YAI4Edu: an Explanatory AI to Generate Interactive e-Books for Education

Francesco Sovrano[1][0000−0002−6285−1041], Kevin Ashley[2], Peter Brusilovsky[2][0000−0002−1902−1464], and Fabio Vitali[1][0000−0002−7562−5203]

[1] University of Bologna, Bologna, Italy
[2] University of Pittsburgh, Pittsburgh PA, USA

Abstract. In this article, we investigate how explanatory AI can better harness the full potential of the vast and rich library of books at our disposal. Based on a recent theory of explanations from Ordinary Language Philosophy that frames the process of explaining as illocutionary process of answering to questions, we have developed a new kind of interactive and adaptive e-book. Using the most recent question answering technology, our e-book automatically generates a specialized knowledge graph from a collection of books and other resources and extracts questions and answers. With this knowledge graph, the e-book generates interactive and adaptive explanations that guide readers through the materials in a pedagogically productive manner.

Keywords: Explanatory Artificial Intelligence · Interactive e-book · Question answering · Knowledge graph extraction · Education.

1 Introduction

Being able to harness and share knowledge is central to the health and prosperity of our society. Since the invention of writing, we (as society) managed to gather together a huge amount of diverse written contents. Nowadays, thanks to recent advancements in artificial intelligence and computer science, we have the ability to search through impressive amounts of books for answers or many other types of information. Nonetheless, fully harnessing the potential of knowledge in an intuitive and user-centred way is still an open problem.

For example, different readers might seek and require different types of information regardless of the fact that a single book has a predefined exposition and content. This is why different books about the same topic exist, unfolding the same knowledge in different ways and with heterogeneous levels of detail. Furthermore, the background knowledge of the reader might vary considerably so that even the most basic concepts should be explained thoroughly whenever the reader needs to acquire them or refresh memory.

These insights lead us to the identification of the following problem. Most of our educational content (e.g. books) is static, although rich in contents possibly scattered throughout hundreds of pages, indirectly relying on external knowledge for the reader to understand. This static type of representation, in the most generic scenario, is sub-optimal and time consuming for a human reader because useful information can be either sparse or lacking.

To address this problem we study how to automatically enhance (static) books making them interactive, thus reducing the sparsity of relevant information and also increasing the explanatory power of the medium by linking it to a knowledge graph extracted from a wide collection of related books. To do so, we exploit a recent theory of explanations from Ordinary Language Philosophy, framing the process of (interactively) explaining as a process of illocutionary question answering [16,17]. Our work heavily relies on the intelligent interface design for the generation of user-centred explanations proposed by Sovrano et al. [15,17]. In particular, we extend [17] to make it more adaptive and specific to education. To summarize, assuming that the goal of an educational e-book is to explain something to the reader, the technology we are proposing is designed around the idea that organizing the explanatory space (the space of all possible bits of explanation) as clusters of questions and answers is beneficial for the reader.

With the present article we briefly introduce YAI4Edu, a first prototype of Explanatory AI to generate interactive e-books for education, without providing, for now, any empirical results or in-depth evaluations (besides those already carried out in [17]).

2 Related Work

There are studies suggesting that using interactive e-books leads to an increase in use, motivation, and learning gains versus static e-books [5]. In particular, we have several streams of work on the topic of interactive e-books. Most of these works seem to focus on the cognitive process of the reader, studying how to enhance the pedagogical productivity of textbooks through expert systems or sophisticated interfaces. They usually do it by showing personal progress through open learner models [6,7], or by specialising on ad hoc tasks through some kind of domain modelling [4,3,9], or by student modelling through questions in order to identify and suggest personalised contents [19,11,9], or by providing tools for manually creating new interactive e-books [12,8].

In this sense, the use of AI for the automatic generation of interactive e-books seems to be under-explored. Differently from all the examples we found in literature, our approach attempts to fully automatically convert an existing e-book into an interactive version of it by exploiting theories of explanations and intelligent interfaces.

3 Background

The goal of this section is to provide enough background information for the reader to understand what are explanations and the existing metrics to evaluate explanations.

Achinstein's Theory of Explanations. In 1983, Achinstein [1] was one of the first scholars to analyse the process of generating explanations as a whole, introducing his philosophical model of a *pragmatic* explanatory process. According to the model, explaining is an *illocutionary* act coming from a clear intention of producing new understandings in an explainee by providing a correct content-giving answer to an open question.

Definition of Illocution. According to [15,17], it is possible to define *illocution* in a more "computer-friendly" way as an act that involves informed and *pertinent* answers not just to the main question, but also to other (archetypal) questions of various kinds, even unrelated to causality, that are relevant to the explanations. Many examples of these archetypal questions are given by [15,17], i.e. why, what, when, who, how, etc.

Explanatory AI. An example of intelligent interface based on Achinstein's theory of explanation has been discussed in [15,17]. These works rely on AI for knowledge graph extraction, question-answer extraction and question-answer retrieval. In particular, the explanandum[3] is reorganised and represented as a special hyper-graph where information can be either explored through *overviewing* or searched through *open questioning*. On one hand, *overviewing* can be performed iteratively from an initial explanation by clicking on annotated words for which an explanation (in the form of a cluster of questions and answers automatically generated by the AI) is needed. On the other hand, *open questioning* can be performed asking questions in English through a search box that uses an underlying knowledge graph for efficient question-answer retrieval.

DoX is an algorithm proposed by [18,16] that can measure the quality of explainable information. DoX is a model-agnostic approach based on *Achinstein's theory of explanations*. In practice, DoX can quantify the degree of explainability of a corpus by estimating how adequately that corpus could be used to answer in an illocutionary way an arbitrary set of archetypal questions about the concepts of the explanandum.

4 YAI4Edu: an Explanatory AI for Education

Our proposed solution is called YAI4Edu (meaning Explanatory AI for Education) and it is an extension of the Explanatory AI used by [15,17] to generate interactive user-centred explanations. More specifically, interaction is given by word glosses (called *overviews*) and a special kind of search box that allows the reader to get answers about any English question, as described in section 3. In particular, we adapted such Explanatory AI to transform static educative

[3] Explanandum means "what is to be explained" in Latin.

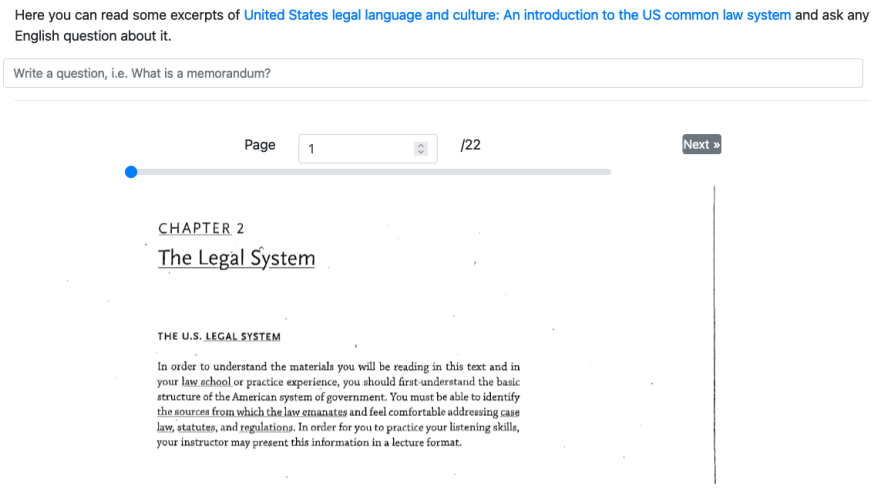

Fig. 1. Explanatory AI - Landing Page: This figure contains a screenshot of the annotated textbook and the input for *open questioning*. The textbook is an excerpt of [2]. Clicking the underlined words opens an *overview*.

textbooks (in PDF format) into interactive e-books. To this end, we developed several AI-based mechanisms for: i) smart annotation generation, ii) adaptive overviewing, iii) and granular overviewing.

Smart Annotation Generation is a mechanism for automatically annotating a PDF book. Similarly to [15,17], these annotations, when clicked, open an *overview* (a special cluster of information explaining the annotated word). Differently from [15,17], the mechanism for the identification of which words to annotate is more intelligent and it relies on DoX. Indeed, our smart annotation mechanism annotates only those concepts and words that are the most explainable (i.e., with a DoX greater than a predefined threshold) by the content of the knowledge graph extracted from the textbook and other related resources. This annotation mechanism is intended to significantly remove noisy annotations and distractors, so that the reader focuses only on the most central and well-explained concepts.

Adaptive Overviewing. We improved the mechanism of *overviewing* proposed by [15,17] in order to support adaptive and more fine-grained explanations. More specifically, we designed a naive knowledge tracing mechanism that keeps track of pieces of information previously shown to the reader in order to filter them and re-organise the content of *overviews* accordingly. Furthermore, we changed the ranking mechanism that orders information inside the *overview* so that the most explanatory questions are presented first. The degree of explainability of such questions is computed through DoX as in the *smart annotation generation*.

Granular Overviewing. Similarly to [15,17], the content of the *overviews* we use is composed by a set of pre-defined archetypal questions (i.e., why, what,

how, who) about the main topic of the *overview*. Differently from [15,17] though we consider also more domain specific archetypal questions automatically extracted from the knowledge graph through an AI specifically trained for question-answer extraction. In order to automatically extract pairs of meaningful questions and answers, we trained in a supervised manner a general-purpose deep language model on 2 data-sets [10,13] composed by tuples of (s, q, a), where s is a source sentence, q is a question (implicitly) expressed in s and a is an answer expressed in s. We decided to adopt the T5 [14] technology in order to combine different tasks (e.g. the extraction of both discourse relations and abstract meaning representations) within a single language models.

To summarize, assuming that the goal of an e-book is to explain something to the reader, our YAI4Edu is designed around the idea that organizing the Explanatory Space (the space of all possible bits of explanation) as clusters of questions and answers is beneficial for the reader. In figure 1 and figure 2 we show an example of our Explanatory AI applied to an excerpt of a textbook for teaching how to write legal memoranda in the US legal system. This textbook is used in the course of "Applied Legal Analytics and AI" at the University of Pittsburgh. More precisely, "Applied Legal Analytics and AI" is an interdisciplinary "joint course, co-taught by instructors from the University of Pittsburgh School of Law and Carnegie Mellon University's Language Technologies Institute, providing a hands-on practical introduction to the fields of artificial intelligence, machine learning and natural language processing as they are being applied to support the work of legal professionals, researchers, and administrators".

5 Discussion

The prototype we just presented is the first step towards a more thorough evaluation of the underlying theory of explanations. The overall hypothesis behind our work is that explaining is somehow about question answering so that the more questions a book can answer, the more it explains. In other terms, the explanatory power of a book can be improved by making it interactive in a way that helps its readers to identify the most important questions to be answered and to get answers about their own questions.

To verify this hypothesis we need an experiment that would show that students can acquire new knowledge more deeply with an interactive e-book generated with our enhanced Explanatory AI. Furthermore, we should be able to verify this on multiple domains and with multiple textbook to claim that our proposed solution is generic enough and to verify the hypothesis in the most generic case. An experiment to this end could be the following.

We identify a population of N students and we give them a normal book to study and a goal in the form of "Explain in the most detailed way topic T and anything related to it". Then we take another population of N students and we give them the same goal and an interactive version of the book generated

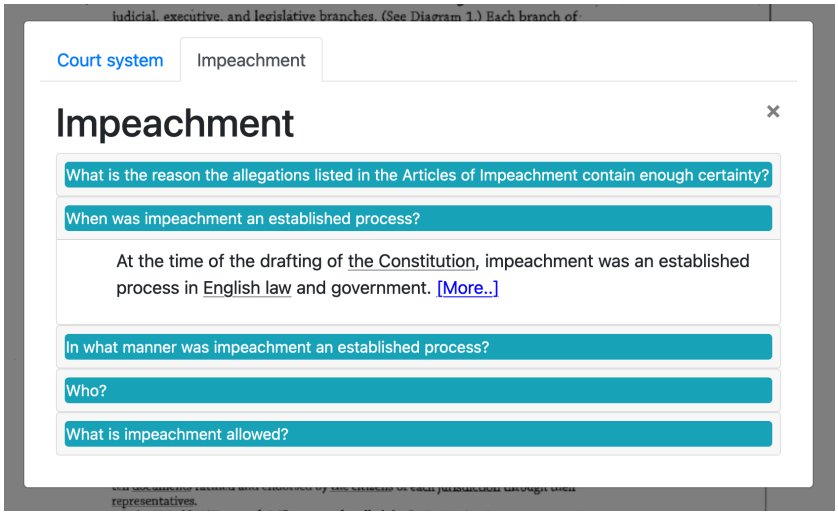

Fig. 2. Explanatory AI - Overviews: This figure shows an example of interactive *overview* in the form of an accordion of relevant questions and answers. When clicking on one question, a sequence of pertinent answers is provided to the reader. The reader can also select new concept to overview by clicking on any underlined word.

by YAI4Edu. We collect the answers from both the populations and we shuffle them. Then we give these answers to a professor for the evaluation, in a way that guarantees that the professor does not know in advance whether a student comes from the first or the second population. Eventually, if the second population of students, in average, gets better evaluations than the first population, then we can say that the hypothesis holds.

6 Conclusions and Future Work

With this paper we presented a prototype of YAI4Edu, an Explanatory AI for the automatic generation of interactive and adaptive e-books for education. To create YAI4Edu we enhanced the Explanatory AI proposed by [15,17], making it more adaptive and smart. More precisely, we devised a novel mechanism for selecting explanatory contents based on DoX [16] and a naive strategy for knowledge tracing. Such strategy we adopted for knowledge tracing is extremely naive and it should considered only as baseline whereas more sophisticated mechanisms might be used instead, e.g. FAST [20].

As future work, we plan to run the experiment discussed in section 5 on different textbooks or other educative media used in the context of Law and Computer Science. Such experiment will consist in a user study focused on understanding whether the underlying theory as well as the presented prototype of YAI4Edu are good enough to address the problem of automatically generating interactive e-books.

Acknowledgements

This work was partially supported by the European Union's Horizon 2020 research and innovation programme under the MSCA grant agreement No 777822 "GHAIA: Geometric and Harmonic Analysis with Interdisciplinary Applications".

References

1. Achinstein, P.: The Nature of Explanation. Oxford University Press (1983), https://books.google.it/books?id=0XI8DwAAQBAJ
2. Brostoff, T.K., Sinsheimer, A.: United States Legal Language and Culture: An Introduction to the U.S. Common Law System. Oxford University Press USA (2013), https://books.google.it/books?id=SVsGAQAAQBAJ
3. Chacon, I.A., Barria-Pineda, J., Akhuseyinoglu, K., Sosnovsky, S.A., Brusilovsky, P.: Integrating textbooks with smart interactive content for learning programming. In: Sosnovsky, S.A., Brusilovsky, P., Baraniuk, R.G., Lan, A.S. (eds.) Proceedings of the Third International Workshop on Inteligent Textbooks 2021 Co-located with 22nd International Conference on Artificial Intelligence in Education (AIED 2021), Online, June 15, 2021. CEUR Workshop Proceedings, vol. 2895, pp. 4–18. CEUR-WS.org (2021), http://ceur-ws.org/Vol-2895/paper11.pdf
4. Deligiannis, N., Panagiotopoulos, D., Patsilinakos, P., Raftopoulou, C.N., Symvonis, A.: Interactive and personalized activity ebooks for learning to read: The iread case. In: Sosnovsky, S.A., Brusilovsky, P., Baraniuk, R.G., Agrawal, R., Lan, A.S. (eds.) Proceedings of the First Workshop on Intelligent Textbooks co-located with 20th International Conference on Artificial Intelligence in Education (AIED 2019), Chicago, IL, USA, June 25, 2019. CEUR Workshop Proceedings, vol. 2384, pp. 57–69. CEUR-WS.org (2019), http://ceur-ws.org/Vol-2384/paper06.pdf
5. Ericson, B.: An analysis of interactive feature use in two ebooks. In: Sosnovsky, S.A., Brusilovsky, P., Baraniuk, R.G., Agrawal, R., Lan, A.S. (eds.) Proceedings of the First Workshop on Intelligent Textbooks co-located with 20th International Conference on Artificial Intelligence in Education (AIED 2019), Chicago, IL, USA, June 25, 2019. CEUR Workshop Proceedings, vol. 2384, pp. 4–17. CEUR-WS.org (2019), http://ceur-ws.org/Vol-2384/paper01.pdf
6. Kay, J., Kummerfeld, B.: Scaffolded, scrutable open learner model (SOLM) as a foundation for personalised e-textbooks. In: Sosnovsky, S.A., Brusilovsky, P., Baraniuk, R.G., Agrawal, R., Lan, A.S. (eds.) Proceedings of the First Workshop on Intelligent Textbooks co-located with 20th International Conference on Artificial Intelligence in Education (AIED 2019), Chicago, IL, USA, June 25, 2019. CEUR Workshop Proceedings, vol. 2384, pp. 38–43. CEUR-WS.org (2019), http://ceur-ws.org/Vol-2384/paper04.pdf
7. Kay, J., Kummerfeld, B.: PUMPT: an e-textbook platform based on a personal user model for learning (short paper). In: Sosnovsky, S.A., Brusilovsky, P., Baraniuk, R.G., Lan, A.S. (eds.) Proceedings of the Third International Workshop on Inteligent Textbooks 2021 Co-located with 22nd International Conference on Artificial Intelligence in Education (AIED 2021), Online, June 15, 2021. CEUR Workshop Proceedings, vol. 2895, pp. 27–34. CEUR-WS.org (2021), http://ceur-ws.org/Vol-2895/paper12.pdf
8. Kluga, B., Jasti, M.S., Naples, V., Freedman, R.: Adding intelligence to a textbook for human anatomy with a causal concept map based ITS. In: Sosnovsky, S.A.,

Brusilovsky, P., Baraniuk, R.G., Agrawal, R., Lan, A.S. (eds.) Proceedings of the First Workshop on Intelligent Textbooks co-located with 20th International Conference on Artificial Intelligence in Education (AIED 2019), Chicago, IL, USA, June 25, 2019. CEUR Workshop Proceedings, vol. 2384, pp. 124–134. CEUR-WS.org (2019), http://ceur-ws.org/Vol-2384/paper13.pdf

9. Matsuda, N., Shimmei, M.: PASTEL: evidence-based learning engineering method to create intelligent online textbook at scale. In: Sosnovsky, S.A., Brusilovsky, P., Baraniuk, R.G., Agrawal, R., Lan, A.S. (eds.) Proceedings of the First Workshop on Intelligent Textbooks co-located with 20th International Conference on Artificial Intelligence in Education (AIED 2019), Chicago, IL, USA, June 25, 2019. CEUR Workshop Proceedings, vol. 2384, pp. 70–80. CEUR-WS.org (2019), http://ceur-ws.org/Vol-2384/paper07.pdf
10. Michael, J., Stanovsky, G., He, L., Dagan, I., Zettlemoyer, L.: Crowdsourcing question-answer meaning representations. In: Walker, M.A., Ji, H., Stent, A. (eds.) Proceedings of the 2018 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, NAACL-HLT, New Orleans, Louisiana, USA, June 1-6, 2018, Volume 2 (Short Papers). pp. 560–568. Association for Computational Linguistics (2018). https://doi.org/10.18653/v1/n18-2089, https://doi.org/10.18653/v1/n18-2089
11. Mohammed, M., Shaffer, C.A.: Increasing student interaction with an etextbook using programmed instruction (short paper). In: Sosnovsky, S.A., Brusilovsky, P., Baraniuk, R.G., Lan, A.S. (eds.) Proceedings of the Third International Workshop on Inteligent Textbooks 2021 Co-located with 22nd International Conference on Artificial Intelligence in Education (AIED 2021), Online, June 15, 2021. CEUR Workshop Proceedings, vol. 2895, pp. 40–44. CEUR-WS.org (2021), http://ceur-ws.org/Vol-2895/paper14.pdf
12. Pursel, B., Ramsay, C.M., Dave, N., Liang, C., Giles, C.L.: Bbookx: Creating semi-automated textbooks to support student learning and decrease student costs. In: Sosnovsky, S.A., Brusilovsky, P., Baraniuk, R.G., Agrawal, R., Lan, A.S. (eds.) Proceedings of the First Workshop on Intelligent Textbooks co-located with 20th International Conference on Artificial Intelligence in Education (AIED 2019), Chicago, IL, USA, June 25, 2019. CEUR Workshop Proceedings, vol. 2384, pp. 81–86. CEUR-WS.org (2019), http://ceur-ws.org/Vol-2384/paper08.pdf
13. Pyatkin, V., Klein, A., Tsarfaty, R., Dagan, I.: Qadiscourse - discourse relations as QA pairs: Representation, crowdsourcing and baselines. In: Webber, B., Cohn, T., He, Y., Liu, Y. (eds.) Proceedings of the 2020 Conference on Empirical Methods in Natural Language Processing, EMNLP 2020, Online, November 16-20, 2020. pp. 2804–2819. Association for Computational Linguistics (2020). https://doi.org/10.18653/v1/2020.emnlp-main.224, https://doi.org/10.18653/v1/2020.emnlp-main.224
14. Raffel, C., Shazeer, N., Roberts, A., Lee, K., Narang, S., Matena, M., Zhou, Y., Li, W., Liu, P.J.: Exploring the limits of transfer learning with a unified text-to-text transformer. J. Mach. Learn. Res. **21**, 140:1–140:67 (2020), http://jmlr.org/papers/v21/20-074.html
15. Sovrano, F., Vitali, F.: From philosophy to interfaces: an explanatory method and a tool inspired by achinstein's theory of explanation. In: Hammond, T., Verbert, K., Parra, D., Knijnenburg, B.P., O'Donovan, J., Teale, P. (eds.) IUI '21: 26th International Conference on Intelligent User Interfaces, College Station, TX, USA, April 13-17, 2021. pp. 81–91. ACM (2021). https://doi.org/10.1145/3397481.3450655, https://doi.org/10.1145/3397481.3450655

16. Sovrano, F., Vitali, F.: An objective metric for explainable AI: how and why to estimate the degree of explainability. CoRR **abs/2109.05327** (2021), https://arxiv.org/abs/2109.05327
17. Sovrano, F., Vitali, F.: Generating user-centred explanations via illocutionary question answering: From philosophy to interfaces. ACM Trans. Interact. Intell. Syst. (feb 2022). https://doi.org/10.1145/3519265, https://doi.org/10.1145/3519265, just Accepted
18. Sovrano, F., Vitali, F.: How to quantify the degree of explainability - experiments and practical implications. In: 31th IEEE International Conference on Fuzzy Systems, FUZZ-IEEE 2022, Padova, July 18-23, 2022. pp. 1–9. IEEE (2022)
19. Thaker, K., Brusilovsky, P., He, D.: Student modeling with automatic knowledge component extraction for adaptive textbooks. In: Sosnovsky, S.A., Brusilovsky, P., Baraniuk, R.G., Agrawal, R., Lan, A.S. (eds.) Proceedings of the First Workshop on Intelligent Textbooks co-located with 20th International Conference on Artificial Intelligence in Education (AIED 2019), Chicago, IL, USA, June 25, 2019. CEUR Workshop Proceedings, vol. 2384, pp. 95–102. CEUR-WS.org (2019), http://ceur-ws.org/Vol-2384/paper10.pdf
20. Thaker, K., Zhang, L., He, D., Brusilovsky, P.: Recommending remedial readings using student's knowledge state. In: Rafferty, A.N., Whitehill, J., Romero, C., Cavalli-Sforza, V. (eds.) Proceedings of the 13th International Conference on Educational Data Mining, EDM 2020, Fully virtual conference, July 10-13, 2020. International Educational Data Mining Society (2020), https://educationaldatamining.org/files/conferences/EDM2020/papers/paper_39.pdf