



# System Overview

A short description of some of the key components within Realizeit



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# Introduction

For some time now intelligent and adaptive systems have been used to underpin advances in many fields such as medicine, engineering and financial analysis. We rely on this intelligence when we travel in an aircraft, undergo a procedure in a hospital and in countless ways in an everyday context. CCKF is now applying similar intelligence in a fundamental area - to underpin education and learning.

The origins of Realizeit lie in a desire to provide the means for individuals to have a 'better' learning experience, using an intelligent and adaptive on-line system that will help each learner to achieve personal learning objectives to the greatest possible extent.

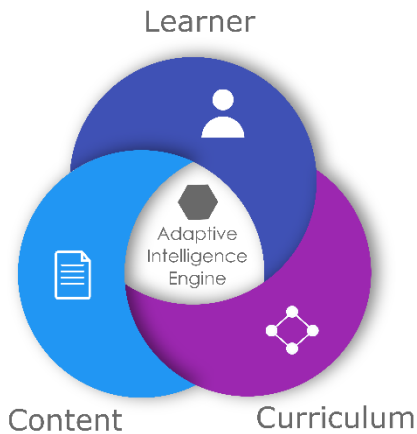
CCKF began with a vision of the next generation of learning experience that would deliver **truly personalized learning** using a system that could adapt to the individual **but also adapt and evolve itself as it was used**. The system would be content **agnostic** and would consider the **lifelong learner** as its target user.

Realizeit is the result of this vision. It is more than a platform. It is an ecosystem containing an intelligent learning engine that can take any target knowledge space, accompanied by any associated content, and provide an adaptive learning experience for each individual learner.

## System Concept

As no two learners are the same it cannot be expected that they will learn at the same rate or in the same manner. In a one-on-one situation good teachers can take this into account and tailor their instruction to the unique needs of the individual. They achieve this by having expert knowledge of the concepts being taught, the many methods available to teach these concepts and, most significantly, by knowing the strengths, weaknesses and learning preferences of the individual. The teachers acquired this in-depth knowledge over time and they balance the interaction of these three elements;

**adapt to the  
individual but also  
adapt and evolve  
itself**



curriculum, content and the individual, to ensure that learning is taking place and is effective.

The goal of Realizeit is to emulate this process and to provide an effective, efficient and personalized learning experience for each individual learner. Realizeit aims to provide support to the learner when they are working independently and to support both the learner and the teacher in a classroom environment.

Realizeit solves this problem by separating curriculum from content. The curriculum is represented as a set of related concepts and is used to drive the direction of the learning. It is the content which delivers the learning to the individual. Just as a teacher can teach the same concept in many different ways, Realizeit can have multiple pieces and types of content available to it for each concept in the curriculum.

In a learning environment, to require a learner to both navigate a curriculum and select content would place an enormous additional cognitive load on them. The teacher avoids this by making decisions and suggestions to the learners as they learn. Realizeit achieves this through the use of its Adaptive Intelligence Engine which bridges the gap between the curriculum, content and the learner.

The Adaptive Intelligence Engine is built from many models and algorithms. While these are separate components which are tasked with learning, understanding and adapting to a specific part of the learning environment, they are highly connected and rely intimately upon each other. Together they build a detailed picture of each individual's learning.

**Realizeit is content agnostic. It is built to be applicable in any learning domain and to deliver learning content in any format.**

It has been deployed in fields as wide ranging as Mathematics and Engineering to Criminal Justice and Psychology and with content ranging from text and audio to video and interactive animations

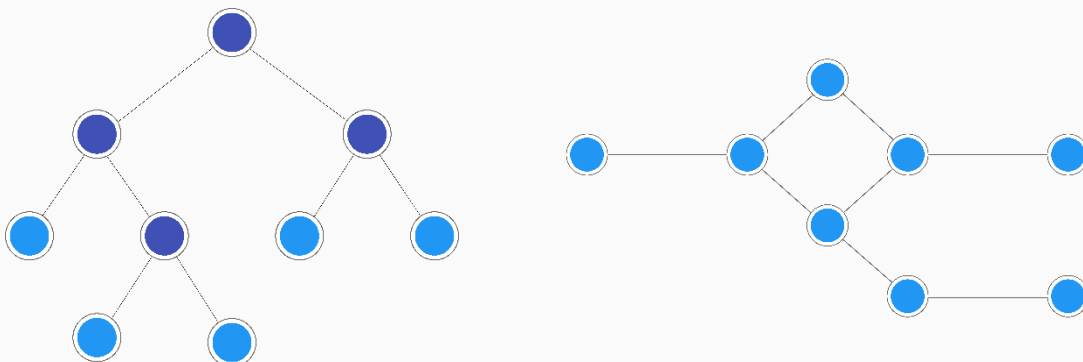
# Curriculum

A curriculum is traditionally a hierarchical representation of all the concepts and knowledge within a particular domain. The nodes at the bottom of the hierarchy represent the finest grained pieces of knowledge in the curriculum definition. While the hierarchy does capture part of the relationship that exist between these granular knowledge items it fails to capture the full picture.

Realizeit supplements this hierarchical representation with a second structure known as the Curriculum Prerequisite Network. This is a directed acyclic graph that describes the relationships between the most fundamental pieces of knowledge in a curriculum, known as knowledge items. These knowledge items are represented as nodes on the graph and the edges represent the relationships between the items.

The Curriculum Prerequisite Network is structured so that knowledge items are preceded in the directed graph by their prerequisite items. The prerequisite items are knowledge items that should be mastered before the current knowledge item is studied.

Learning in the Realizeit system is driven by the Curriculum Prerequisite Network. In this way it provides a map to aid a learner in navigating their way through a curriculum.



# Content

It is through the content that learning takes place and it is the primary interface for interaction between Realizeit and the learner. Realizeit provides the potential for **a rich repository of learning content for every single knowledge item**. This can include everything from alternative versions of learning material to additional resources such as videos, audio files, documents, presentations and URLs.

Each piece of content that is served is **individually tailored**. Realizeit provides the infrastructure to allow the content to be interactive and adaptive. The elements of the content are not generated at the start - Realizeit **generates and serves them in response to learner actions** during the learning process.

Realizeit contains a fully integrated authoring system that **allows an author to determine the pedagogy to be used**, and to leverage the ability of the adaptive intelligence engine to adapt and personalize the content for each individual learner. To achieve this Realizeit begins by separating content into learning material, questions and resources.

## Content Agnosticism

Realizeit is designed to be content agnostic. It is built to be applicable in **any learning domain** and to deliver learning content in **any format**.

Content authoring is an integral part of the Realizeit model. Learning material can be created either through automated ingestion or through native authoring. Authors and editors can work individually or collaboratively, creating next generation learning content.

Content is created against a curriculum as an integral part of the course creation process. Any material created can be linked to one or more knowledge element, and the system is immediately aware of the context in which it can be used.

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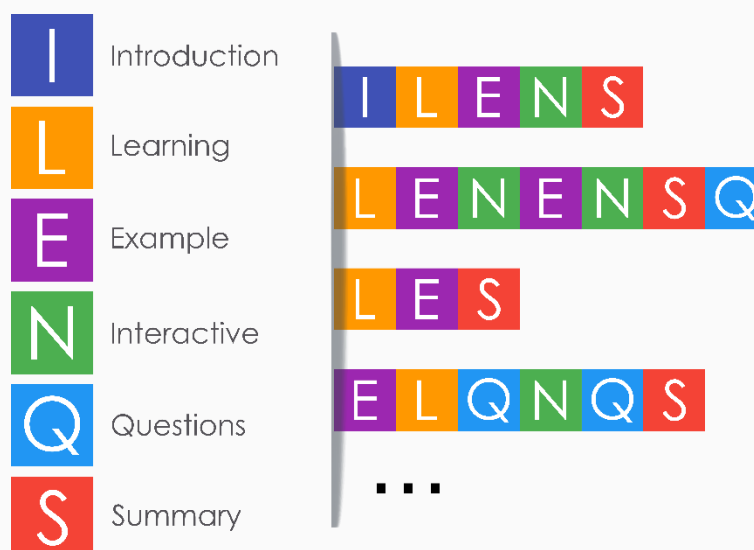
## Learning Material

Realizeit determines the most suitable piece of content for an individual learner to use, at all times trying to maximize the probability of successful learning. It evolves **content profiles** through observations of learner behaviors and level of success as it figures out when the content should be used and when it should not.

Within Realizeit learning material is broken down into **Learning Bits**. These are the small pieces of learning material that a learner can use, such as an example or summary. This allows Realizeit not only to determine **which** content to use but also to determine the most effective **ordering** of these bits (referred to as a learning template) to deliver to the learner given their current ability, skills, preferences and needs.

Realizeit breaks learning material into **eight different types of learning bit**. Some pieces of content may have several bits of a single type or indeed no bit of a particular type.

- introduction
- learning
- example
- worked example
- interactive example
- questions
- summary
- review



## Questions

Traditionally learning systems have provided **banks of static questions** to present to a learner, with an over-reliance on multi-choice questions. There are several drawbacks to this approach. The creation of large banks of static questions is **time consuming** and only provides a limited supply of opportunities for a learner to practice. Multi-choice questions are really only suited to **lower-order skills**; they can be ineffective in gauging partial knowledge and provide a reasonably high chance of **guessing** the correct answer.

Realizeit enables a wide range of question types such as input answer, ordering, matching, mathematics input, point and click and attachment. Composite questions can also be constructed which can include any combination of available types.

Additionally a **question generation component** exists within Realizeit. Questions are defined using generic data structures which are used to represent question forms. **The author of a question creates a form or 'template'** which can be used by Realizeit to generate any number of instances of the question, rather than specifying static questions.

Variable and adaptive questions allow learners to attempt questions which will be generated in real time with different variable values. This allows the learner to have a seemingly infinite number of chances to practice a question, with the assurance of knowing that the same question will not be

What is the **<func>** of the following numbers?

**<a>**, **<b>**, **<c>** and **<d>**



What is the mean of the following numbers?

2, 5, 10 and 17



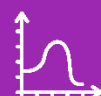
What is the mode of the following numbers?

2, 5, 2 and 7



What is the variance of the following numbers?

6, 13, 8 and 26





presented again. These variable questions are not tied to a specific content delivery, but can be re-used in different contexts throughout Realizeit - in a lesson, when determining knowledge, when practicing and in an assessment.

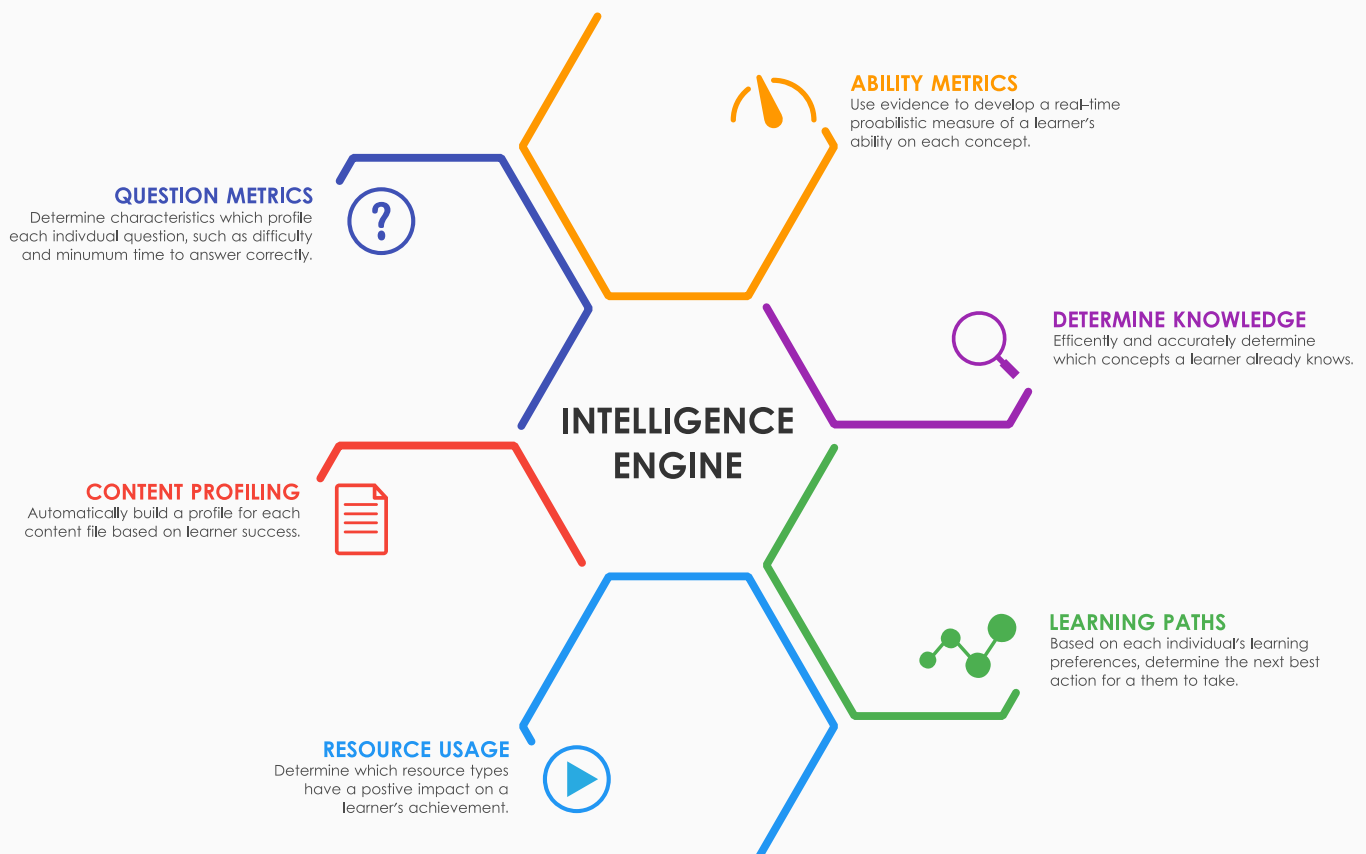
# Adaptive Intelligence Engine

***emulate what a good teacher would do in a one on one situation***

The main goal of the Realizeit Adaptive Intelligence Engine is to manage the interaction between the curriculum, content and learner in order to provide an **effective, efficient and personalized learning experience for each individual learner.**

The Adaptive Intelligence Engine is responsible for **discovering and adapting** to each individual learner's **changing** abilities, behavior and preferences. It manages its own accuracy and performance to ensure the individual receives a complete personalized learning experience. It essentially tries to emulate what a good teacher would do in **a one on one situation.**

The Adaptive Intelligence Engine of Realizeit is built from several components, each of which controls a specific task within the engine and employs the techniques of Machine Learning and Adaptivity. Machine learning is concerned with making use of algorithms that allow Realizeit to discover



behaviors and characteristics for an individual or group based on interaction data. Adaptivity then makes use of this knowledge to adapt the interactions between the learners and Realizeit, its structures and content to enhance the learning process.

## Curriculum based components

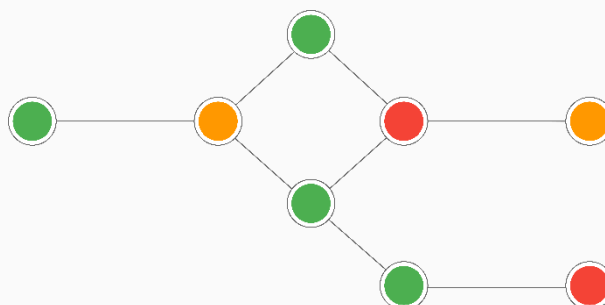
### Ability Metrics

Traditionally a learner's ability on a particular subject is measured using a single number, usually estimated from the result of a single exam. But this does not capture the deeply complex and granular nature of an individual's ability. Learners have **strengths and weaknesses** on individual and interconnected concepts and areas that **cannot be captured by a single score.**

Results can be directly measured, ability cannot. Ability is a latent variable that can only be inferred from evidence obtained by monitoring a learner while engaged in learning. Realizeit achieves this by using a **probabilistic model** to provide an estimate of the learner's true ability on each Knowledge Item in a curriculum. As new evidence is collected on the learner's ability the probabilistic models are updated according to **Bayes' theorem.**

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

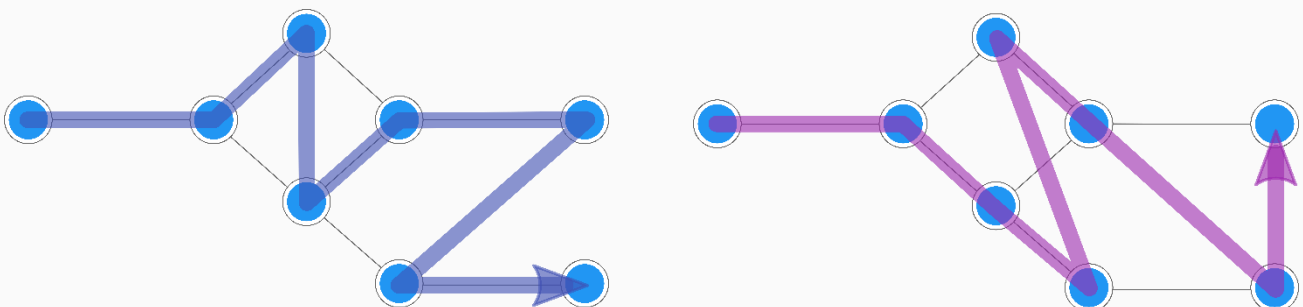
It is this collection of ability metrics, with their associated probabilities, in combination with the curriculum map, which provides Realizeit with the means to capture the complex, granular and interconnected nature of learner ability.



### Learning Paths

The Curriculum Prerequisite Network is a map of the interdependencies and relationships that exist between concepts in a curriculum. It provides learners with a map which can guide them from building a base of knowledge on the foundational items at the start of the curriculum, to attempting the more advanced items at the end.

The Curriculum Prerequisite Network allows each learner to take the path through the concepts that best suits their individual needs and preferences. However, once a curriculum contains a substantial number of concepts the Curriculum Prerequisite Network can be quite complicated. To reduce the cognitive load on the learners when choosing the direction of their path, Realizeit provides assistance. Based on their learning outcomes and patterns it makes suggestions at each step how best to navigate through the curriculum to ensure each individual follows the path that is most effective for them, while still covering all the required items.

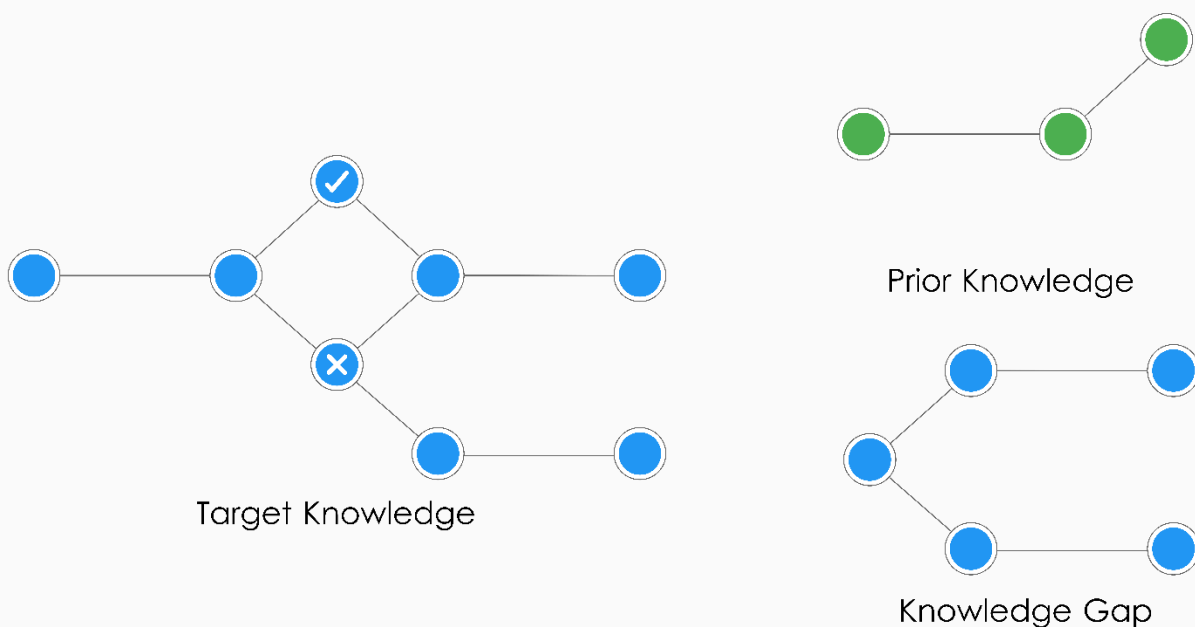


### Determine Knowledge

The Determine Knowledge procedure is used to determine any concepts that a learner may already have mastered before they begin studying a curriculum or objective. It allows Realizeit to uncover the gap between the learner's current Knowledge State and their Target Knowledge.

The procedure makes use of the structure of the Curriculum Prerequisite Network and Information Theory to establish the minimum number of concepts that must be examined in order to accurately determine their initial Knowledge State. Once a concept has been chosen the procedure makes use of the Question Metrics to ensure that the questions it asks are effective and efficient.

$$H(X) = - \sum_{i=1}^n p(x_i) \log_b p(x_i)$$

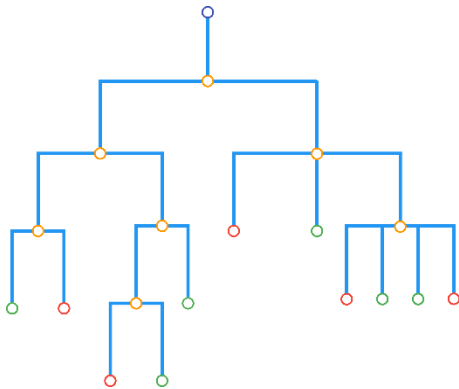


## Content based components

### Content Profiling

Just as there is no perfect path through a curriculum, there is no perfect content to use that will suit every individual. However there is the most appropriate path and content to use for an individual learner.

For each knowledge item in a curriculum Realizeit can have several pieces of content available for a learner to use. Content can be created with a target audience in mind and therefore will not be appropriate for all learners. The Content Profiling procedures center on using data mining techniques to build a content profile. This can be matched against a learner profile in order to select the most appropriate content to use for the individual learner.



For each piece of content the Adaptive Engine monitors the success or failure of that content for each individual who uses it. **A Classification Tree algorithm** can make use of this data and any data or metrics in the Learner Profiles to build the Content Profile for each piece of content within Realizeit. This algorithm contains the model which establishes how successful the piece of content is for particular groups of learners.

The algorithm assigns individuals to groups in order to build the tree. In the real world people rarely fall into neat categories. To overcome this restrictiveness, fuzzy group membership is used. For example a learner does not need to be assigned to one of the categories strong, average or weak but could be 30% strong, 60% average and 10% weak.

$$mem(V, T_1) = \begin{cases} 1 & \text{If } V < A_0^- \\ \frac{1}{2} \left( 1 + \frac{V - A_0^-}{A_0^+ - A_0^-} \right) & \text{If } A_0^- < V < A_0^+ \\ \frac{1}{2} \left( \frac{V - A_0^+}{A_0^+ - A_0^-} \right) & \text{If } A_0 < V < A_0^+ \\ 0 & \text{If } A_0^+ < V \end{cases}$$

### Question Metrics

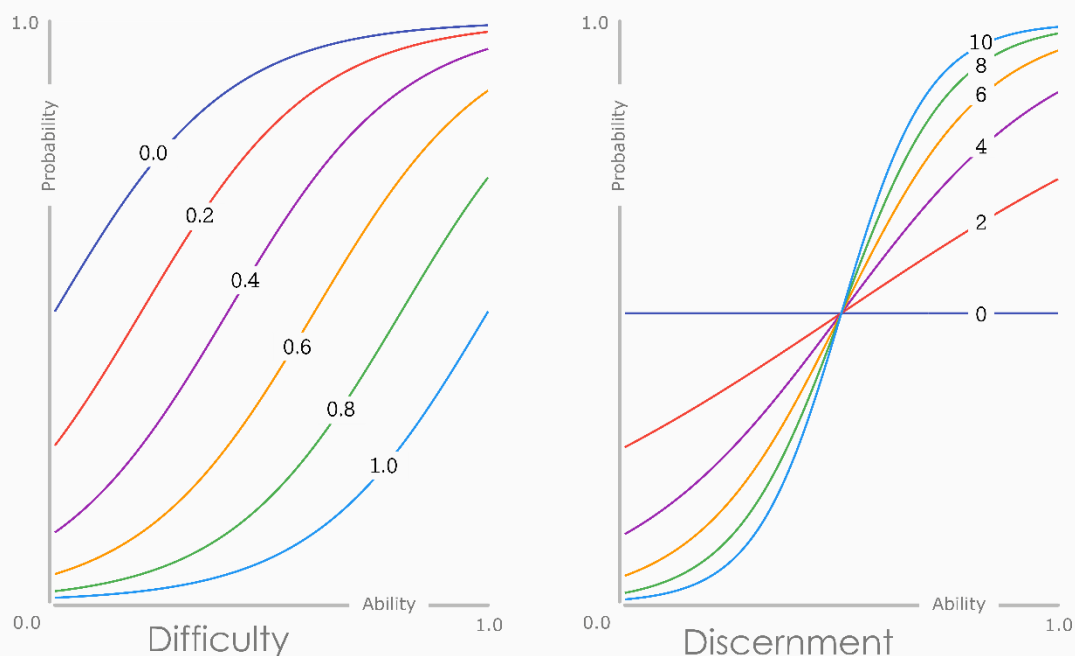
In addition to the Content Profiles the Adaptive Intelligence Engine builds a set of Question Metrics for each question in Realizeit. These measure the difficulty, discrimination and time parameters of each individual question.

There are two models which provide the question metrics. The first is concerned with predicting the probability of getting the question correct and the second predicts the time required by the individual to do so. The Intelligence Engine uses an IRT-2PL model to predict the probability that a learner will answer an item correctly based on their ability.

$$p_{ij}(\theta_j) = \frac{1}{1 + e^{-a_i(\theta_j - b_i)}}$$

There are two parameters to the model: difficulty and discrimination.

- The difficulty is the ability level at which a learner has exactly a 50% chance of answering the question correctly.
- The discrimination measures the ability of the function to distinguish between learners who will pass and those who will fail. It can be viewed as a measure of how accurately the model reflects the data.



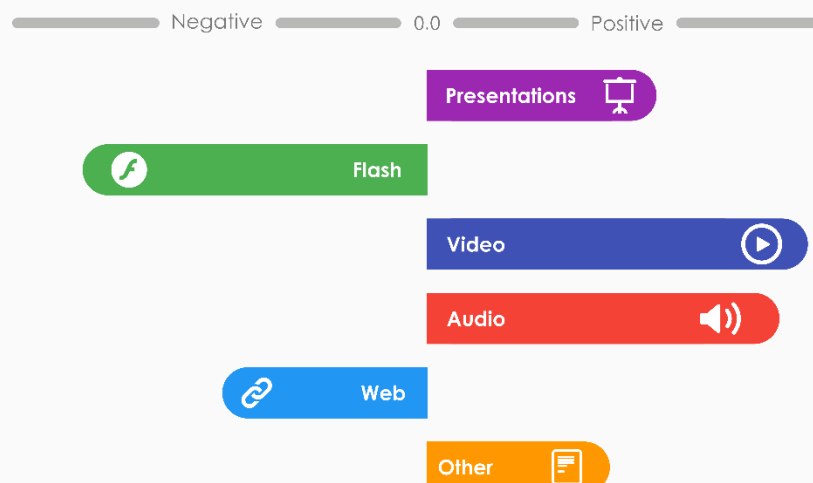
The second model determines the relationship between ability and the response time for a correct answer. A predicted time can be used to ensure a learner has sufficient time to complete a given task. The Intelligence Engine can monitor current time versus expected time to decide when a learner may be experiencing difficulty and take action.

These models are used by Realizeit to adapt the questions it offers to learners and are also fed back to authors as Realizeit can identify "bad" questions (e.g. too high a chance of guessing the answer, questions that weaker learners answer better).

### Resource Usage

Within a piece of content there may be several resources available for the learner to use. These could range from audio and video files to interactive animations. Realizeit can track the learner's use of these types of resources and infer their preference for them. This can help with the profiling and selection of content.

To achieve this, the Adaptive Intelligence Engine monitors the difference in outcomes from those Knowledge Items where a particular resource type was used, as against the items when the particular resource type was available but not used.





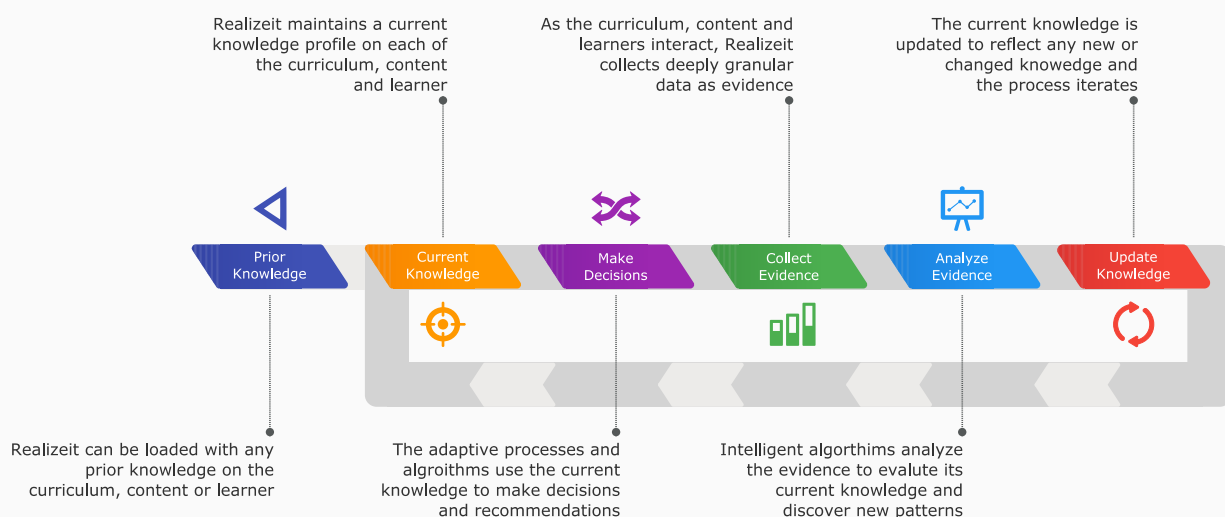
## Evolution of Components and Metrics

In addition to these key components, the Adaptive Intelligence Engine makes use of statistical, data mining and machine learning algorithms in many different components. These include the Practice functionality, selecting and measuring the effectiveness of Items for Review, Content Sequencing, Assessments and many more.

In addition to the metrics derived by these components Realizeit also maintains all evidence generated by the learner, including the length of time spent learning, the number of attempts and outcome of each question, the number and types of interactions between the instructor and the learner as well as any recorded interventions external to Realizeit.

There are two key features that are required of the engine. The first is that it must be able to function and make intelligent decisions when there is no data present. This can occur when a new user, curriculum or content is added to Realizeit. The second feature is that the engine must be able to improve its accuracy, efficiency and effectiveness as data is collected. To achieve this all components in the Adaptive Intelligence Engine follow the Bayesian approach outlined below:

1. The Adaptive Intelligence Engine gathers any prior knowledge that is available regarding the content, curriculum or learners.



2. The engine uses this prior knowledge in conjunction with the adaptive processes to make its initial decisions.
3. As the learner interacts with the content, curriculum and system all available evidence is collected.
4. The machine learning processes use this evidence to update and supplement their current knowledge of the content, curriculum and learners.
5. This new knowledge replaces the prior knowledge when the adaptive processes are making their decisions.

This process is repeated throughout the learning cycle to improve the interaction between the learner and Realizeit; it ensures continuous improvement in the accuracy and effectiveness of the learning.

# Analytics

Data is the critical element of Realizeit. It continuously learns about each student; tracks progress and attainment, identifies knowledge strengths and weaknesses and in turn provides a personalized and adaptive learning experience to each individual. The platform has been designed from inception to generate key data points which go beyond the traditional summative metrics. **Rather than requiring data for retrospective reports and analysis, the platform has been built so that in real-time it integrates the use of that data, and the associated analytics, into the learning process to support both the learner and the instructor. This type of analysis is known as Learning Analytics.**

Academic analytics is the application of business intelligence methodologies and strategies to guide decision-making practices in educational institutions. In Realizeit the deeply granular learner data is available for any analysis that an institution might require. This drives insights and discovery of new patterns, relationships and features at any level, from the individual learner or instructor to course level metrics and institutional level analysis.



## Realizeit for Faculty

### Learning Analytics

Realizeit provides faculty with access to detailed evidence of performance and engagement for groups of learners. Overall progress, achievement and ability levels for are readily available. These are available at as granular a level as needed, so that faculty can identify specific areas of weakness, and can adjust their teaching accordingly.

In addition, the same level of granular evidence can be seen for each individual learner, with the result that faculty can recommend further content for an individual, set additional sub-objectives in Realizeit, prompt practice of questions for a given topic, or provide any appropriate intervention.

### Assessing learners

Faculty can quickly and automatically create tests and assessments to include as part of the learning process. Again faculty simply has to identify the topic or area that needs to be tested and all the rest is done by Realizeit.

If so desired, criteria such as level of difficulty, number of attempts allowed, ways in which the questions should be grouped etc. can be specified. Faculty can also decide whether or not each individual is to get the same assessment – Realizeit can, for example, be instructed to set a test for each learner with a difficulty level appropriate to each individual. Faculty can also preview any assessment that has been constructed, and reconstruct it if they are not happy with everything.

### Learning material

Faculty have access to a unified set of knowledge that integrates the learning material with other teaching resources that may be used. They can easily add or customize learning material. This can range from something as simple as adding a link to an external resource, to adding notes in a document or presentation format, to including a video, and to authoring questions that can be used to assess learners. A faculty member can quickly learn how to incorporate generalization capabilities in questions, so that each learner will be presented with different questions.

## **Realizeit for the Institution - Academic Analytics**

Realizeit represents a new paradigm of learning. It breaks the traditional boundaries that surround formative and summative assessment by providing an ongoing and evolving continuum of assessment.

Realizeit naturally gathers pieces of evidence and uses them to affect its understanding of the learner's abilities, strengths and weaknesses. Furthermore it can provide a mechanism to collate data across many different levels: course, school, department, institution, thus providing a real-time view into the state of learning and understanding at each level.

At the lowest level, instant access to cumulative metrics is available at all times for cohorts of learners or for individual cases. Not only is this data available to a school, or department, but it is also used by Realizeit to evaluate the effectiveness of individual pieces of content in achieving the learning objectives. In addition, the Realizeit academic analytics are used to question curricular assumptions, using accumulated evidence to indicate strengths and weaknesses of prerequisite relationships between knowledge items. Thus the quality of a course being delivered can be improved using evidence gathered from learners of that course and their usage of Realizeit.

Realizeit utilizes all interactions with the learner as a form of assessment result, or evidence, in conjunction with innovative algorithms and tools, to ensure that a complete and immediate picture of the learner's ability and progress is available and is used at all times. This is in contrast to traditional approaches to assessment which simply measure the learner's knowledge and ability at a particular point in time, with the consequence that decisions are made based on assumptions that are out of date. Evidence harvesting at a granular level ensures that visibility of educational progress is transparent and integrated.

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