What Makes ALEKS Unique

ALEKS is a web-based learning and assessment system that has been successfully used by millions of students in the U.S. and abroad, from the third grade through higher education covering more than fifty subjects. It was developed over several decades by researchers at New York University and The University of California, Irvine (UCI), and is derived from Knowledge Space Theory ("KST").[1] All content in ALEKS is created by experts with advanced degrees, thorough knowledge of their respective fields of study, and extensive experience in education and teaching. ALEKS is based on active learning.

The most important feature of ALEKS is that it uses artificial intelligence (AI) to map the details of each student's knowledge. ALEKS *"knows,"* at each moment, with respect to each individual topic, whether each individual student has mastered that topic. If not, ALEKS knows whether she is ready to learn the topic at that moment. ALEKS uses this knowledge to make learning more efficient and effective by continuously offering the student a selection of only the topics she is ready to learn at the current time. This builds student confidence and learning momentum.

The vast majority of ALEKS problems are "open-ended" (rather than multiple-choice) questions requiring the student to provide authentic input appropriate to the discipline. For example, students may be required to input their final answer as a mathematical expression, chemical equation, histogram, step-by-step math proof, graph of a function, an accounting entry, or a geometrical construction using a virtual pencil, ruler and compass.

ALEKS has sophisticated answer processing, enabling real-time machine evaluation of student answers, including immediate feedback where desirable. As a result of these features, the inferences that ALEKS draws from student responses are far more reliable than those achieved using a multiple-choice format. For example, when confronted with open-ended questions in ALEKS, students must actually solve the problem; they cannot merely try out different proposed solutions. In ALEKS, the lucky guesses common with multiple-choice questioning are virtually non-existent. Students are required to solve open-ended problems, instead of reading, watching other people solve problems, or using the various and sundry possible techniques for answering multiple-choice questions.

ALEKS updates its comprehensive delineation of the student's knowledge after each new topic is learned by the student so ALEKS AI is always 100% current. ALEKS continuously collects and analyzes an immense amount and variety of statistical data during student assessment and learning. Over the last 20 years, this massive database has been used to continually improve and upgrade the ALEKS AI and subject-specific content.

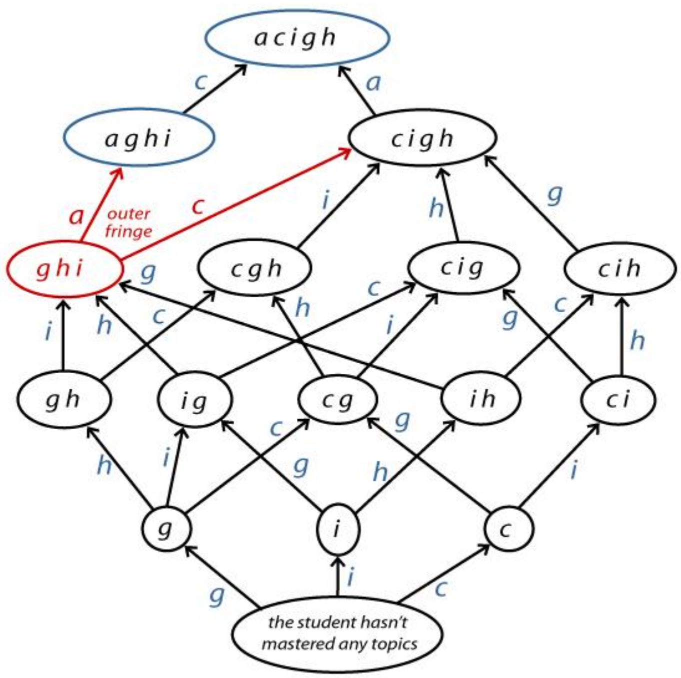
[1] Learning Space Theory is set forth authoritatively in *Learning Spaces* by Jean-Claude Falmagne and Jean-Paul Doignon (Springer-Verlag, 2011). This monograph is a revision and expansion of *Knowledge Spaces* (Springer-Verlag, 1999) and includes an examination of the mathematical basis for learning space theory and its applicability to various practical systems of knowledge assessment (such as ALEKS). The mathematical areas used in LST are primarily Combinatorics, Probability, and Stochastic Processes.

Pinpointing the Current Knowledge State of Each Student

The artificial intelligence of the ALEKS system lies in its learning and assessment engines. The output of these engines is not a numerical aptitude score or an achievement level. Rather, it is a *knowledge state,* describing all the skills and concepts mastered so far by a student in a given subject, such as Algebra 1 or General Chemistry. This means specifying each and every topic that the student is capable of solving (and therefore all the topics the student is not yet capable of solving).[2]

All the feasible knowledge states for a given subject are organized into a *learning space,* which is a mathematical structure specifying the precedence relation between such knowledge states; that is, which knowledge states may precede or follow other states in the learning process. Figure 1 depicts a miniature learning space formed by five topics labeled *a,* c, *g, h,* and i. Each ellipse represents one of 16 feasible knowledge states in this miniature learning space[3]. The blank circle at the bottom represents the empty knowledge state (i.e. the student hasn't mastered any of the five topics). Learning proceeds from bottom to top, the topics being mastered successively. The knowledge state represented by the red ellipse contains the items *g, h*, and *i*; topics *a* and *c* form the topics the student is highly likely to be ready to learn next. In fact, every knowledge state automatically specifies the collection of topics that the student is *ready to learn* at that moment. These topics form the *outer fringe* of the student's knowledge state; in ALEKS, we call these topics the "ready to learn."

<u>Figure 1</u>

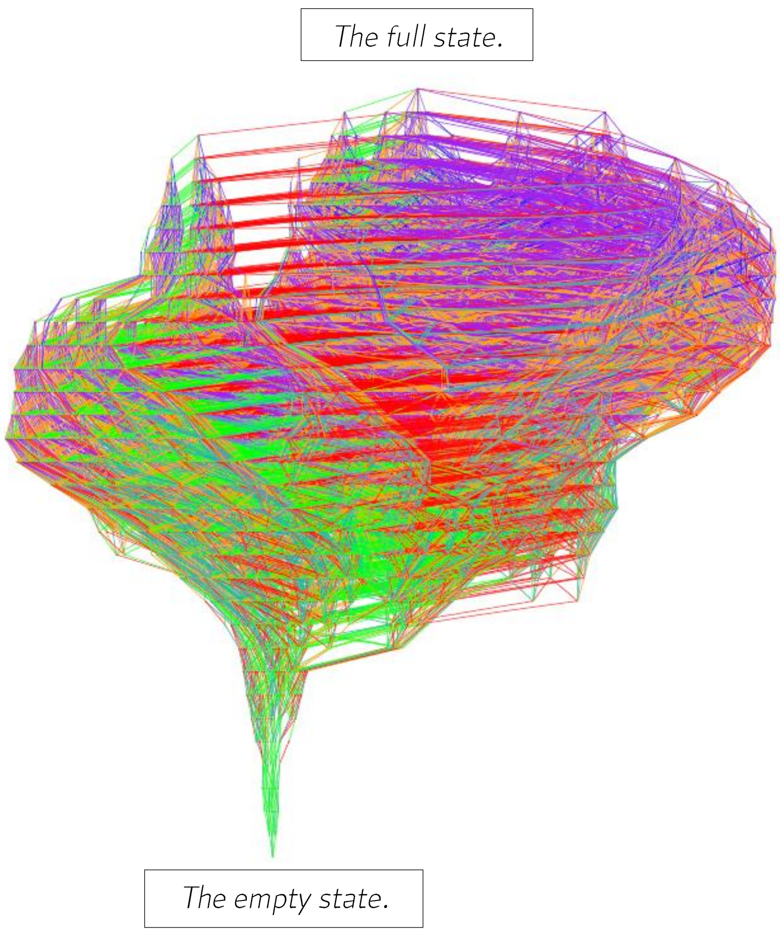


[2] Not all assortments of problem types constitute feasible knowledge states. A feasible knowledge state must have a reasonable chance of actually occurring. For example, there is no feasible knowledge state in the subject of Pre-Algebra containing the topic long division without also containing the topic whole number subtraction.

[3] Note that the 16 feasible knowledge states constitute half of the $2^5 = 32$ mathematically possible subsets in a learning space containing 5 topics.

Drawing the same type of graph for ALEKS Beginning Algebra, for example, which contains hundreds of topics, is not only daunting, but impractical. Some idea of the difficulty is conveyed by the graph in Figure 2, which represents the learning space of just 45 of the topics in Beginning Algebra. Every point in the graph represents a knowledge state; the colors of the lines linking the states correspond to the various topics. However, the assessment and learning engines within ALEKS are capable of efficiently managing such enormous structures.

Figure 2



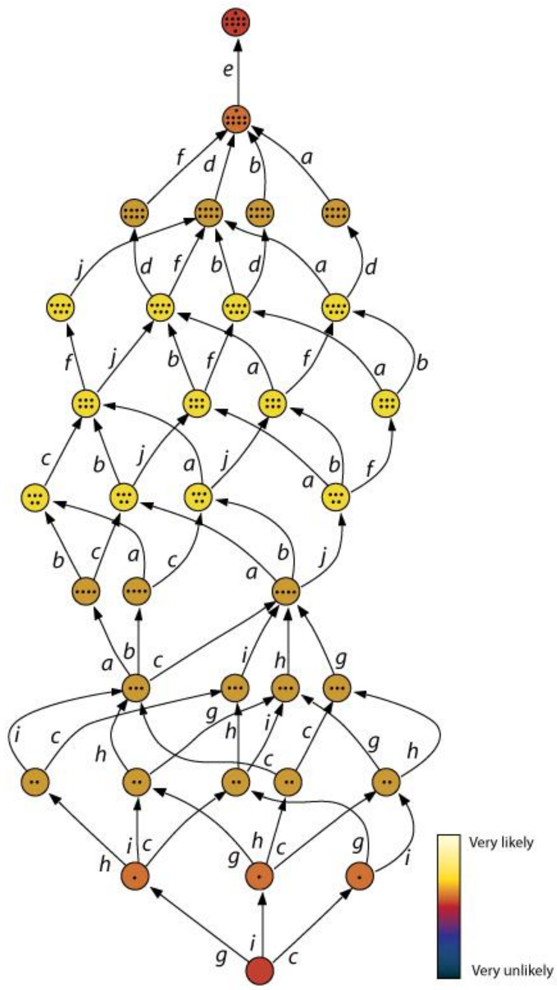
Another example, ALEKS Algebra 2, is currently a domain of 586 topics; a typical implementation uses 384 of them. This gives rise to over a trillion feasible knowledge states. The mathematical language of Knowledge Space Theory has made possible the creation of ALEKS computer algorithms that rapidly and efficiently search and apply the feasible knowledge states in a particular subject to each individual student's behavior during learning and assessment.

ALEKS Individualized Assessment

The task of the assessment engine is to uncover, by efficient questioning, the knowledge state of a student. The powerful assessment engine within ALEKS is capable of pinpointing a student's knowledge state after asking only 20-30 questions. Additionally, its probabilistic nature makes it capable of correcting for an occasional mishap, such as the student making a careless error.

For purposes of visualization, the graph in Figure 3 represents a learning space of only 10 topics and 34 knowledge states. (As mentioned earlier, an actual learning space in ALEKS would often contain roughly 400 topics and over 1 trillion knowledge states.) At the outset of the assessment, each of the knowledge states is assigned a certain initial probability of being the current state of the student. These initial probabilities are pictured by colors varying from reddish to yellow. Each circle represents a knowledge state; the colors of each circle represent the probability of the corresponding state. Bluish black means very unlikely, and bright yellow means very likely.

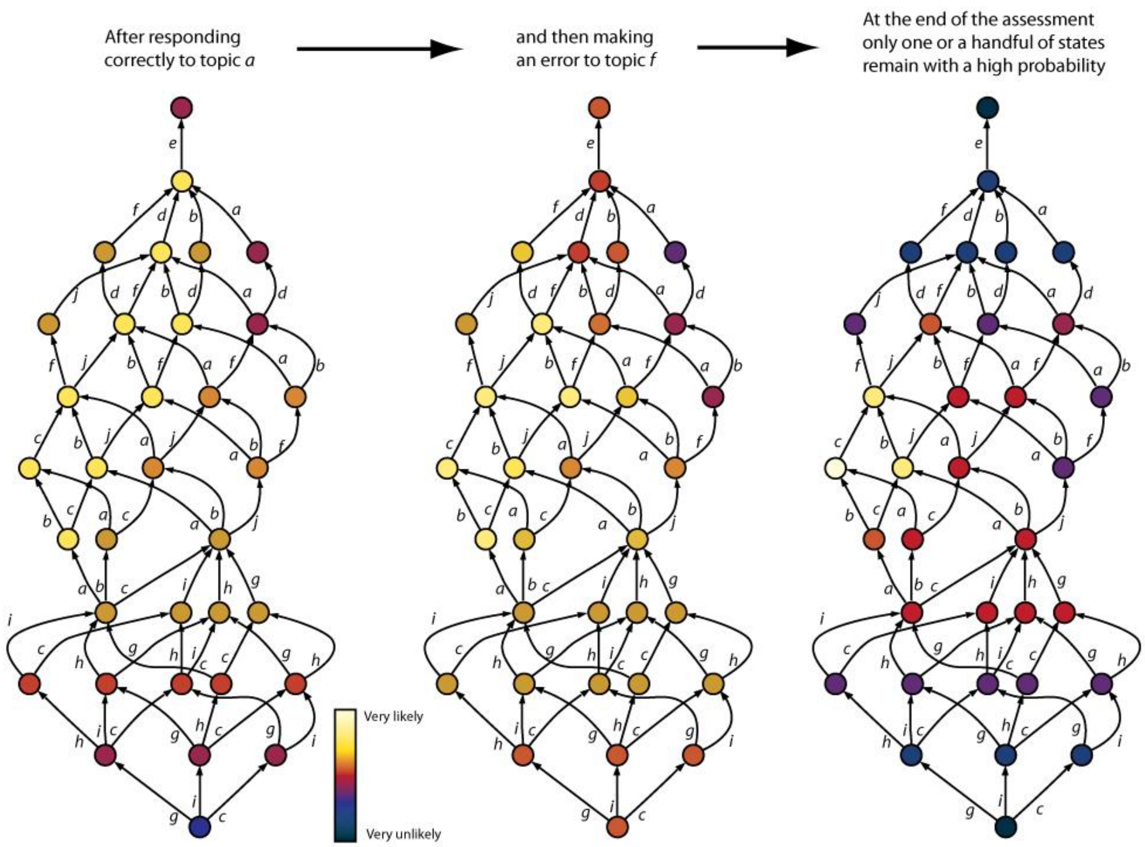
Figure 3



Despite the fact that the number of topics in a typical learning space is large, only a few questions can actually be asked in any given assessment. Therefore, the successive questions must be scientifically chosen. ALEKS begins by asking the student to solve a problem that has been chosen to be as informative as possible on the basis of the initial probabilities of all the knowledge states. ALEKS always attempts to ask the individual student a maximally informative question; i.e., a question for which that student has as close as possible to a 50% chance of answering correctly based on all the information available, including all the student's previous answers.

Suppose that the first topic asked is *a*, and the student's response is correct. ALEKS will then increase the probabilities of all the knowledge states containing *a*, and decrease the probabilities of all those states not containing *a*. This is illustrated by the leftmost graph of Figure 4 in which the colors of the circles are brightened and darkened accordingly. If the next topic asked is *f* and the response is incorrect, ALEKS will then decrease the probabilities of the states containing *f* and increase the probabilities of the states not containing *f; t*he middle graph pictures the result of such an updating. At the end, the situation may be as shown by the graph on the right; only one state remains with a very high probability. ALEKS will then choose the state containing the topics *a, b, g, h,* and i as being the current state of the student. In an actual implementation, the ALEKS assessment hones in on one of the most probable knowledge states out of the extremely large number of feasible states.

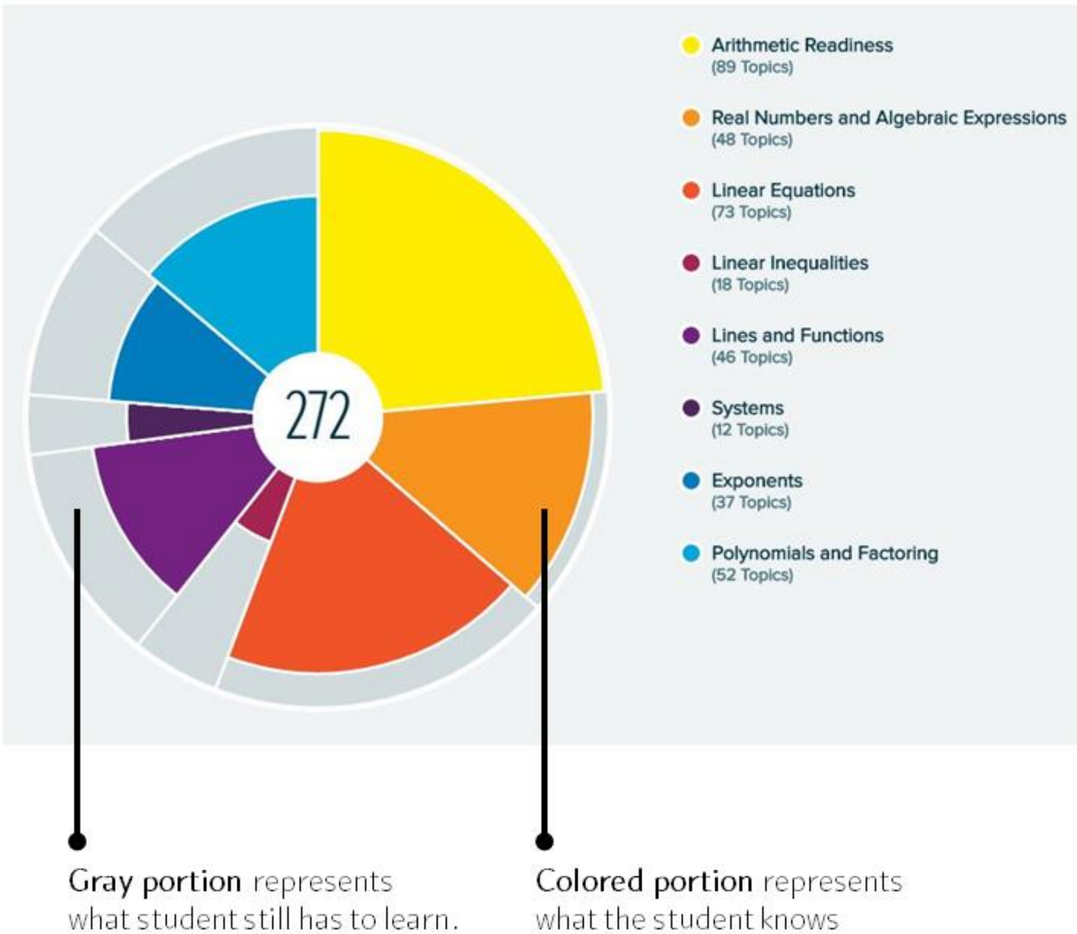
Figure 4



ALEKS Adaptive Learning

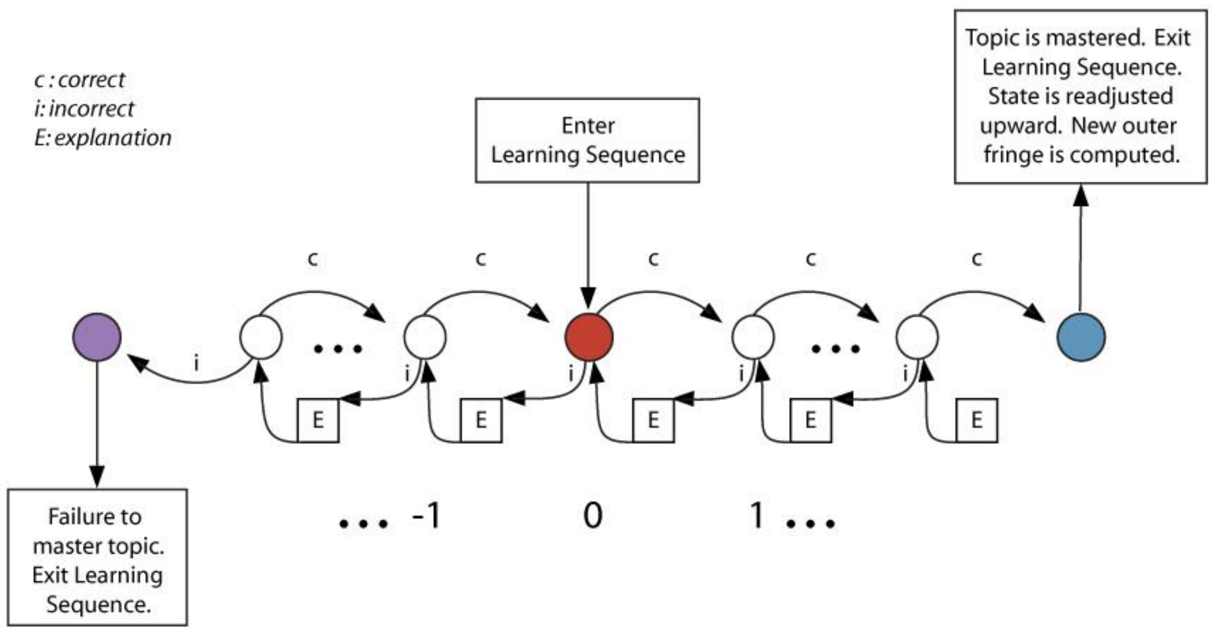
At the end of the assessment, the student proceeds into the ALEKS Learning Mode, where the student is given a list of topics that he or she is ready to learn. The concept of ready to learn is critical because this is where the student's learning progress takes place: learning proceeds by mastering a new topic in the ALEKS "ready to learn" creating a new knowledge state. The new knowledge state has its own ready to learn, and so forth. ALEKS presents the student a Learning Path which guides the student to topics she is most ready to learn. In ALEKS, the student's learning path is continually modified to reflect the student's most recent learning. The student's knowledge is represented by a multicolor pie chart, which also serves as a powerful motivator. See Figure 5 below.

Figure 5



With ALEKS, learning takes place step-by-step, one topic at a time. ALEKS will guide students to a topic via the student's current Learning Path or allow a student to choose a topic in the ALEKS Learning Mode, which initiates a learning sequence illustrated by Figure 6. ALEKS monitors the sequence of successes and failures of the student in attempting to solve the problem and understand the explanation, and guides the student's progress.

Figure 6



The student enters the system at the red dot and is given an instance of the problem. The student is given an explanation [E] of the solution in certain cases of a failure to solve an instance or whenever she clicks on "Explain." When the student gives a correct response to an instance, a new instance is given. When a sufficiently long sequence of instances is observed[4], ALEKS may decide that the problem has been learned and the student will then leave the system at the blue dot. The knowledge state of the student is then adjusted upward. Empirical data derived from millions of students over more than 20 years reflects a success rate greater than 90% when ALEKS determines that a student is "ready to learn" a particular topic.

Each problem type has an extremely large number of specific instances. These instances are algorithmically generated by ALEKS – randomizing numerical values and other problem parameters as each new question (and its explanation) is generated.

Each time a student masters an additional topic, ALEKS immediately updates the student's knowledge state and provides the student with a new list of topics that she is ready to learn. The result is a continuous re-optimization of the student's learning path.

ALEKS Assessment and Learning Mastery Cycle

Throughout the learning process, the student periodically completes ALEKS progress assessments, called Knowledge Checks – 25-question, AI-driven assessments that employ the (previously explained) ALEKS adaptive technology. ALEKS Knowledge Checks focus on topics the student has recently mastered; results of the Knowledge Check are employed by ALEKS to adjust the system's detailed map of the student's knowledge. In other words, since students do not initially retain 100% of the material they learn, ALEKS

[4] The length of that sequence depends on the context and the student's behavior. ALEKS models such a sequence as a type of stochastic process.

Knowledge Checks serve to recalibrate the student's knowledge state. Research demonstrates that assessing students on previously learned material functions to more effectively and permanently store the material in the student's long-term memory. ALEKS Knowledge Checks ensure that topics are fully mastered and retained. Because ALEKS requires students to periodically demonstrate mastery of the material through mixed-question assessments, learning in ALEKS results in true mastery of the subject matter.

The cycle of individualized assessment and adaptive learning continues throughout the student's learning in ALEKS to ensure that he has truly mastered and retained the concepts presented. At the conclusion, the student has a deeper understanding of the material and dramatically improved mastery of the topics.

Summary

Academic subjects are best learned, and knowledge is best assessed, through "open-ended" or "free response" questions. ALEKS uses open-ended questions and sophisticated answer processing to maintain a precise and exhaustive map of each student's knowledge at each point in time. While working in ALEKS, students learn by practicing problems as if they were using a pencil and paper while being guided by a talented tutor. The sophisticated ALEKS answer processing enables real-time computerized evaluation of a student's answers, including immediate feedback where appropriate. ALEKS relies on millions of data points in the ALEKS system to continually update the student's knowledge state, and re-optimize the student's individual learning path.

There are assessment tools (such as standardized tests) that attach a number to a student's knowledge of something at one particular point in time – generally by means of undependable multiple choice questioning. These instruments cannot uncover precisely what a student knows and is ready to learn, and they cannot accurately update this information on a continuing basis. There are also online homework management tools, but they are not intelligent; the students follow the syllabus regardless of their current individual skills and knowledge.

ALEKS achieves better learning outcomes by utilizing artificially-intelligent, individualized assessments, combined with a learning process that meets the exact needs of each student at all times. ALEKS targets and fills gaps in knowledge, and provides a completely individualized and optimized learning path. As a result, ALEKS students are much more motivated, have a deeper level of understanding of the course material, and a greater degree of success.