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RESEARCH ARTICLE

RECOMMENDING REMEDIAL LEARNING MATERIALS TO STUDENTS BY FILLING THEIR KNOWLEDGE GAPS

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Appendix A

MINLP Problem Statement and Comparison Analysis

In stage three (of the "Filling-the-Gap Recommendation Method" section of the paper), we discuss the problem of identifying the best matching subset of units of knowledge from each source of materials $S \in L$ for each topic T in the course taxonomy. In particular, we search for subset X that maximizes criterion (1). This problem can be formulated as a mixed integer nonlinear programming (MINLP) problem as follows.

Let us denote by $a_X = \{a_1, \ldots, a_s\}$ the indicator vector of subset X, such that $a_i = 1$ if i^{th} unit of knowledge from the source S belongs to subset X, and $a_i = 0$ otherwise. Therefore, the problem can be formulated as searching for the vector a_X with values $a_i \in \{0, 1\}$ maximizing the following criterion:

$$\max_{a_X}\left(\frac{\left(\sum a_i \cdot V(U_i)\right)\cdot V(T)}{\|\sum a_i \cdot V(U_i)\| \cdot \|V(T)\|}\right)$$

constituting the MINLP problem.

Furthermore, since the described problem, as specified in stage three by Equation (1), can be solved optimally in a "reasonable" time for small sources of knowledge S, we compare the time and the performance of the heuristic proposed in stage three with the full (optimal) MINLP approach. In particular, we used the SCIP library (Achterberg 2009) to generate the MINLP solution of the problem. It turned out that this "hard" problem could be solved optimally in a reasonable time only for those cases when the number of items in a source did not exceed 30. Therefore, we compare the proposed heuristic with the MINLP approach based on the sources containing up to 30 items. The results of this comparison are presented in Figure A1 and show the times needed to identify the best matching subset from a given source for these two methods respectively.[1] Note that different subjects, topics, and sources have a different number of important key concepts, and, thus, they need different times to calculate cosine similarity distances. Therefore, the trend in the MINLP graph is unstable, as can be seen in Figure A1. Note, however, that the performance differences between our heuristic and the MINLP approach are recognizable and are quite significant in the cases of large numbers of items, as is shown in Figure A1.

[1]The X axis shows the numbers of items in the sources, and the Y axis the average times needed to identify the best matching subset for sources with a given number of items (in seconds).

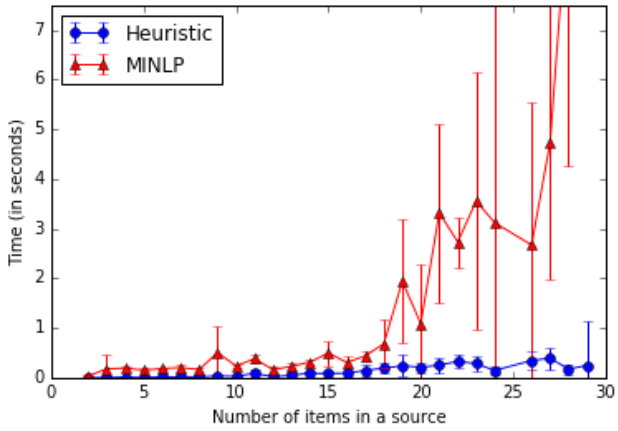

Figure A1. Comparison of the Proposed Heuristic MINLP Approach in Terms of the Time Needed to Identify the Best Matching Subset of Items from the Source for a Given TOpic

As Figure A1 shows, it takes only 5 seconds for the MINLP method to identify the best matching subset of the units of knowledge from the source having 27 book chapters for a given topic from the course taxonomy. If a course has 100 topics, a book containing 27 chapters would take 8.33 minutes by the MINLP approach to process and identify the best matching subsets for all of the topics in the course. In contrast, it would take only about 30 seconds to do the same by our method. Note that this difference is significantly bigger than in our particular example for those cases having a larger number of units of knowledge in a source because the MINLP problem is NP-hard as is explained above.

Furthermore, we compared the performance of the two approaches in terms of how well they identify the best matching source of knowledge for a given topic of the course taxonomy. It turned out that the proposed heuristic and the MINLP approaches identify the same source of knowledge to be the most relevant for a given topic in 96.3% of all the cases. In the rest of the cases, our heuristic identifies the source with cosine similarity measure to the topic having 95.3% of the cosine measure to the best source identified by MINLP approach on average. This means that the proposed heuristic identifies the most relevant sources of knowledge in most (96.3%) of the cases, and identifies almost the best matching source in the rest of the cases.

Note that our heuristic does not guarantee finding the best matching subset of items in the source. However, for the leaf topics of the course taxonomy, it guarantees finding the best set of items consisting of one or two elements, which is enough for our particular problem having natural constraints of limiting the number of leaf units to a very small set, as explained in stage three (i.e., we do not want to overload the students with too much information). The situation is more complex for the interior nodes where our heuristic does not necessarily find the best matching subset of items from the source. However, our heuristic works fine (identifies the most relevant subset of units of knowledge from the source in many cases and almost the best matching subsets in the remaining ones) for the following reasons. First, the comparison of the proposed heuristic with the MINLP approach described above showed that both of them identify the same subset of units of knowledge from the source in 58.8% of the cases. Second, in the remaining 41.2% of cases, the proposed heuristic identified the subset with cosine similarity measure to the topic being, on average, within 94.6% of the cosine measure of the best subset identified by MINLP approach.

Reference

Achterberg, T. 2009. "SCIP: Solving Constraint Integer Programs," *Mathematical Programming Computation* (1:1), pp. 1-41.

Appendix B

An Example of a Recommendation Letter

Dear Joe,

Based on the analysis of the materials covered in the course so far, we believe that you should review the following topics and the corresponding materials while preparing for the Final Exam:

Course: Art History
Themes:

- Ancient Greece and Rome
  We suggest that you study chapters: 2, 3 from "Art History The Basics"
- Art of Revolution: Neoclassicism and Romanticism
  We suggest that you study the following pages: page_1; page_2; page_3 on cite www.radford.edu.

Note that all the listed materials are clickable.

We hope that you will find them useful in your study.

Best regards,

****

Associate Provost for Academic Affairs
**** University

If you want to opt out of the future e-mails, please follow this link: unsubscribe.

Appendix C

The Survey Questions

Did you recall receiving at least one e-mail letter from Education Tools with recommendations of additional materials?

- YES
- NO – then skip to the end of survey

Part 1: Details

Please specify for which course you received recommendations?
(If you have received recommendations for more than one course, please choose only one of them and fill this form based on it.)

To the best of your memory, how many e-mails with recommendations / for this course have you received during the last term?

Which of the following statements describes your experience of / obtaining recommended materials?

- I had no problems with obtaining them
- I had problems with opening e-mails
- I had problems with opening recommended web-sites
- I had problems with downloading recommended PDF documents
- I had problems with opening recommended PDF documents
- Other: TEXT

Part 2: Time

How many assignments have you done in this course during the current term?

- None
- Less than a half
- More than a half
- All assignments

How many hours per week have you spent on average studying for this course?

- less than 1 hour
- 1–2 hours
- 2–3 hours
- 3–5 hours
- 5–8 hours
- more than 8 hours

How much time have you spent studying additional materials/recommended to you via Education Tools?

✣ In preparing for the first Graded Quiz
✣ In preparing for the second Graded Quiz
✣ In preparing for the Final Exam

- not received
- 0 hours
- less than 1 hour
- 1–2 hours
- 2–3 hours
- 3–5 hours
- more than 5 hours

Based on your experience would it be better if our Education Tools provided

- Much more materials
- More materials
- Same amount of materials
- Less materials
- Much less materials

How much time would be optimal for you to spend on studying additional materials recommended by Education Tools during preparation for the Final Exam?

- 0 hours
- less than 1 hour
- 1–2 hours
- 2–3 hours
- 3–5 hours
- more than 5 hours

What should the best time be for you to receive recommendations of additional materials (comparing to the actual time when the recommendations were provided to you)?

✣ In preparing for the first Graded Quiz
✣ In preparing for the second Graded Quiz
✣ In preparing for the Final Exam

- Should be earlier
- It was the right time
- Should be later
- Not applicable

Please specify your preferences of time (e.g., a few hours/days/weeks earlier/later):

TEXT

Part 3: Quality

To what extent do you agree or disagree with each of the following statements?

✣ Recommended materials were relevant for the course
✣ Recommended materials were hard to understand
✣ Recommended materials were helpful in your studies
✣ You have learned new things from recommended materials
✣ You understand why we sent you that particular recommendations
✣ You discussed your recommended materials with your classmates
✣ You would like to recommend use of this Education Tools to your friend
✣ You would like to recommend this course to your friend

- Not Applicable
- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

Please make suggestions, how we can make our recommendations better?

TEXT

Part 4: Demographics

What is your gender?

What is your age?
- Under 25 years old
- 25–44 years old
- 45 years or older

Education: What is the highest degree or the school level that you have completed?

Employment Status: Are you currently…?

How much time per week do you have left after fulfilling all of your work and family obligations?
- 0 hours
- 1–3 hours
- 3–6 hours
- 6–9 hours
- more than 9 hours

Appendix D

Analysis of Survey Data

We analyzed the survey data to see how various types of survey variables affect student performance on the final exam. For each of the variables from the survey, we performed statistical tests to check if a student's performance on the final exam differs significantly across different values of these variables.[2] Our results show that there are no statistically significant differences in student performances on the final exam for most of the variables. Only in the following two cases were these differences significant. First, for the variable "Studying time for a course per week," the performance was significantly better for the value of "3–5 hours" than for the value "more than 8 hours." This surprising and unintuitive result could be explained by the fact that an underperforming student needs more time to study but still falls behind. Another plausible reason could be the fact that an average or a bad student tends to report exaggerated working hours in order to look better, whereas a diligent student tends to report honest answers. Second, for variable "Studying time of recommended materials in preparation for the final exam," the performance was significantly better for the value of "2–3 hours" than for "1–2 hours." This result confirms our claim that our recommendations were helpful. In summary, we did not observe any significant influences of the survey variables on students' performance on the final exam with the exception of the few cases described above. In those few cases where we indeed observed it, we cannot draw any serious conclusions because (1) the population of the students submitting their surveys was small and (2) we expect that many students did not provide honest answers in their surveys (such as telling us the correct time they spent studying for the course).

[2]Note that, as explained in the subsection "Student Performance Results" in the paper, the student population was limited only to those students who submitted the survey and replied to the particular question corresponding to this variable.

Appendix E

Results for Good Students

Table E1 shows the performance results for the good students. The first column in this table presents the name of the corresponding performance metric (such as normalized difference to two previously taken courses considered across all available courses). The rest of the columns specify the performance metric for the following groups of students respectively: control group (C); nonpersonalized group (Non P); students from nonpersonalized group who followed the recommendations (Non P-F); personalized group (P); and students from personalized group who followed the recommendations (P-F).

Note that we use the following marks in the table:

* – marks the result for the personalized group if it is significantly different from the control group at 0.05 significance level
† – marks the result for the personalized group if it is significantly different from the nonpersonalized (i.e., standard) group at 0.05 significance level.

Table E1. Results for Good Students Having Average GPA Between 70 and 90

Type of Difference	C	Non P	Non P-F	P	P - F
Absolute Exam Grades	79.39	80.47	79.32	81.92	83.22*
Normalized Exam Grades	-0.16	-0.05	-0.02	0.04*	0.10*
Diff to Last courses: All subjects: Absolute	-0.37	0.64	0.78	3.47*	5.83*
Diff to Last courses: All subjects: Normalized	-0.10	-0.11	-0.04	0.10*	0.38*
Diff to Last courses: Same subjects: Absolute	1.32	1.38	0.39	2.89	7.32*
Diff to Last courses: Same subjects: Normalized	-0.13	-0.11	0.06	-0.13	0.22*
Diff to All previous courses: All subjects: Absolute	-1.68	0.07	-1.30	0.59*	1.75*
Diff to All previous courses: All subjects: Normalized	-0.16	-0.14	-0.09	0.03*	0.09*
Diff to All previous courses: Same subjects: Absolute	1.70	1.74	0.85	1.73	4.35
Diff to All previous courses: Same subjects: Normalized	-0.13	-0.11	-0.02	-0.02	0.09