Tobbits Calculation Workbook: An Offline-to-Online Intelligent Textbook

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Abstract. This paper describes an offline paper workbook that offers online intelligent tutor service through OCR with a smart phone. Tobbits calculation workbook is an example of such Offline-to-Online(O2O) intelligent workbook. Learner practices mental calculation on the paper workbook, grades them by taking a photo of the booklet through smartphone app, and gains access to the diagnosis of their procedural misconceptions. Among the recipients of half a million of paper workbooks, more than 30% of them used the online service.

Keywords: Intelligent Textbook, Offline-to-Online, Optical Character Recognition, Procedural Misconception

1 Introduction

Mental Calculation is a key component in Chinese math education [1, 3] during the first three years of the primary school. Students are expected to perform simple calculations without pen and paper within the time limit. There are specialized workbooks with basic arithmetic questions, designed to cultivate students' mental math capability. Despite the wide usage of these workbooks among Chinese families, it is a tedious job for parents to check their children's responses, as each page contains about 50 calculation items. In addition, parents usually do not have the pedagogical know-how, or the patience, to diagnose their children's procedural misconceptions. There are popular video clips recording a frustrating parent yelling at their wailing kid for not getting "3*4" right, whose comment section is filled with parents suffering from the same fate.

Technology can save these parents from themselves. Optical Character Recognition (OCR) powered by deep learning can check students' response with 99% accuracy. A learning analytics can reconstruct learner's procedural misconception to help the tutor (usually the parent) better understand the problem. An interactive course can step in as the pedagogical intervention. These three components can be integrated in a single smartphone app. Tobbits Calculation Workbook introduced in this paper is such a blended intelligent textbook. The workbook is a paper product, but the user can access intelligent tutoring services through both mobile apps and WeChat mini programs.

Within the literature context of the intelligent textbook, this paper is unorthodox in two ways: Its subject is a workbook, rather than a textbook. The workbook is paperback rather than digital. The first difference can be bridged by equating the workbook to the

homework, or practice, portion of the textbook [5]. In our business scenario, the second difference is a feature not a bug. Although adaptive hyperlink system [2, 6] or more broadly digital course management [8] has made great strides and hold great promises in the age of ubiquitous smart devices, pen and paper is still the dominant mode of learning now and probably for the next decades. Especially in K-12 education, parents have serious misgiving about leaving their kids alone a smartphone or a pad while teachers maybe uneasy about handing their students each with a pad in the classroom. Though the paper textbook is a natural reference point of efficacy [6] if e-book is viewed as its substitutes, it may be productive to think paper-book and intelligent tutor system as compliments. The blended approach introduced in this paper, human tutor, whether parents or teachers, have strong control on the exposure to smart devices.

Another practical advantage of the blended approach is affordability. As students need to use their digital textbooks or workbooks on a frequent basis, owning or having easy access to smart devices is a requirement. While under the blended approach, students can work on physical textbooks or workbooks, and borrow their parents' devices for grading and getting feedback. Given limited levels of household income in developing countries, greater affordability means that the blended approach is feasible to scale up. For educational companies, it makes economic sense to distribute the paper book at a reduced price, or even for free, to bring users onto the digital platform and achieve economic return via premium services. Such business model is called Offline-to-Online (O2O), which is proven to be effective in China but may be alien to readers outside of China. Several leading educational technology companies have distributed such intelligent workbooks, and collectively reached millions of users.

2 The Tobbits Calculation Workbook

2.1 The offline Workbook

The first version of Tobbits calculation workbook has four volumes, targeting elementary school students from grade one to four in spring semester. Pedagogical experts select and sequence the exercise items to match what students will learn at school. Each workbook consists of 60 pages, 30 items per page, covering around 150 knowledge components. Students are expected to finish one page of exercises per school day

Fig. 1. Example Pages from Tobbits Calculation Workbook of Grade One

2.2 The Online Service

The online tutoring services for Tobbits calculation workbook can be accessed via a WeChat mini-program. A WeChat mini-program supports features similar to a mobile

app, but it resides in the WeChat ecosystem instead of existing as an independent app on the smartphone. The main function of the mini-program is to take a photo of the paper workbook to initiate the automatic correction service. Users may accumulate points by registering, using the automatic correction service, or recommending this mini-program to their friends. Users can use these points to redeem tutoring courses offered in the course center.

Fig. 2. A Screenshot of the WeChat Mini-program Interface

After users take a picture of the filled-out worksheet, the photo will be sent to a backend server for grading and diagnosis. Within a second, the user interface will display a graded worksheet (see Fig 2). the user may click red question marks to check detected mistakes, along with diagnosis of procedure misconception (see Fig 3). Users can choose to submit feedback in case the automatic correction service fails. A team of product managers and algorithm experts review user feedback regularly to keep improving the service.

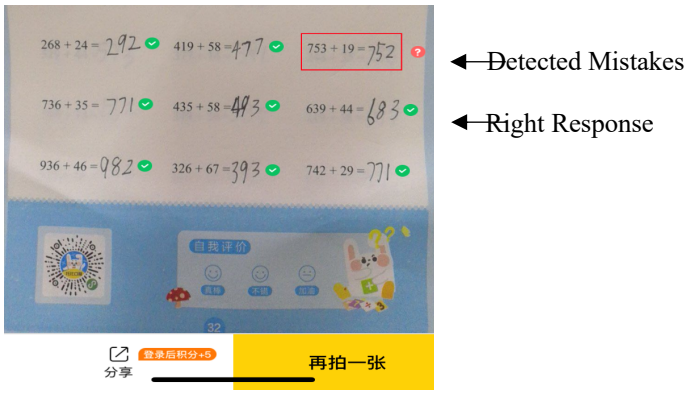

Fig. 3. Segment of a Graded Worksheet

Fig. 4. Example of Diagnosis Section

3 Technologies that Power the Workbook

3.1 The Automatic Grading

The auto-grading algorithm consists of two parts, an OCR algorithm to recognize students' handwriting and an algorithm to grade students' response.

Off-the-shelf open-source OCR algorithms that recognize handwritten numbers are typically trained by adults' handwriting data. Therefore, they have low accuracy in recognizing children's different handwriting styles. The new OCR model includes formula detection and recognition. The detection model marks formulas from other irrelevant texts and symbols with a rectangular box. Scale and aspect ratio variety is the most difficult part to handle. A carefully designed data augment proves to be helpful for this task. With 10000 samples as training data, the accuracy of the detection model can reach 99.6% on normal images. The formula recognition is relatively complicated for variety of students' handwriting.

To develop a new OCR algorithm for primary school students, it requires new data sets. Due to the lack of online data collection mechanism in the early stage, the training of recognition model is divided into two steps: offline training and online iteration. At the first step, we collected 10,000 of students' workbook pictures for annotation, which are as close as possible to online images. When the model converges, the accuracy of the offline data we collected can reach more than 98%. When the model is online, the accuracy of the model is not unexpectedly reduced to a lower level, about 90%, for online images. It shows that students who decide to use online service generates a substantial different sample from those we collected offline. Despite the initial setback, As online users use this feature and upload pictures, larger, more diverse data are collected to iterate the OCR and grading algorithms. Within a month, the accuracy reaches 99%.

Similarly, the grading algorithm requires AI experts coding specific grading rules for different types of equations as the cold start. Table 1 shows some selected identifiable question types. Within 2 months of the launch, the grading accuracy of common question types increased to 99% accuracy.

Table 1. Selected Identifiable Question Types

Question Types	Example
Basic arithmetic (Addition / Subtraction / multiplication / division)	13-4=;2*3 =
compare	13-4 __ 15-7
Unit calculation	1km = ( ) m
Percentage-to-number conversion	35% =
Complete	13- __ =9
Solve for variable	15+3x = 24, x= ( )

3.2 Procedural Misconceptions and Adaptive Tutor Service

Among all errors identified by the OCR algorithm, about 32% of the errors diagnosed by pedagogical experts with a specific procedural misconception. The analytics team groups these misconception diagnoses into 31 major categories, mostly covering single addition, subtraction, multiplication and division of integer number, decimal number and fraction. For example, multiplication of integer has 4 major categories of procedural misconceptions. For each category, the pedagogical expert gives a description of the wrong procedure, which may not be self-obvious. If a learner answers 23*15=138, she is diagnosed with "vertical form misalignment" (115+23=138). The description of the wrong procedural reads "The multiplication result of the digit of tens is mistakenly aligned with that of the ones."

Table 2. Major Procedural Misconceptions of Multiplication of Integers

Category	Example
Insufficient Mastery of the Multiplication Table	4*4=36
Forget to Carry	23*15=335
Vertical Form Misalignment	23*15=138
Do not Understand Vertical Form	55*9=95;23*15=215
Mistreatment of 0 as the Last Digit	25*20=50

The analytics team turned the work pedagogical expert into a rule based expert system, which is dubbed as the calculation bot. Following the previous example, if the text contains the print of "23*15", the calculation bot is invoked by the app and lists all possible wrong responses, along with the diagnosis and pedagogical suggestion. If the recognized user answer matches any of the listed answers, the app shows the corresponding diagnosis on the screen, as in Fig 4. When a wrong response is associated with multiple possible misconceptions, which is likely in the case of multiple steps of calculation, the calculation bot randomly picks one of them. If the recognized answer does not match any of the listed answers, the app leaves the tutor section blank.

As stated previously, the overall diagnosis coverage rate is 32%, but the coverage is uneven among knowledge components. The bot is better at covering single step calculation of integers or decimals, with a coverage rate around 60%. The bot is relative weak on fractions and multi-step calculations, with a coverage rate around 20%.

To gauge whether such light-weight tutor service is helpful to parents, we designed a voting system of "helpful" or "not helpful" for users to voluntarily express their opinion. To date, about 6000 user ratings are collected, with an overall "useful" rating of 52%. Table 3 shows the votes of major misconceptions associated with integer multiplication. Per manual checking, diagnosis that are voted as "not useful" has an accuracy rate of 70%. Therefore, the label "not useful" may have ambiguous meanings for users: the diagnosis is not useful either because it is wrong or because I know it already although it is right.

Table 3. Feedback Votes of Procedural Misconceptions of Multiplication of Integers

Category	Votes	Useful Percentage
Insufficient Mastery of the Multiplication Table	197	51%
Forget to Carry	72	57%
Vertical Form Misalignment	6	50%
Do not Understand Vertical Form	28	57%
Mistreatment of 0 as the Last Digit	211	51%

4 Discussion

Since Jan of 2019, more than 500,000 of Tobbits calculation workbooks are distributed to students and parents. Over 30% of the recipients became active users of the WeChat mini-program. Over 20% of these active users recommended the WeChat mini-program to their friends. About 10% of the users checked the diagnosis details. Although the current version of the Tobbits workbook is not a run-away success, it proves that the Offline-to-Online strategy does acquire users for the online intelligent tutor service quickly and at scale.

Moreover, the technologies described in this paper do not limit to grading only the proprietary workbook. In fact, it can be used to grade any calculation exercises as long as the equation type is supported, which makes the O2O strategy extremely scalable. In addition, on the native IOS or android app, the intelligent tutor service offers more than just description of the procedural misconceptions but also interactive teaching courses, adaptive practice items and reports of learner mastery. Within three months after the intelligent tutoring services were added to the mobile app, more than three million users have uploaded photos of calculation exercises for automated grading. Majority of these photos are non-proprietary calculation workbooks distributed by traditional publishers.

5 References

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