questions and the patient answers in video and transcript.

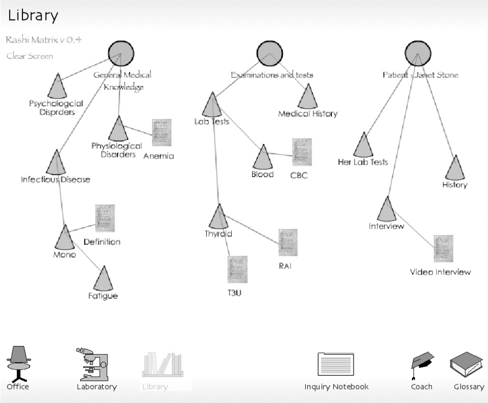


Figure 4. Students explore a library of source material in complex networks of data by expanding and collapsing connected nodes.

Rashi provides an *Inquiry Notebook*, with places for the student to record open questions and hypotheses, Figures 2, 5 and 6. As the student explores the problem space, competing hypotheses at various levels of specificity may be considered.

In the *Collect Data Phase* students gather and request data to confirm or refute the hypothesis and resolve open questions. For example, in the biology module, students interview the patient about symptoms and examine her, see Rashi Components and Figures 3, 7. During this phase, data recorded in the *Inquiry Notebook* may reveal flaws in hypotheses, in which case students can revise their hypotheses, change their belief in hypotheses, and generate new hypotheses. In addition, students may make inferences from combinations of data (or other inferences) and information gleaned from articles.

In the *Communication Phase,* students write-up their hypotheses and supporting data and ask the coach for an assessment of their work. This might be a request to criticize the argument supporting one hypothesis or it might be a request to analyze the totality of what the student has done. The system analyzes the state of the student’s *Inquiry Notebook* and the history of activities the student engaged in and gives the feedback on how the student might best proceed. At some point the student may make a final submission which involves designating one hypothesis as the “best” or most-believed and turning in the *Inquiry Notebook* complete with all the competing hypotheses and their arguments.

4. Functional Overview of the Rashi System

Propositions. Rashi presents a student with a case and gives her a notebook for collecting information, similar to [4]. Once the student is oriented to the goal of the case, they enter the virtual world of the domain, which includes various data gathering tools and libraries, see Rashi Components below. Additionally, students may make use of web sites and textbooks. Each meaningful unit of data is called a *proposition* and it is the students’ responsibility to keep track of where propositions come from (i.e. cite their sources). All propositions are recorded in the *Inquiry Notebook*. Students may indicate relationships between propositions by linking them with *supports/refutes* links, Figure 5. These relationships are propositions as well. Relationships are often justified by some fact or principle found in an article. Finally, these chains of relationships terminate in a proposition, which is a hypothesis.

As an example of reasoning about propositions, a student may gather from the interview, Figure 3, that the patient is eating a varied and healthful diet and does only a small amount of exercise. These two propositions would be inserted into the *Inquiry Notebook*, Figure 6, using the interview tool. By examining the patient in a virtual-world exam room, Figure 7, the student finds the patient weighs 100 lbs, along with other data points like pulse, blood-pressure, etc. By looking into the patient's medical records (another virtual-world tool) the student may find that the patient weighed 135 lbs 8 months ago. A simple deduction may be made that the patient has lost a significant amount of weight despite good eating habits and not much exercise. The student types the text of this deduction into the proposition search engine, which returns a list of possible propositions that match. The student selects one and enters that into the *Inquiry Notebook.* Later in the investigation the student comes across an article in the library that lists the symptoms of hyperthyroidism. The list of symptoms includes "weight loss despite good appetite" among other things. When the student clips the article it is inserted into the *Inquiry Notebook*. At this point the tutor reasons that the student has the proposition in his notebook stating that the patient has weight loss despite good appetite, but he doesn't have the proposition that the patient has hyperthyroidism. The act of clipping this article could automatically insert the proposition that the patient has hyperthyroidism into the notebook, link the weight-loss proposition to the hyperthyroidism proposition and justify that link by citing the clipped article. The student would still have to edit the hyperthyroidism proposition and declare it to be a hypothesis, but there is a fair amount of automated reasoning that can be performed by the system to relieve the student of some of the burden of citing sources and inserting propositions. Of course an instructor may wish for a student to go through this process in which case they may shut off this kind of feature.

Coaches associated with the *Inquiry Notebook* evaluate the student's use of propositions to support hypotheses. For example, the *Syntactic Coach* checks that a node cannot support or refute itself (circular logic) and that a student should list more than one hypothesis. It also checks that factors may not support or refute data/principles and that principles may

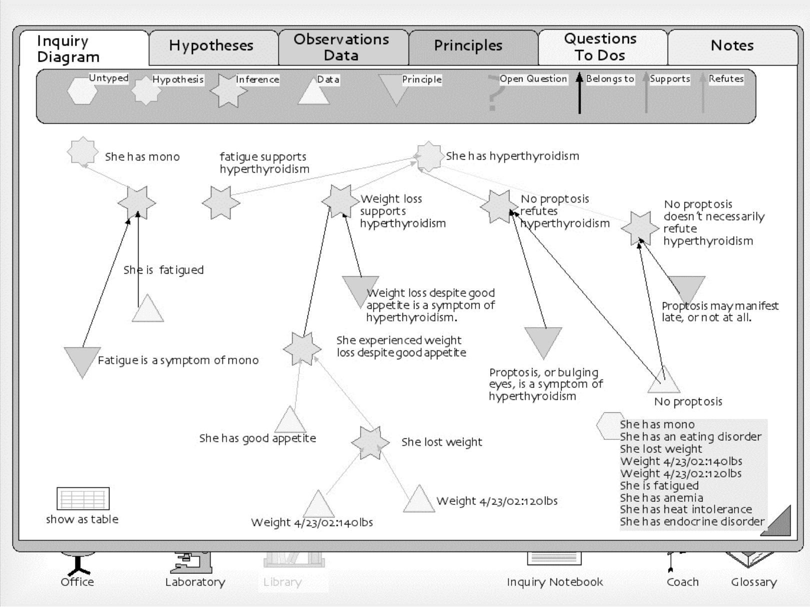


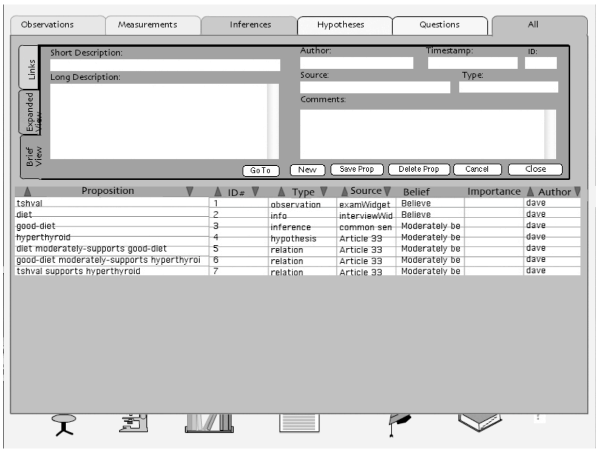
Figure 5. The Inquiry Diagram allows students to add propositions of any type and create links. An inference such as "weight loss supports hyperthyroidism" encapsulates a complex network of propositions and data. A further complication is introduced to the right, where the lack of proptosis appears to weaken the case for hyperthyroid, but another inference weakens the diagnostic power of proptosis. In the bottom right, an object is being matched to a list of propositions via a drop down menu. The visual complexity of the graph is managed by expanding and collapsing individual nodes, so that selected regions may be displayed at different levels of detail.

not support or refute data. If a factor f1 is AND-linked to a factor f2, then any data/principle that supports f1 cannot also refute f2 and vice versa. The *Semantic Coach* recognizes when a node is correctly used but overly abstract and it will suggest that the student further specify the proposition, by perhaps, looking more closely at texts stored in child links of the Domain Model. The domain model will contain “permissible,” "essential,” and “misconception” links between data and factors. If a student uses links that are not permissible, essential or misconception, then the coach will state that data is irrelevant.

Rashi Components. The Rashi system is composed of various subsystems including: authoring tools to create domain knowledge bases, case specific data, a text-base of articles, a user interface composed of an *Inquiry Notebook* and several virtual-world data gathering tools, a proposition search engine, an inquiry coach which is author-configurable along some dimensions, and a student overlay (essentially a variant of the knowledge stored in the domain knowledge base) maintenance system which performs storage and retrieval of student-created data. In describing Rashi from the end-user perspective, the system interface immerses the student in the world of the case by utilizing multimedia programming languages such as Flash and Director to create a realistic perspective on the important sources of information applicable to each task domain.

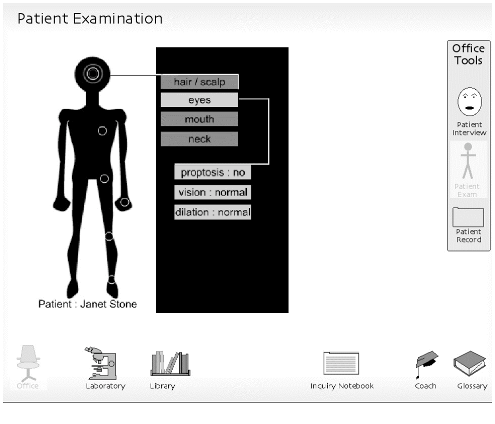
Virtual-world data tools are domain specific and recreate investigations in “the real world.” For example, in the biology module, students interview the patient about her symptoms and examine her in an exam room, Figures 3, 7. The interview tool, contains video and simple text input. The student types in a textual question to the patient and the tutor responds with a set of possible matches. A video of the patient responding to the question is shown in addition to a textual transcription. The student chooses which interaction (piece of data) should be saved in the *Inquiry Notebook*. In the real world data may have a cost associated with it, in which case, the instructor specifies the criteria that allows a student to access the data set. Some data is made visible by the student taking certain actions (e.g. asking for a chest x-ray, asking to prescribe a certain drug to see if it works, using a measurement tool). Some data is interpreted for the student (e.g. “x-ray normal”). Other data is provided raw and the student interprets it and draws her own conclusions.

The *Inquiry Notebook,* Figure 6*,* serves as a repository of all student gathered information and integrates and filters it into various views. For instance, the student can look at an individual hypothesis, accompanying arguments, data gathered and a list of “to-



Proposition	ID#	Type	Source	Belief	Importance	Author
tshval	1	observation	examWidget	Believe		dave
diet	2	info	interviewWid	Believe		dave
good-diet	3	inference	common sen	Moderately be		dave
hyperthyroid	4	hypothesis	Article 33	Moderately be		dave
diet moderately-supports good-diet	5	relation	Article 33	Moderately be		dave
good-diet moderately-supports hyperthyroi	6	relation	Article 33	Moderately be		dave
tshval supports hyperthyroid	7	relation	Article 33	Moderately be		dave

Figure 6. In the Inquiry Notebook, the background table displays the student’s propositions and hypotheses. Propositions are given “supports” or “refutes” links. The foreground dialogue box enables students to edit a hypothesis, e.g., “she has mono,” and qualify it with confidence levels and comments, etc.



proptosis : no
vision : normal
dilation : normal

Figure 7. Patient Examination Tool enables students to measure weight, pulse, blood-pressure, etc.

do” items. The notebook provides an *Inquiry Diagram,* Figure 5*,* so the student may view and manipulate propositions graphically.

Linked propositions in the student’s notebook form a model that can be thought of as overlay of the expert’s model. A model of the expert’s knowledge, using a set of rules that may be altered by an author, is used by the inquiry coach to compare the student’s overlay with the expert knowledge base. In addition, the coach has access to the history of the student’s activities within the system and uses this information to suggest how the student might proceed or to criticize his past behavior. The coach is non-interventionist; it makes no criticism of the student until the student requests help.

Knowledge Engineering. Building the domain knowledge base, so that Rashi can reason about the propositions, has been one of the most challenging parts of this research. Adding new domains to Rashi is no small undertaking. Building a general authoring tool for creating new inquiry modules is one of our goals. Currently a domain expert must confer with a knowledge engineer to create the various components of a domain knowledge base in Rashi based on a case. Some authoring tools for inquiry systems do exist, e.g. Indie[2] is used to create goal based scenario systems which do bear certain similarities to our system. Among other issues, Indie-based systems do not run cross-platform and they force students to acquire knowledge along the lines of an ASK network.

The Rashi knowledge base contains several proposition types: argument propositions, functional propositions, case-specific propositions and relational propositions, and we can distinguish those propositions which define a particular case (e.g. patient temp=98.6) from those propositions that are more general and take on a the truth-value depending on the case-specific proposition (e.g. patient has a fever). Authoring tools make it easy to create new cases by altering the values of case propositions (e.g. medical record weight=150lbs). In addition the author may manually set the truth-value (e.g. it is TRUE that the patient has a fever) of an argument proposition or the functional value of a function proposition (e.g. the patient has lost 40 lbs). As an alternative, the knowledge base can compute the truth-values of argument propositions and functional values on functional propositions by forward-chaining from case-specific data. In tandem with creating propositions and case values, the author creates principles and text sources that form the justification for the relational propositions (propositions that say something like “patient has a fever SUPPORTS patient has meningitis) in the knowledge base. These text sources then are put into articles that become part of the library. Finally all the virtual-world data-gathering tools are built in a multimedia language that communicates with the *Inquiry Notebook* through a standard API.

Hardware and Software. Rashi runs on Windows and Mac platforms and is a client/server desktop application. The platform must have a version of Java 1.3 or higher installed, and Flash and Director players. The front-end is built entirely in Director and Flash while the server is built using Java servlets. Communication between client and server is in a homegrown XML protocol because more standard protocols like SOAP do not work smoothly in Director. The server uses a standard relational database to store student information. Issues associated with multiple students collaborating on a single project have been considered in the design of the user interface but have not been carried out on the server side.

Client-server software supports storing data about students. A simple database houses the text entered by the student as well as the *Inquiry Diagram* objects, Figure 5. Intelligence is distributed between server and client. Director® and Flash® modules are used in the front end for visual activities and graphical user interfaces. Java® is used in the back end for reasoning about the student. Java handles analysis to match student text entries

[2] http: http://www.cs.nwu.edu/~wolff/chi98/chi98.html)

against the database object and analysis of *Inquiry Diagram* by various coaches. The server communicates the results back to the client running in a browser. The object database and all the algorithms for doing the analysis reside in the application and the server is only contacted to store the student data.

5. Evaluation

The Biology Inquiry Tutor in now being evaluated with students, who use the system, complete surveys and participate in group discussions. Data analysis of this evaluation, specifically about the value of the module, problems with it, and suggestions for improving it will be reported at the AI&ED conference.

6. Acknowledgement

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