Training Graph Literacy: Developing the RiskLiteracy.org Outreach Platform

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Abstract

Visual aids have been found to provide an unusually efficient means of risk communication for diverse and vulnerable individuals facing high-stakes choices (e.g., health, finance, natural hazards). Research indicates the benefits of visual aids follow from scaffolding of cognitive and metacognitive processes that enable independent evaluation and understanding of risk—i.e., risk literacy (see *Skilled Decision Theory*; Cokely et al.,. 2012; in press). Here, we present a brief review and progress report on the development of an online adaptive graph literacy tutor developed as part of the RiskLiteracy.org decision education platform. We begin with a brief review of theoretical foundations of the current tutor based on graph comprehension theory. Next, we discuss key steps in developing and validating our pseudo-intelligent adaptive tutor with emphasis on cognitive and psychometric item analyses and transfer assessments (i.e., decision-making biases). Finally, we present recent changes in technical implementation of the RiskLiteracy.org platform (i.e., Python based with a NoSQL database) that are designed to facilitate interactive, yet brief (5 minute to 3 hour) and easier-to-develop training and risk communication tutors. Discussion focuses on emerging opportunities including cognitive oriented usability analyses that should help promote an effective, enjoyable, and inclusive user experience.

Keywords: Graph literacy, decision making, risk literacy, intelligent tutors, risk communication, brain training, numeracy

Introduction

Well-informed, skilled decision making is associated with a wide-range of socially and economically valuable decision making outcomes (e.g., health, wealth, happiness; for a review see *Skilled Decision Theory*, Cokely et al., in press). In part, the benefits of general decision making skill, as measured by tests like the Berlin Numeracy Test, result because skilled decision makers tend to be better prepared to independently evaluate and understand risk as presented in common risk communications (e.g., information about health, finance, natural hazards; RiskLiteracy.org) (Cokely et al., 2012). Unfortunately, individuals with lower skill levels, including many at-risk individuals, are routinely biased by standard and well-intentioned risk communication practices, which can result in dangerous decision errors (e.g., ignoring a heart attack; Petrova et al., 2016).

To help address limitations of current risk communication practices, recent scientific efforts have endeavored to develop more inclusive decision education technologies and outreach platforms (e.g., adaptive decision support and training). For example, simple, *transparent* visual aids have been found to dramatically enhance risk literacy and independent decision making, conferring major benefits to diverse decision makers who vary widely in ages, backgrounds, abilities, cultures, and values (Garcia-Retamero & Cokely, 2013). Consider a recent systematic review by Garcia-Retamero and Cokely (2017) spanning dozens of experiments involving more than 25,000 participants from 60 countries. This work specifically mapped informed, skilled decision-making and how it interacts with graph literacy and visual aids, presenting insights on (a) visual aid effectiveness, (b) heuristics for construction and evaluation of user-friendly visual aids, and (c) the relatively large and robust benefits of visual aids for diverse individuals. While the review documented remarkably large benefits of visual aids for "real world" decision making in general, the review also identified some significant problems, namely: 1) Despite the successes of well-designed visual aids, some at-risk users lack basic graph evaluation and interpretation skills and are not graph literate enough to benefit from effective risk communications (Galesic & Garcia-Retamero, 2011) and 2) Given conflicts of interests and other factors, it can be hard to get risk communicators to adhere to best design practices (e.g., distorted visual aids can shape attitudes and perceptions without violating truth in advertising regulations, etc.).

In what follows, we present an overview of details, successes, and obstacles in our ongoing efforts to develop a brief and adaptive computerized training programs using the RiskLiteracy.org platform. Focus will be on the development of our Graph Literacy Tutor (Cokely et al., in press; Woller-Carter, 2015). A growing body of evidence has documented that substantial, decision-relevant benefits tend to emerge in a relatively short amount of time. Recent advances in the platform also enable more rapid and robust development of pseudo-intelligent (adaptive, but not fully intelligent) interfaces that reduce the costs and time required for development of brief interactive training and risk communication programs (Koedinger & Corbett, 2006). Accordingly, we begin by reviewing our formal cognitive science based on graph comprehension research and Skilled Decision Theory. We then discuss the development and testing of specific graph literacy modules and assessments and we present results from a recent control trial study documenting near and (relatively) far transfer (i.e., graph literacy training improved graph literacy skills, but also improved text based decision skills including resistance to framing and reference class neglect). Next, we consider advances in platform design and implementation, including efforts to integrate psychometric approaches to circumvent the need for more extensive intelligent tutor engines. We close with brief discussion of future directions, limitations, and ongoing projects focusing on user experience optimization.

Cognitive Processes in Graph Comprehension

Theoretically, the design of an efficient graph literacy training program will depend on the accuracy of our understanding of the underlying essential (causal) cognitive processes. As such, we drew from the well-established body of empirical literature on graph comprehension to provide a foundation for our tutor development. Graph comprehension models generally indicate that when an individual views a graph they engage in three processes: 1) encoding of the visual pattern, 2) translation of the identified visual features into conceptual relations, and 3) the selection of referents for the identified concepts (Bertin, 1983; Carpenter & Shah, 1998; Cleveland & McGill, 1986; Kosslyn, 1989; Lohse, 1993; Okan, Galesic, & Garcia-Retamero, 2016; Pinker, 1990; Simkin & Hastie, 1987; Shah & Carpenter, 1995). Together these processes allow for individuals to make a piece-wise interpretation of graphs before fully integrating the underlying mental model required for inductive and deductive inferences (e.g., reasoning that goes beyond givens). Theoretically, each step of this evaluation process involves essential processes and judgments that an individual must accurately make to correctly interpret the visualized data.

Broadly, it is often assumed that graph comprehension focuses on encoding the visual pattern, which requires the identification of key features of the graph (e.g., attending to many bars of varying height in a bar chart). Once key features are identified, a relative visual judgement is made to determine relative shape of the graph (e.g., positions of the graph elements within the axis, size, and length of the elements within the graph, the slope or angle of graph items).

Translating the identified visual features into conceptual relations then assigns relative quantitative meaning to the features of the graph. The comparison of size and spatial relations between graph features (e.g., a line graph with one positive and one negatively slopped line). For example, tall bars on a traditional bar graph would be interpreted as "more" compared to short bars. There is reason to believe that the spatial-to-conceptual mappings (e.g., "higher equals more," "steeper equals faster") found with graphs are analogous to ecological heuristics that persist within both adults and children with zero graphing experience (Gattis, 2002; Gattis & Holyoak, 1996).

Theoretically, the final step in graph comprehension is determining the referents of the concepts identified. Here, one must accurately identify the associations of variables within the graph with numerical values. This is where the conventional features of the graph (title, axes labels, legends, and numerical values) are added into the mental representation of the whole graph. For instance, one must identify the context that the graph represents or the scale at which the y-axis is set before an inference can be made. This process seems to be closer to a skill that is not analogous to real-world conventions (Okan, Garcia-Retamero, Galesic, & Cokely, 2012). This assumes that the skills needed to create proper schema for the conventional elements are trainable.

Skilled Graph Comprehension

The idea that reading a graph is trainable is embodied in many theories. One holds that graph schema will be formed in long-term memory (Maichle, 1994; Peebles & Cheng, 2001; Pinker, 1990; Ratwani & Trafton, 2008). Training graph literacy should then aim to increase the available schemas and enhance the already present ones, aiding in the identification of the conventional graph features and improving inferences made. Specifically, the training of skills would be aimed at the increasing of knowledge content, and thus can be relatively independent of limited working memory or visuospatial abilities (Hegarty & Waller, 2005; Shah et al., 2005). Previous research has found that expertise in a specific domain can increase associations between visual patterns and concepts (Tabachneck-Schijf, Leonardo, & Simon, 1997) and that inferences become easier to make (Roth & Bown, 2003). One strategy to train is the use of online adaptive tutors (Anderson, Corbett, & Koedinger, 1995; Koedinger & Corbett, 2006; Lovett, Meyer, & Thille, 2008).

The benefits of tutors are often attributed to factors such as: reduction of cognitive load during learning via worked examples, faster (ideally immediate) performance feedback, easier to understand instructions, frequent and more precise diagnostic tests of knowledge, consistent and direct modes of delivering material, and greater opportunities for detection and self-correction of errors during learning (Corbett & Anderson, 1991; Koedinger & Aleven, 2007; Mathan & Koedinger, 2005; Roediger & Karnicke, 2006; Sweller, Van Merrieoboer, & Pass, 1998).

Validated adaptive tutors are currently available for many topics in math, statistics, reading, and physics. However, despite the ubiquitous nature of visual aids in risk communications, there are few validated computerized graph tutors available. However, the available graph tutors are generally designed for specialized, narrow audiences (e.g., geared toward younger high school students). Among the few graph literacy training programs that have been specifically designed for diverse adults, none have been subject to evidence-based validity studies providing estimates of: 1) the efficacy of graph literacy training for various users, 2) the magnitude of associated benefits for naturalistic decision making (e.g., interpreting real high-stakes risk communications about health and natural hazards), and 3) essential usability and user experience outcomes, strengths, and weaknesses.

RiskLiteracy.org Graph Tutor Methods

Woller-Carter (2015) created an online graph tutor for RiskLiteracy.org that trained participants on the foundations of graph literacy and the application of graphs to everyday risky situations. The graph tutor was the prototype that which the new online graph tutor was created upon. The goal of the graph tutor is to briefly and efficiently train adult learners in essential selection, design, and display of graphs that are common in risk communications and related decision education programs. Broadly, the graph tutor contains two major components. The first consists of graph selection tasks where participants choose the correct graph that (by current standards) is best-suited for depicting specific types of data. The second major training component is the graph design task, which requires participants to identify the necessary information from data to create a graph that accords with best practices by selecting from four candidate graphs.

Note that all graph selection tasks were chosen from an initial study where 217 participants completed multiple graph selection problems, the Berlin Numeracy Test, and the Graph Literacy Assessment (Cokely, Galesic, Schulz, & Garcia-Retaneri, 2012; Galesic & Garcia-Retamero, 2011). An item analysis based on Classical Testing Theory was conducted to parse out item difficulty and discriminability, in accordance with Formal Item Response Theory approaches. The same procedure was followed for the graph design task. In total, 862 participants completed a random sample of 10-11 graph design problems (e.g., Approximately 100 participants/problems). Analyses provided a detailed account of the relevant psychometric properties of all task items, facilitating a theoretical optimization of problem type across the underlying skill dimensions (e.g., precisely selected items that were most representative and unbiased problems spanning the difficulty range; see Woller-Carter, 2015).

Control Trial Results

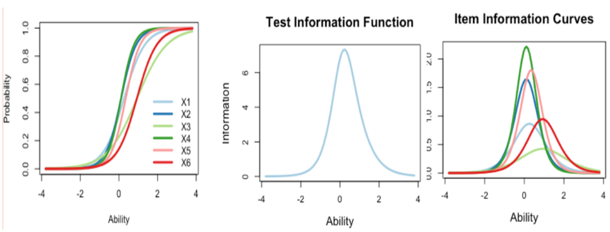
Woller-Carter (2015) found large pre-test, post-test differences in graph literacy that remained significant even after controlling for initial levels of graph literacy ($t(89) = 5.23$, $p \leq .001$, $d = 1.10$) after participants completed the graph tutor. Interestingly, beyond general competency in graph literacy, compared to a control group that completed a STEM Foundations study skills training, graph literacy training also significantly improved some general decision making skills for decision tasks that did not otherwise include any visual aid or graphical content ($F(3, 87) = 10.08$, $p \leq .001$, $R^2 = .033$, $d = 1.30$). Findings are consistent with Skilled Decision Theory and theoretical accounts of risk literacy (Cokey et al., in press). Partial mediation between condition and decision task performance indicated that improvements in graph literacy directly mediated observed improvements in general decision making skills (e.g., learning how to represent data in a graph also helps people represent decision-relevant data in useful ways).

Additional Decision-Making Items

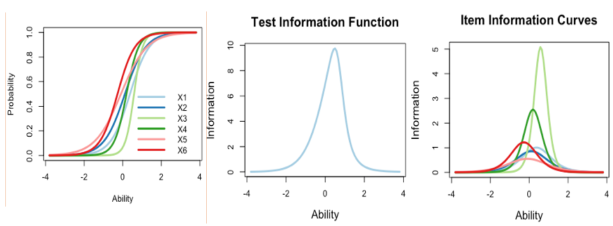
To further explore how risky decision-making interacts with graph literacy the creation of sensitive measurement tools is needed. The results of the 2015 tutor indicated what type of tools may be necessary. Training graph literacy aided in general decision-making skills that focused on "visualizable" risk situations (e.g., sunk cost). For instance, if someone is confronted with a risky decision and the aid of a graph would increase their ability to decide (e.g., icon arrays and safe sex practices), then graph literacy training will help (Cokely & Garcia-Retamero, 2015). Our lab took the firsts steps by conducting a battery of previous, validated bias questions. Then we used Formal Item Response Theory to analyze the problems for difficulty and discriminability. The battery focused on three different biases: Sunk cost, reference class neglect, and framing. Fifty-three University of Oklahoma students completed 90 (30 each bias) decision tasks taken from various sources.

The finished product are six psychometrically sensitive questions for each of the three types of bias. Results of the analysis are seen below in Figure 1.

Sunk Cost



Reference Class Neglect



Framing

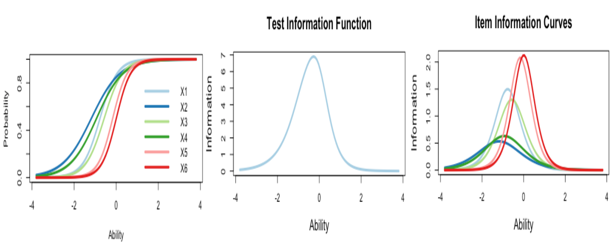


Figure 1. Visual representations of the Formal Item Response Theory analysis for the three biases in our pilot measurement study: Sunk cost (top), reference class neglect (middle), and framing (bottom).

Construction of Python Graph Literacy Tutor

To better create a tutor development platform that meets the needs of brief risk interventions the decision was made to transfer the initial graph tutor from a Flash based platform built in Carnagie Mellon University's Cognitive Tutor Authoring Tools (CTAT) to an independent Python built, Flask tutor. For an example of the original graph tutor see figure 2. A large and growing body of research has made CTAT a quintessential and evolving intelligent tool for large scale tutors. Despite many advantages, there are many potentially valuable applications for (pseudo)intelligent and adaptive tutors which may be narrow. For example, many general-use decision support systems or decision aids made for risk communication may only require between 10 and 120 minutes to complete (e.g., mortgage or surgical risk disclosure; medical treatment risk information). There is currently no well-established solution, like CTAT, for the creation of small scale, brief, scientifically validated interventions. To fill this gap, following a survey of the available literature, we developed a "proof of concept" application in Python, following best practices based on CTAT and related efforts (Aleven, Mclaren, Sewall, & Koedinger, 2009; Anderson, Corbett, Koedinger, & Pelletier, 1995; Walker, Koedinger, Mclaren, & Rummel, 2006). Specifically, we implemented the Risk Literacy Graph Tutor platform in Python, to assess viability and trade-offs, as compared to standard approaches implemented in Adobe Flash.

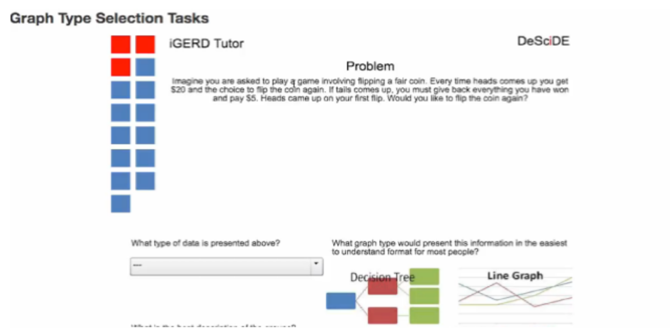


Figure 2. The original graph literacy tutor programmed in CTAT. The tutor was hosted on moodle.com, an open source Learning Management System.

The new graph tutor was built from the ground up with Flask, a micro web framework written in Python. Some notable advantages of Flask include:

- Flask is not tied to specific libraries or tools allowing flexible design of the graph tutor to better suit immediate needs (e.g., database connectivity, form validation, etc.).
- Flask is lightweight (no object-relational mapping, simple routing, and easy set-up) reducing the system requirements and development time.
- Flask is documented and community adopted, reducing the learning curve of implementing new solutions.

Beyond several notable benefits of re-development of the graph tutor, there are also some notable costs. First, the initial tutor programmed in Flash proved problematic with the number of online interfaces pivoting from the platform and potentially requiring extra authentication. These issues were persistent enough that, ultimately, an entirely new web template (e.g., User interface) had to be created. Second, the Learning Management System (LMS) platform (e.g., Moodle or Blackboard) had to be entirely abandoned to better accommodate easier implementation for experimentation, which could prove problematic whenever researchers want to track large numbers of specific users over extended periods of time (e.g., months). Third, creating online tools that use the Intelligent Tutoring System (ITS) model.

Creating an authorizing adaptive tutor in Python also required development of additional infrastructure components. First, we developed APIs ("Application Programming Interfaces") for user profiles and tutor validation, database connectivity, and a user interface. More specifically, the previous graph tutor used a LMS to track students, which needed a student to enroll in the created class and be approved by the class admin. Now, users can create their own profile that is encrypted and inserted into a database. This design allows for the sharing of the tutor to participants for experimental purposes or for a casual user to independently take the tutor.

Backend and platform development also employed MongoDB, a NoSQL database, to power our tutor application. As a NoSQL database, MongoDB records are structured like that of Python dictionary objects. This feature was emphasized in our selection of a database management system (DBMS) as it relied on existing knowledge of Python, reducing the prerequisites to contribute new features for the graph tutor in the future. There are many technical differences between MongoDB and other DBMS; however, the nuances of SQL versus NoSQL, or variations of DBMS within the NoSQL categories generally seem practically irrelevant for (most) projects of similar size and scope. Finally, authorizing via Java Script allows for the immediate feedback essential to worked-example tutors, which proved essential given the theoretical and practical importance of immediate user feedback during training.

Conclusions

Graphs are ubiquitous across modern media and risk communications. For many people, graphs simplify and clarify important information about risk, which is essential for informed decision making. In this paper we presented a brief overview of progress and ongoing efforts aimed at developing inclusive decision education programs designed to efficiently improve fundamental adult graph literacy and decision making skills. These efforts represent a significant extension to the RiskLiteracy.org platform, which has been accessed by more than 50,000 people from 166 countries since 2012. The mission of this multinational collaborative effort is to advance the *science for informed decision making*, with support of a network of scientists who provide validated educational resources such as research instruments (e.g., Berlin Numeracy Test) and inclusive decision education programs (e.g., the Graph Literacy Tutor). Beyond increasing the availability of skilled decision making resources, the current review also provides an overview of the first proof-of-concept for the Python-based (simplified) extension of the RiskLiteracy.org platform. Although this new approach may streamline development of related dynamic risk communications and training programs, several pressing issues remain. For example, we currently have a need for greater integration of iterative (life-cycle) approaches to user-experience and usability optimization. There is also a need to further investigate the robustness of and longitudinal stability of training effects across diverse participants and naturalistic decision tasks.

In closing, it is useful to note that most consumers should not expect to gain any general cognitive benefit from commercially available products designed to train *general cognitive capacities*. While this may seem problematic for us given our stated goals, our approach is actually quite different. Our goal is *not* to train basic abilities or capacities. Instead, we are focused on complex types of cognitive *skills* that must be acquired through deliberate practice and training (Cokely et al., in press), with an emphasis on acquired skills that are known to be valuable for everyday and high-stakes naturalistic decision making (e.g., numeracy, risk literacy, graph literacy). Accordingly, it should not be surprising that our basic skill tutor results indicate near and far(ish) transfer to applications beyond the specific training context (e.g., learning how bar graphs can be used to deceive in general may help people navigate complicated graphs in political, financial, or health contexts). Just as skilled reading comprehension is a valuable component of many everyday activities, the ability to evaluate and understand risk is also widely-applicable. To the extent our control trial results generalize, we should expect that there are likely many currently under-appreciated opportunities to develop and apply pseudo-intelligent tutoring programs to great effect.

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