Final Report

Social justice embedded in middle school maths problems(7th, 8th Grade)

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12/12/2019

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Overview

Social justice depicts the uneven relationship in society related to gender and race in particular. It can be measured by the "distribution of wealth, opportunities for personal activity, social privileges"[1](Clark, 2015).In middle school, students started to form social awareness and identity and the learning materials they approach will have a huge impact[2](Gutstein, 2003). Therefore, maths problems with social justice elements would be a good option for cultivating students as empathetic and responsible citizens. In other words, educators could use Maths to cultivate social justice awareness. One social justice question could be why females, students of color, and low-income students score lower on the SAT and ACT exams[3] (Reeves and Halikias, 2017).

In this project, the authors target at maths knowledge of the linear equations, systems of linear equations, and solutions for systems of linear equations. In terms of social justice, the project's client Nikki G. Lobczowski provided different themes for social justice and its corresponding content. Cooperating with our client, the authors decided to settle on the money category. Money category has nine problems(3*3) including the combination of check cashing(race, race gender) and linear equations(systems of linear equations, and solutions for systems of linear equations).

Compared to the traditional intelligent tutor in CTAT which is mastery learning(students will get questions based on the assessment of system using Bayesian knowledge tracing), students will have the agency of assessing their own understanding at the beginning of practice.

This report will walk people through the goal, math problems, initial CTAs, and iteration, as well as intermediate CTAs, and user-testing. Lastly, the authors will introduce the tutor(example-tracing and rule-based).

Goal

The tutor will provide students with different problems adapting to student's choice of

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[1] Clark, Mary T. (2015). *"Augustine on Justice," a Chapter in Augustine and Social Justice*. Lexington Books. pp. 3–10. ISBN 978-1-4985-0918-3.

[2] Gutstein, E. (2003). Teaching and learning mathematics for social justice in an urban, Latino school. Journal for Research in Mathematics Education, 37-73.

[3]https://www.brookings.edu/research/race-gaps-in-sat-scores-highlight-inequality-and-hinder-upward-mobility/

difficulty level and sensitivity to social justice after receiving students' input at the beginning.

- ❖ Maths
  - ➢ Level 1 – write algebraic equations
  - ➢ Level 2 – write systems of algebraic equations
  - ➢ Level 3 – solve systems of algebraic equations
- ❖ Social justice
  - ➢ Level 1 - Check Cashing
  - ➢ Level 2 - Gender
  - ➢ Level 3 - Race and gender

Math Problems

- ❖ **Check Cashing, L1**
  - ➢ Many people use check-cashing services when they don't have access to banks or if the banks are too restrictive in loaning money. Check cashing services often come with higher fees for getting money. For example, at FastCash they charge 2% of the check plus a $3 processing fee.
- ❖ **Checkcashing, L2 & L3**
  - ➢ Many people use check-cashing services when they don't have access to banks or if the banks are too restrictive in loaning money. Check cashing services often come with higher fees for getting money. John chose FastCash and Anna chose the AppleCash. At FastCash they charge 2% of the check plus a $3 processing fee. As for AppleCash, they will charge 3% of the check. John paid twice as much service fee as Anna did. Anna wanted $20 more than John. Questions: How much money did John want? How much money did Anna want?
- ❖ **Race, L1**
  - ➢ In October 2019, 5% of Black adults in the US were unemployed. Define a variable for the number of Black adults in a given area and use that variable to write an expression for the number of people that are unemployed.
- ❖ **Race, L2 & L3**
  - ➢ In the fourth quarter of 2018, African American workers had the highest unemployment rate nationally, at 6.5 percent and white workers had the lowest unemployment nationally at 3.1 percent. The amount of unemployed African American is twice as much as unemployed white workers in the nation.(unit: million). The amount of unemployed African American is 10 million more than

the unemployed white workers. Questions: How many African American workers were unemployed in the fourth quarter of 2018? How many White workers were unemployed in the fourth quarter of 2018?

❖ **Race and gender, L1**
  ➢ In 2018, the median annual income of black women is approximately 60% of that of white men. A is a white man and B is a black woman. Both of them happened to have an annual income that equals the median income of their groups in 2018. Define variables and write an expression.

❖ **Race and gender, L2 & L3**
  ➢ In 2018, the median annual income of black women is approximately 60% of that of white men. A is a white man and B is a black woman. Both of them happened to have an annual income that equals the median income of their groups in 2018. A made $20,000 more than B. Questions: How much did A make in 2018? How much did B make in 2018?

Initial CTAs

❖ Theoretical CTA
  ➢ Initial KC analysis
    ■ Mathematical ability:
      ● Understand the information and enter the correct information in the table.
      ● Understand and apply addition, multiplication, and division.
      ● Defining variables. Transform the text into linear equation expression using the variables.
    ■ Textual ability:
      ● Understand the implicit social justice issues in the problem.
      ● Interpret the data and generate possible reasons between the data with the aid of data visualization and some related videos or audios.
❖ Empirical CTA (Think-aloud: two experts and three novices)
  ➢ We conducted five think-aloud sessions. Two of the subjects are experts and three of them are novices from the actual target population (middle school students). For novices, the ages are 14 ,18 and 11. For experts, they are all

METALS students.

➢ The task assigned to them is the problem above. They are required to solve this problem first. Then they will talk about their general feedback both in terms of format and the content. Testers will not provide the social justice survey until they finish sharing their thoughts and comments.

➢ Basically, they adopt two types of strategies. On one side, they utilized the concept of variables and actually came up with linear equations which we are aimed at training. On the other side, students will play with the concept of relationship in terms of percentage. The strategies they adopt would be solving the problems through division. After analyzing their think aloud, we inferred that due to the relative easiness of the nature of the problem, students can solve problems without introducing the unknowns. Also, it could be that the way we phrase our problems has a tendency of replacing the process of symbolizing which we feel like it would a difficult factor but denied after the empirical data.

➢ The error type is mainly about the skills instead of understanding and sense-making. It points out when we design our instructions, we should focus more on the induction and refinement part instead of sense-making. We are still in the process of doing CTAs. Hopefully, with the increasing number of participants, we could demystify more cognitive difficulty in the measurement of the knowledge component.

➢ Calculation problem：Students expressed the willingness of being scaffolded by a calculator since they are used to calculate using tools. One of our novices actually tried to calculate in the brain. Nevertheless, she failed with the wrong answer 80,000 for the 20,000/0.4. The right answer should be 50,000 instead.

➢ Empirical evidence: "Can I use a calculator?"

➢ Students complain about the format of the problem.

➢ Empirical evidence: ""A" looks like the word here instead of a letter".

Iteration 1

❖ Did not use systems of equations. "A make 20?, 20,000 dollars divided by 40 times a hundred". (14-year-old boy). **"I would have probably needed a refresher on systems of equations since I forgot how to do them."**
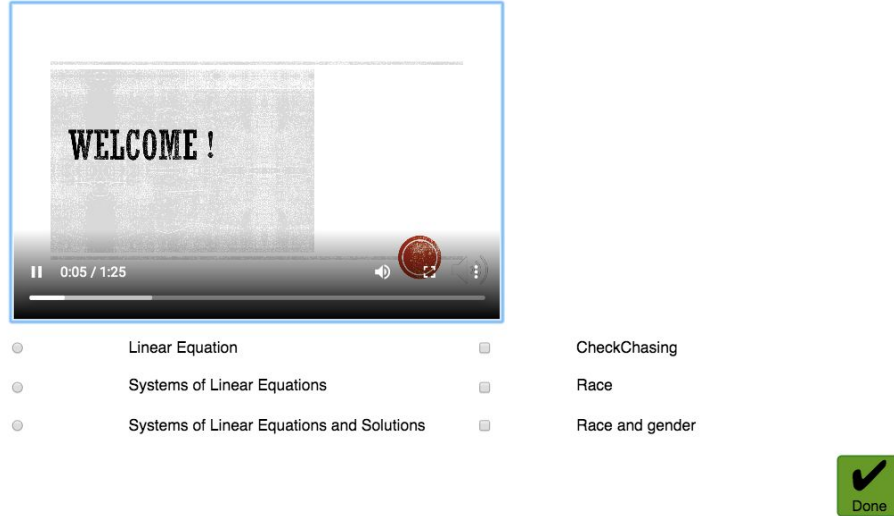
    ➢ Solution: Instructional Video

Fig.1: Instructional video

❖ Calculation problem **"Umm.. I may need a calculator"** （18-year-old girl The calculation seems too difficult due to the large number, and it is not the focus of our tutor. So we decided to make the tutor generate the result for learners.
  ➢ Solution: Tutor performed Action for calculation
❖ Intensity of social context

Fig.2: Survey response related to social justice topic

➢ Solution:Adaptation of intensity level of social context

User testing

We conducted some user testing with the GenderPayGap problem of difficulty level 3. Here is the problem in tutor that we originally had.

In 2018, the median annual income of black women is approximately 60% of that of white men. John is a white man and Jasmine is a black woman. Both of them happened to have annual income that equals the median income of their groups in 2018. John made $20,000 more than Jasmine.

Questions:
How much did Jasmine make in 2018?
How much did John make in 2018?

Define a variable for John's annual income

Define a variable for Jasmine's annual income

Transform percentage to decimal   % =

Expression 1   =   ▼

Expression 2   =   ▼

Eliminate one variable   =   ▼

          =   ▼

          =

          =   =

John's annual income

Equation for Jasmine's annual income   =   ▼   =

Jasmine's annual income

Write the first expression
Enter Jasmine's income
Eliminate one variable
Calculate John's income
Rearrange the equation
Convert percentage to decimal
Write equation for Jasmine's in
Write the second expression
Define variable
Enter John's income

Fig.3: GenderPayGapL3 Problem Interface

Iteration 2

❖ **Confused about the input expected from the tutor (21-year-old girl**)
❖ Solution:
➢ Provide more hints to guide students through the thinking process.

Please Edit Hint Message 1:
What's the first relationship between the two variables that you can find from the problem?

Please Edit Hint Message 2:
The median annual income of black women is approximately 60% of that of white men

Please Edit Hint Message 3:
John is a white man and Jasmine is a black woman

Please Edit Hint Message 4:
So the median annual income of Jasmine is approximately 60% of that of John

Please Edit Hint Message 5:
We should use multiplication here

Clear Hints   Add Hint Level

More Options

Copy hints from the following link:
Select one

Copy hints from the following rule:
Define_variable Systems_of_equations

Done   Cancel
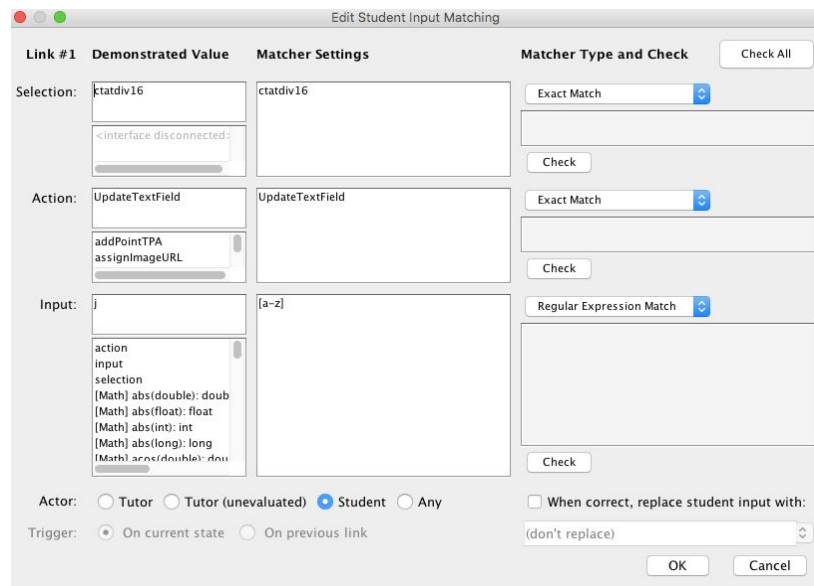
Fig.4: More levels of hints

➢ Add a version with more scaffolding while still keeping the old one to adapt to the diversification of our learners (prior knowledge, learning styles, self-regulation).

Fig.5: More scaffolded version

❖ **Variables should not be constrained in certain types.（18-year-old girl)**
   ➢ Solution: Agency of defining variables by students using regular expressions.

Fig.6: CTAT Regular Expression Match for any letters

And we used the Check Cashing Problem in the fig.5 to conduct another the user testing with a 14-year old boy.

- ❖ **It is kind of inconvenient to sroll all the way down in order to hit the hint button.（14-year-old boy)**
  - ➢ Solution: Move the hint widget from the bottom to the side.
- ❖ **The interface was pretty long and very heavily scaffolded, it was kind of overwhelming to look at（14-year-old boy)**
  - ➢ Solution: Break down the solutions into different parts
- ❖ **Do not convert percentage to .03 in the middle. （14-year-old boy)**
  - ➢ Solution: Convert 3% to .03 at the beginning of the solution part.
- ❖ **Skill bar is a motivation for him. （14-year-old boy)**
  - ➢ Solution: Keep the skillometer.

Many people use check-cashing services when they don't have access to banks or if the banks are too restrictive in loaning money. Check cashing services often come with higher fees for getting money.
John chose FastCash and Anna chose the AppleCash. At FastCash they charge 2% of the check plus a $3 processing fee. As for AppleCash, they will charge 3% of the check. John paid twice as much service fee as Anna did. Anna wanted $20 more than John.

Questions:
How much money did John want?
How much money did Anna want?

Step 1: Variable   the money that John wanted [   ]

the money that Anna wanted [   ]

Step 2: Expressions   John's service fee   2% [   ] [▼] 3

Anna's service fee   3% [   ]

Relationship between
Anna's service fee and   2% [   ] [▼] 3 = 3% [   ] [▼] 2 ⓘ
John's service fee

Anna wanted $20 more   [   ] = [   ] [▼] 20 ②
than John.

Step 3: Solution   0.02 [   ] [▼] 3 = 0.03 ([   ] [▼] 20) [▼] 2

0.02 [   ] [▼] 3 = 0.03 ([   ] [▼] [   ]) [▼] 2

0.02 [   ] [▼] 3 = [   ] [   ] [▼] [   ]

[   ] [   ] = [   ]

[   ] = [   ]

Step 4: Answer   the money that John wanted [   ]

[   ] = [   ] [▼] 20 = [   ]

the money that Anna wanted [   ]

Interpreatation
SystemsofEquationSolutions
Interpretation
Quantification
Transfering
Variable
Quatification
Checkcashing
Calculating

Fig.7: Check cashing Level 3 Refined Version

Tutor

❖ Example-tracing tutor
  ➢ Reinforcement

    Students are asked to rewrite the english expressions to let them have more essential processing of social justice. For example, the salary of blac woman = the salary of white man * 0.6

Fig.8.: Reinforcement of social justice information

➢ Redirection

Students have the agency of assessing their own knowledge through clicking two buttons they would love to enter. The authors have six buttons for students to choose. Each button is associated with a skill. Traditionally, in the tutorshop, if students fulfill the skillmeter, they will be assigned different problems. In other words, they are assessed by the tutor to give them appropriate problems. In this design, the authors want to give students agency and let them assess their knowledge. If students choose linear equation and Check Cashing, Tutorshop will deem that they master the other two ones by setting the parameters of P(Learn) of all skills into 0.99.

Fig.9: Change P-learn in Tutorshop.

➢ Interface

Many people use check-cashing services when they don't have access to banks or if the banks are too restrictive in loaning money. Check cashing services often come with higher fees for getting money.
John chose FastCash and Anna chose the AppleCash. At FastCash they charge 2% of the check plus a $3 processing fee. As for AppleCash, they will charge 3% of the check. John paid twice as much service fee as Anna did. Anna wanted $20 more than John.

Questions:
How much money did John want?
How much money did Anna want?

Fig.10: Interface of Check cashing L3 problem

➢ Hints

There are two special hints content in our design including the multi-level hint to walk students through the thinking process and social justice info hint.

"According to the most recent survey from the Federal Deposit Insurance Corp. (FDIC), 7 percent of U.S. households — that's around 9 million families — were "unbanked" in 2015."

Hint one: John made $20,000 more than Jasmine
Hint two: Which means Jasmine's annual income equals John's minus 20.000.
Hint three: Please select '20000' in the highlighted field.

❖ Cognitive tutor
  ➢ Problem

Fig.11: Interface of Gender Pay Gap L1 Problem

➢ Working Memory Diagram

Fig.12: Working Memory Diagram

➢ English Rules

The functions that we realize using the cognitive model are basically "update text field" and "update combo box". Here are some sample English rules.

A.IF the salary of white man given in the problem statement for (1) is A and the salary of white man has not been written THEN Write A as the salary of white man.

B.IF the salary of black women given in the problem statement for (1) is B and the salary of black woman has not been written THEN Write B as the salary of black woman.

C. IF the salary of white man given in the problem statement for (1) has been written and the first blank in the show your work column has been written and the combobox of white man has not been written THEN update the Combobox as "x".

Reflection

This project gave us a chance to experience the whole process of building an intelligent tutor targeting at the real-world problem covering identifying the problem, communicating with a client, as well as designing the content, visual, the sequence of presenting the info, and building the rule-based and example-tracing tutor, this project taught us a lot. The domain that we chose also made us reflect deeply on how to integrate ill-defined domain and well-defined domain and how to maximize the pedagogical value of the ITS. Nevertheless, we do feel some things could be addressed better in future studies.

Firstly, considering the multidisciplinary nature of this task, diverse skills are required in this process. In the formation of teams, we do differentiate technical and non-technical persons, but we turned out to have two people having similar backgrounds in the team. After our collaborations, we realized the importance of having a multidisciplinary team. We brainstormed many ideas but could not make many of them come true due to technical constraints. And it was not possible for us to acquire all those skills at such a short time.

Secondly, we gained a lot of helpful information through limited user testing with the targeted learners. And we learned that It is critical to interact with target audience. Nevertheless, we failed to have access to many students at the right age. It would be better if the client could have a clear vision of what they are trying to accomplish while providing the ways of accessing

to
the ideal participant pool in the initial pitch. However, we recognize that this is hard to implement due to time and resource constraints and our client Nikki is actually very helpful.

Lastly, we actually failed to have a big picture to guide all our actions. It was difficult for us to accomplish a good final product after the intermediate presentation due to limited time, which is regretful. Next time, we should make a schedule instead of meeting the check points of this course.

There is still a lot to be improved in our tutor. In future, we hope to craft every hint and error message of our problems carefully and do more user testing with the target audience to keep iterating our tutor.

Appendix

Think-aloud Transcriptions

Novice 1 (14 years old)
Reading the problem.

20000 less than B
Ugh
So In 2018, the black women make 40% less Ah than the white man. And it
is approximately 60% of that of white men. And it had equal jobs.

A make 20?, 20,000 dollars divided by 40 times a hundred

(Did you want to write down anything?)

So ugh okay That would be 1% that you multiply whatever this is times 100 to get 100 percent that is person A would be. Can I use a calculator?

I have it on my phone. So I am gonna do this math which is 20,000 divided by 40 times a hundred times 50,000 Okay Then ugh

Then B is just ok laugh A is 20,000 more than B

Wait.
Never mind.

So A is 20,000 more than B A is okay then so 20,000 more than B A also makes 40% more than B.
So if A make 100 percent and B make 60%
This means A would be
Oh wait I already did that.
I was wrong.
Okay, then. Yes, then. B make is divided 50,000 by 60 so
Calculator
60 times 30,000
Ok B would be 30,000.

A looks like the word here instead of a letter.

Well I mean It definitely addresses a real-world problem.

Novice 2 (18 years old)

So when I saw the first sentence I firstly saw the base income
It was .6
And then I listed another function
Which is A's income minus 20,000 dollar is B's income
Then I just solved the equation
(OK. So how much did A make?)
I got 80,000
Umm.. I may need a calculator
……
Oh, I got 50,000
(What about B?)
B…. I got 30,000.

I got it wrong the first time because I was not doing the math right. I used multiplication instead of division to solve the problem.

I feel like the content is like a little bit increase some racial awareness. It is not usual to include those content.

Novice 3 (11 years old)

(After reading the problem)
I am not sure because it did not give the original price of B.
Because then I can add on to B's price, the 20,000 dollar
And then I can get the price of A

(If you rewrite the problem as a math sentence, what would it be?)
I don't know..I will need something to multiply by or to subtract

(If you use letters rather than numbers, what would you do?)
I don't know what to then
Ummm.. I may do A-20000=B

Oh actually I learned something about percentage
20000 and 60%
So I will divide 20000 by 60%
(Write down
P20.000 60%
W   100)
(Using the calculator)
So 20000*100
= 2000000 / 60
I got 333333.333

Pre test Problem

The admission fee at a small fair is $1.50 for children and $4.00 for adults. On a certain day, 2200 people enter the fair and $5050 is collected. How many children and how many adults attended?

$x = C$
$y = A$

$1.50c + 4.00A = 2200 \quad 505000$

$C + A = 2200$
$x \cdot 400 - x \cdot 400 - x \cdot 400$

$-400c + -400A = -880000$

$-250c = -375000$
$x \cdot 1 \qquad x \cdot 1$

$\dfrac{250c}{250} = \dfrac{375000}{250}$

$\boxed{c = 1500}$

$1,500 + A = 2200$
$-1,500 \qquad -1500$

$\boxed{A = 700}$