DEKXTROSE: An Education 4.0 Mobile Learning Approach and Object-Aware App Based on a Knowledge Nexus

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Abstract—**The exponential growth in knowledge coupled with the decreasing knowledge half-life creates a challenging situation for educational programs - particularly those preparing software engineers for their very dynamic high-technology field. Teachers in high technology education areas are challenged in selecting and making relevant knowledge intuitively accessible to students, especially with regard the highly dynamic digital and software technologies. This paper contributes a knowledge nexus-based multimedia approach aligned with Higher Education 4.0 for creating learning apps on mobile devices that support multiple didactic models, leverage intrinsic curiosity and motivation, support gamification, and enable digital collaboration. Object recognition is used to trigger learning paths, and various didactic methods are supported via workflow-like learning flows to support group or team-based learning. A prototype app was realized to demonstrate its feasibility and an empirical evaluation in software engineering shows the didactic potential and advantages of the approach, which can be readily generalized and applied to the arts, sciences, etc.**

Keywords - Higher Education 4.0; e-Learning; mobile learning; m-Learning; computer science education; software engineering education; mobile app.

I. INTRODUCTION

We are experiencing an exponential growth in knowledge, articulated by Buckminster Fuller [1] and known as the knowledge-doubling curve. IBM extrapolated that by 2020 knowledge would be doubling in a matter of hours [2]. Among the factors fueling this trend are the digital and interconnected global access to knowledge, the transition from industrial to knowledge- and service-based societies, the advancement of science and invention, collaborating teams, computer-based data analysis of big data and that generated by sensors and devices, etc. However, not all knowledge remains stable, valuable, useful, and accurate for long, but goes through a process of knowledge decay or obsolescence, implying that some subset of our knowledge has a "half-life" as articulated by Fritz Machlup, and this half-life is correspondingly decreasing [3]. One can view this trend to be exacerbated for high-technology fields and related education and training.

As to the background context for this paper, Software Engineering (SE) can be viewed as a subset of Computer Science (CS) and Systems Engineering (SysE) as a related field. Because SE is a high technology field and software exists in an artificial man-created environment, it is perhaps even more susceptible to accelerated knowledge dynamics versus other fields. This creates a challenge for educating and training software engineers to acquire relevant knowledge and skills that are not obsolete when conveyed or soon thereafter, and perhaps not yet obsolete by the time they enter the marketplace.

A correlating concept to Industry 4.0 is the concept of Education 4.0 [4], or more specifically Higher Education 4.0 [5], which aims to better align humans and technology in the area of tertiary education. It involves various aspects that are values of a digital native culture, including: student-centric approaches instead of traditional lectures, individualistic (customized) learning, internet and multimedia usage, collaborative peer emphasis, mobile device usage, and leveraging learning analytics to customize experiences.

To deal with these situations, it is imperative that CS, SysE, and SE education (SEE) embrace more technologically sophisticated approaches for conveying and transferring knowledge, especially for the fast-changing area of digital technologies. Despite the budding digitalization, knowledge, particularly related to some high-technology object in our nearby environment, often remains abstract and scattered and hidden within literature or scattered on the web. Learning or direct connections of knowledge and questions regarding visible objects in our environment is not triggered automatically by visible objects in our environment, e.g., Wikipedia expects a search term and Amazon Alexa expects a question or command. In addition, it is becoming increasingly difficult to keep track of the flood of information and to perceive open questions and problems with other questions, including time-delayed ones, and to develop solutions and incorporate new knowledge in a co-operating manner. Emails, social networks (Slack, WhatsApp), and Learning Management Systems (LMS) are not really conducive to linking knowledge to certain objects of interest in a time-delayed manner. The attention and concentration on a topic and the motivation and interest can also be awakened and held by visible objects (such as Internet-of-Things devices), and thus offers an additional tactile incentive to acquire the knowledge behind it.

In previous work [6], our edutainment approach called Software Engineering for Secondary Education (SWE4SE) combined short informational videos and various simple digital games. This paper contributes a knowledge nexus-based multimedia approach for creating mobile learning (mLearning) apps that support augmented reality object identification, multiple didactic models, leverage intrinsic curiosity and motivation, support gamification, and enable digital collaboration. Object recognition is used to trigger learning paths, and various didactic methods support group or team-based learning via learning workflows. A prototype app was realized to demonstrate its feasibility and an empirical evaluation shows its potential and the advantages of the approach for supporting SEE. We call it DEKXTROSE (Didactic-Enhancing Knowledge-neXus TRail-enabled Object-aware Software for Education), which can be viewed as a sweetener for education and training.

The paper is organized as follows: the next section describes related work; Section 3 describes our mLearning solution approach; Section 4 provides details about ou5 realization, which is followed by our evaluation in Section 4; finally, a conclusion is provided.

II. RELATED WORK

Various systematic reviews of mLearning have been performed. Zydney & Warner [7] studied 37 articles, of which three focused on tertiary students. Technology-based scaffolding was used in 23 apps to guide students with mLearning, and 19 apps gave users the ability to digitally construct knowledge. 12 apps supported digital knowledge sharing. Krull & Duart [8] provide a systematic review of the use of mobile devices in higher education. Among their findings was that more research and practice is required in themes related to innovative approaches (such as context-awareness, augmented reality, and gamification). The most common research theme was enabling mLearning applications and systems. Chang & Hwang [9] performed a systematic review of journal publications regarding digital game-based learning in the mobile era. Most of the 113 papers involved role-playing games (41), followed by simulation games (23), and then gamification (20). In their systematic review, Anohah et al. [10] analyzed 86 articles regarding mLearning in computing education, and found the following learning effects reported: knowledge, experience, engagement, interest/attitude, motivation, confidence, interactivity, enthusiasm/excitement, critical thinking, problem solving skills, team work, and analytical skills.

Khaddage et al. [11] proposed an approach for seamlessly blending formal and informal learning in mLearning based on science, technology, engineering, art and mathematic subjects to achieve some required learning outcome in informal settings. Schefer-Wenzl & Miladinovic [12] provide an approach for teaching software development topics that combines mLearning with just-in-time teaching, industry-like student projects and peer assessment. No specialized app was presented to realize their approach.

We found no mLearning work that is specifically focused on the CS/SE/SysE domain with a single app that holistically supports a potpourri of didactic methods via learning workflows, utilizes a collaboratively taggable knowledge nexus with multimedia content, supports social networking via chat and object-aligned commenting, utilizes object recognition for triggering learning paths, integrates quizzes for immediate learning feedback, and supports gamification as a motivational factor for informal learning.

III. MLEARNING APPROACH

Our solution concept and investigation were motivated by several questions and factors. We wanted to determine to what extent is object recognition currently practical for didactic applications, and if the recognition rate good enough for real usage. Furthermore, can digital learning and knowledge content be connected to physical objects and triggered by users in context? How can knowledge and practice (from research and professional practice) be efficiently and effectively modularized into digital units, reused, and linked in a nexus-like way? How can digital long-lived sequential learning trails (routes through knowledge) be technically realized? How can complex learning flow templates (to actively support methods such as research learning, problem-based learning, project learning, experiential learning with assistance and navigation suggestions ("guidance") be technically implemented? To what extent can technically supported learning flows support creative thought processes? Additionally, is gamification motivating for all users, or are some primarily intrinsically motivated? And finally, can we easily reuse digitally available information material in a way that: leverages intrinsic curiosity and motivation, visually shows how one knowledge granule relates to another - and helps users find the next interesting knowledge granule; enables users to add and share their own knowledge or opinions onto a knowledge node; and facilitates individual customized learning and flipped classroom approaches that put the student in the driver's seat.

Underlying presuppositions for our solution include:

1) Individualized (no single one-size-fits-all): For certain courses or training - especially higher-semester courses, a one-size-fits-all didactic model is not effective nor efficient with regard to the post-course relevance of transferred knowledge. Each individual has personal preferences, pre-existing knowledge, competencies, learning styles, etc.
2) Disparate, unpackaged knowledge: Much of the knowledge that "should" be distributed to an individual is not exclusively available from the mind of the expert, but also digital sources, especially in the SE domain. However, the knowledge has typically not been fashioned in a way that lends itself to efficient learning. Web search engines, while designed to quickly find relevant web pages, are not designed to support efficient learning.
3) Networked-knowledge: knowledge is not isolated and (mostly) not immutable, but rather relevant or connected to other knowledge to some degree. Certain knowledge objects have multiple possible representations and ways they can be consumed (e.g., media formats). Digitally accessible resources should be reused if possible.

Figure 1 depicts DEKXTROSE, which incorporates the following capabilities and concepts:

- Scanned object recognition (object-awareness)
- LearningPaths (trails) with the integration of web/video/photo content as tags

- LearningFlows (process stencils) that comply with specific didactic methods
- Gamification via quizzes and badges is supported.
- Data/learning analytics available

Figure 1. DEKXTROSE mLearning approach.

LearningPaths are trails that explain knowledge in a predetermined sequential order using multimedia offers (e.g., about certain technologies that users do not yet know) and contains a quiz at the end. It can be started by object recognition in order to acquire knowledge by curiosity about possibly unknown objects, or by choosing a LearningPath directly from the menu. Users can acquire requisite knowledge and skills using LearningPaths.

LearningFlows are learning workflows that enable different didactic methods (research learning, problem-based learning, project learning, experience-based learning) to be quickly understood and self-directed, alone and as a team, methods previously unknown to users. Thus, by providing students a goal and LearningFlow (process), a team of students is provided with a framework with which they can achieve some goal.

DEKXTROSE links digital knowledge and questions with real objects in the immediate environment using the device's camera together with an object recognition service. Thus, objects can be recognized, parts of such a knowledge nexus can be triggered and visualized, and curiosity can be aroused. Passive LearningPaths provide sequential learning of expertise in these objects using self-motivation; by means of more complex LearningFlows, different didactic methods can be applied in a self-directed fashion to knowledge processes.

Didactically, our solution approach involves cognitive aspects that relate to basic knowledge concepts conveyed via networked knowledge nodes (knowledge granules). It is also instrumental in that it utilizes LearningPaths, quizzes, and badges to motivate. It is formative-educative in supporting the development of skills and abilities and the achievement of educational objectives. Both the LearningPath and LearningFlow facilitate the flipped classroom learning approach, allowing the students to be in the driver's seat and a teacher to take on the role of a facilitator.

As to the applicability to SE, the concepts inherent in SE are exemplified in the SWEBOK [13] and for SysE in the SEBoK [14]. The objectives of the SWEBOK include promoting a consistent view of SE, clarifying the bounds of and characterizing the contents of SE with respect to other disciplines, and providing a topical access to the SE Body of Knowledge (BOK). Knowledge areas (KAs) have a common structure, including a subclassification of topics and topic descriptions with references. Available technologies play a key role in creating viable systems and software that address stakeholder needs, and software and systems engineers need to be aware of current available technologies, understand what they are – including in relation to one another, and to a certain degree how they work. The SWEBOK references technologies and aspects at various points, which are suitable for knowledge our approach can convey. These including Construction Technologies (3-8) as well as various Computing Foundations (13), including Computer Organization (13-13), Network Communication Basics (13-19), the Internet and Internet-of-Things (13-20), Operating Systems Basics (13-16), Basic Concept of a System (13-11), Parallel and Distributed Computing (13-21), Basic User Human Factors (13-22), etc. While the SWEBOK is currently published in a static format, a more dynamic wiki-like format could support more SE community involvement and knowledge updates.

Geddes, Cannon, and Cannon [15] articulate the concept of individual absorptive capacity (IAC), and we argue that education should further students' ability to acquire new knowledge and skills rapidly - even beyond the confines of their current course or curriculum. In our view, our solution approach can be used to further the IAC for students.

IV. REALIZATION

To realize DEKXTROSE, we developed a cross-platform tablet app for iOS and Android using Flutter, the Google Firebase ML Kit service for machine-learning-based object recognition, the mlkit-custom-image-classifier for custom image/object training on a set of images taken of an object, and the Google Firebase Cloud Firestore service for backend data storage.

A graph of knowledge nodes is manually realized (see Figure 2), implemented as a set of JSON documents that contain links to other related knowledge nodes, as well as detailed information and media pertaining to that node (see Figure 3 left). In order to easily add information (e.g., comments, links to external site or photos, etc.), the concept of tags are used. From a technical perspective, our use of cloud storage as a backend for the app permits us to easily add to or adapt the knowledge nexus at any time without requiring the app software to be updated. This supports longer-term sustainability of the knowledge network. Furthermore, moderators, analogous to Wikipedia, can be utilized for certain areas of expertise to validate entries, add new knowledge, and maintain the network.

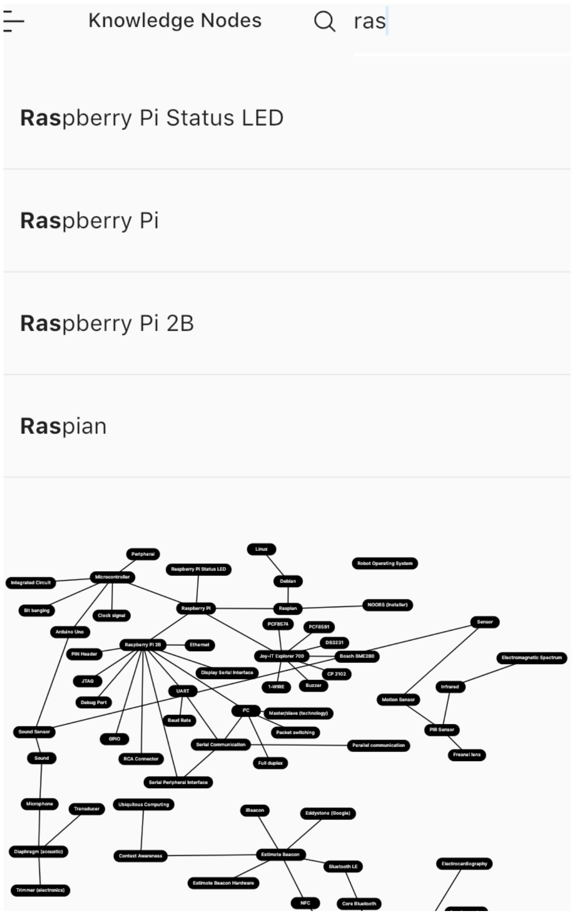

Figure 2. Knowledge nodes can be browsed, searched, and viewed as a list (top) or nexus (bottom, network overview).

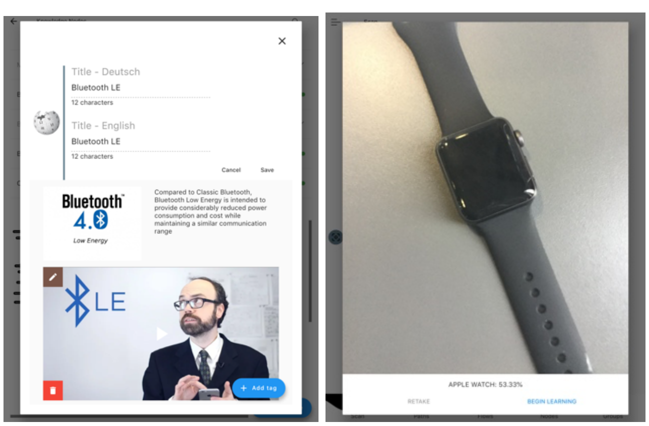

Figure 3. Descriptive information and multimedia can be added via tagging (left); screenshot of object recognition via camera (right).

LearningPaths, a sequence/path of knowledge nodes, can be specified by an administrator (Figure 4 top). Object recognition can be used to trigger a LearningPath, (Figure 3 right), which is implemented using machine learning on a set of images with the ML Kit.

Private and public tags can be added (Figure 5) - must be approved by a moderator before visible to other users, and these can include text, images, and video or other web links.

Figure 4. LearningPath is shown on top with the Knowledge Nexus for context (current node in blue) and Knowledge Object details (bottom).

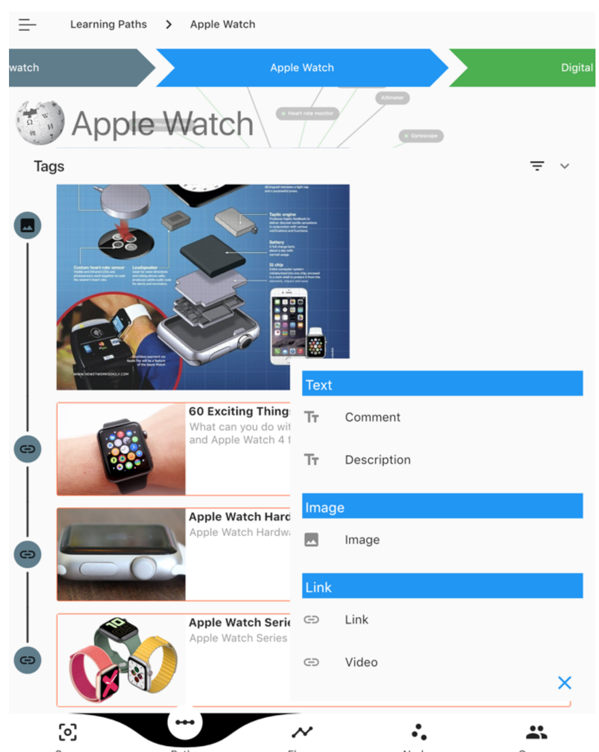

Figure 5. Tagging options with various tag types.

Quizzes provide quick feedback and provide an orientation for users on the relevant knowledge for that LearningPath (see Figure 6 left). To support gamification as a motivational factor, badges (bronze, silver, gold) can be earned based on how well the quizzes were answered (see Figure 6 right).

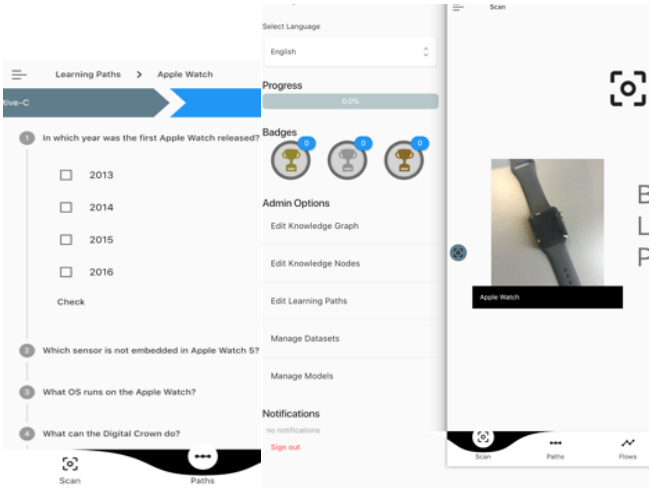

Figure 6. A quiz (left) includes questions such as: What sensor is not embedded in the Apple Watch? Which OS runs on Apple Watch? Depicted on the right are a progress bar and the badges.

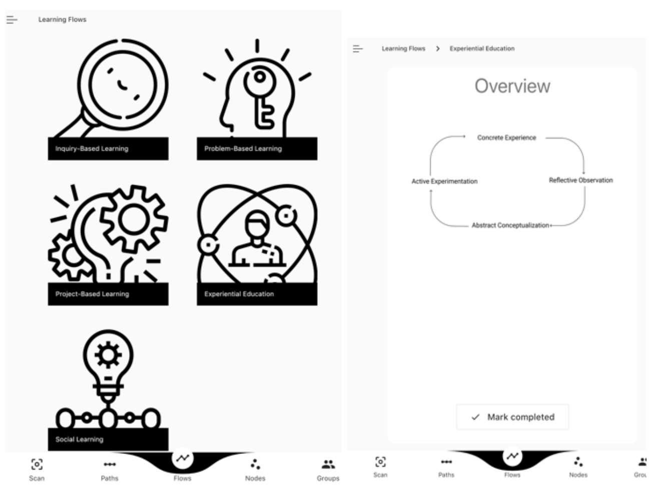

Figure 7. LearningFlow choices (left) and LearningFlow step, completed button, and textual explanation (right).

Once LearningFlows is selected, the set of possible LearningFlows is shown (see Figure 7 left). Once a specific LearningFlow is selected, an initial overview (see Figure 7 right) provides users with quick insights into the intent that particular learning technique. Via swiping the next is shown. Any step can be marked as completed. Details on any step in LearningFlow are provided: the left displays the overall process, while on the right further details and resources can be seen.

To facilitate collaboration, chat functionality is supported directly in the app.

V. EVALUATION

Our qualitative evaluation focused on the subjective impressions of participants in three areas: LearningPaths, LearningFlows, and general impressions. A convenience sample of thirteen computer science students took part (average semester = 5.8, min=3, max=8) using iPads or Sony tablets running Android. Due to data privacy concerns, we did not utilize the data analytics capabilities in the following evaluation.

For the LearningPaths feature, participants only chose paths about topics they had no significant knowledge of. First, they attempted a learning path without our app using URLs only for 15 minutes. They selected a topic and then visited URLs related to that topic (one's we had prescreened) without the assistance of our app, and then they answered a quiz. After that, they were given 15 minutes to use the LearningPath feature of our app, selecting a different unknown topic and then answer the built-in quiz. As to the topics and content we chose to offer, we assume that software engineers should have some knowledge about hardware and electronics (to a slight degree) when, for example, involved with the Internet-of-Things (IOT) or embedded systems. This also ensured that there would be at least some topics with which the computer science students were not yet knowledgeable. The available LearningPaths were:

- Beacon technology
- Raspberry Pi
- Raspberry Pi Internet-of-Things extension board
- Android
- Apple Watch
- Various hardware sensors (light, temperature, motion, sound, moisture)

TABLE I. DEKXTROSE QUESTIONNAIRE RESULTS

Area	Question	Average[a]
LearningPath	How helpful was the LP in learning?	4.00
	How much fun was using a LP?	4.08
	Were the quizzes motivating?	3.69
	Did quizzes provide helpful feedback when learning?	4.23
	Was earning badges motivating?	2.69
	How better/worse was the learning experience with app vs. without an app? (worse=-1, 0, better=+1)	0.85
Learning Flow	How helpful was the LF in learning?	3.15
	How much fun was it to use the LF?	3.69
General	Did you learn things you wouldn't have learned otherwise?	92% Yes
	Intuitiveness?	3.54
	How efficient was learning something new w/ app?	2.23
	Curiosity aroused about new technical knowledge?	3.15
	What was more fun?	100% app
	What would be your preference?	100% app
	What was the overall learning experience like?	4.00

a. Unless indicated, scale 5-1 where 5=Very and 1=Little

Subsequently, the learning experience (with and without app) was evaluated by means of a paper-based questionnaire. The results are shown in the "LearningPath" (LP) area in Table 1. To evaluate LearningFlows, the participants self-formed groups of 2-3 people and were directed to apply the learning flow "Experiential learning" with our app, going through all the steps at least once, in order to optimize a simple paper-based product within 15 minutes. Only one of the participants had prior knowledge of experiential learning. Then they answered questions about the learning experience, the results of which are shown in the "LearningFlow" (LF) area of Table 1. Finally, general questions on the entire learning experience were answered as shown in the "General" area of Table 1.

A selection of participants comments included:

- Can easily & quickly dive into new topics; greater depth of information is available when needed
- App summarizes knowledge compactly & very well; mostly intuitive to use.
- Topic overview via nodes was good and encouraged dig further into the topics of interest
- Learning path is very useful/helpful for unknown topics
- Prepared content is very good
- Graph view of knowledge nodes useful

The evaluation shows DEKXTROSE to be a viable approach. It can be used to support aspects of Education 4.0, including self-directed learning such as the flipped classroom approach, internet-connected multimedia, internet-based collaboration, and student data analytics that can be used to further customize the user learning experience.

VI. Conclusion and Future Work

Our DEKXTROSE Education 4.0 mLearning approach shows how relevant knowledge regarding technologies can be conveyed with a mobile app on a tablet while reusing digitally available knowledge organized as a knowledge nexus. The knowledge nexus can be explored for inquisitive learners. LearningPaths provide guided journeys through knowledge and are followed with a quiz to provide instant feedback and badges to support gamification. Objects in the environment can be used to trigger a LearningPath. LearningFlows support the use of didactic methods by individuals or teams, explaining the steps and tracking the state. Thus, it supports self-directed learning and flipped classroom approaches. Aspects of Education 4.0 are supported, providing digital natives a multimedia self-directed learning experience. The evaluation showed a strong approval and interest by students and shows its potential to help produce career-ready technology professionals who are aware of and knowledgeable about current technologies to "hit-the-ground-running." We believe the approach is generalizable to various other domains, including art, science, etc., and would be beneficial for education and training.

Future work includes: weighting the degree of connectedness between knowledge nodes based on a variable function of user-configurable parameters; utilizing the data and learning analytics to customize the learning experience, including adjusting paths based on a student's profile and career, role, and other interests; applying the approach in other domains; and a comprehensive empirical evaluation.

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