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Design and pilot evaluation of adult numeracy modules on Fair Allocation and Money-Time Trade-offs

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Abstract. Everyday adult decisions often involve mathematics, but their difficulty rarely lies in calculation alone. Dividing resources, assigning responsibilities, purchasing convenience, or trading money for time also requires people to identify criteria, compare unlike quantities, state assumptions, and explain what they regard as fair or valuable. This study reports the design and pilot evaluation of two adult numeracy modules developed during a mathematics-equity-oriented education internship in Xi'an, China: Fair Allocation and Money–Time Trade-offs. The study used a design-based orientation and a one-group pretest–posttest pilot with 36 adults. Evaluation combined rubric-scored tasks, a novel-scenario transfer task, usefulness ratings, a negotiation-agency item, and a one-week follow-up. Mean decision-criteria scores increased from 2.08 to 3.33 out of 4, and model-based reasoning scores from 5.52 to 7.60 out of 10. Usefulness averaged 4.56 out of 5; 88.9% scored at least 3 out of 4 on the transfer task. Negotiation agency rose from 2.94 to 4.19 out of 5. At one week, 19 of 29 respondents reported trying at least one framework element in an actual decision. These descriptive results suggest short-term improvement in explicit, model-based reasoning and perceived relevance, but they do not establish causal effectiveness or durable behavioral change. Adult numeracy models are therefore presented as deliberative scaffolds that make criteria, assumptions, trade-offs, and limitations visible without replacing personal or ethical judgment.

Keywords: adult numeracy, everyday decision-making, mathematical modeling, Fair Allocation, value of time, adult education, mathematical agency, China

1. Introduction

Adults daily need to deal with various decisions such as housework allocation, budget allocation, travel comparison, space division, labour compensation, and payment and time-saving choices. This kind of scene contains mathematical logic such as "ratios", "constraints", "opportunity costs", "expected values" and "optimisation", which are not simple calculation exercises. The premise of solving the resource allocation problem is to transform "fairness" into an explicit judgement standard; the premise of completing the "money-time" decision-making comparison is to match the corresponding units, scenarios and "uncertainty" assumptions for "value".

The *2023 Survey of Adult Skills of OECD* [1] defines numeracy as the comprehensive ability of adults to acquire and apply mathematical information and carry out "critical reasoning" in life scenarios, requiring

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individuals to complete interest interpretation, "relevant quantities" screening, point of view evaluation and scenario-based reasoning. Among all the countries and economies participating in the research, about a quarter of adults' numeracy level is "Level 1 or below" [1]. The data does not correspond to this Xi'an sample, but it is enough to prove that adult numeracy is an important lifelong learning topic.

At present, the research results of adult numeracy teaching are relatively limited. After screening 2,362 pieces of literature from 2019 to 2022, Gal [2] found that only 39 were empirical studies on adult mathematics and numeracy, of which only 7 were focused on front-line teaching practice. At the same time, it was clearly pointed out that "modeling and critical interpretation" is the research direction that urgently needs to be supplemented by empirical evidence. Although most adults have basic "procedural skills", it is difficult for them to clearly explain a "decision rule", identify a "hidden assumption", and critically analyse an existing model.

Numeracy ability directly affects the way individuals process quantitative information. Peters et al. [3] confirmed that people with high numeracy are better at using mathematical principles and are not easily disturbed by "framing effects". However, mathematical ability cannot produce the absolute only rational answer, and the reasoning process will be multiply affected by "affect, context, interpretation, and values". Therefore, adult numeracy education needs to simultaneously cultivate computing ability, "model selection", content interpretation and critical analysis ability.

This research originates from a mathematical equity-oriented adult education internship project in Xi'an. The main study of the Fair Allocation module concerns: when the same resource has differentiated subjective values and costs for different groups of people, how to achieve the reasonable distribution of assets, labour and responsibilities. The Money-Time Trade-offs module focuses on: under what scenarios "paying more to save time" is reasonable, and how the expected duration and risk variables can change the decision-making results. The core goal of the two modules is to help learners upgrade from a subjective feeling such as "This feels unfair" or "this is too expensive" to a clear, adjustable and complete reasoning logic.

The study asked:

(1) How did participants' ability to articulate explicit decision criteria change?

(2) What short-term changes appeared in model-based reasoning and transfer to a novel scenario?

(3) How did participants evaluate usefulness and negotiation agency, and what preliminary evidence appeared at one week?

The study contributes a common instructional cycle, pilot evidence based on performance and follow-up measures rather than satisfaction alone, and a restrained account of mathematics equity: widening access to the language of criteria, trade-offs, justification, and negotiation rather than claiming that a short course removes structural inequality.

2. Literature review and conceptual framework

2.1. Adult numeracy, fairness, and value

Adult numeracy has typical "situated" characteristics, and all mathematical needs depend on specific goals and interpersonal relationships. Percentage, estimated waiting time, family budget, and workload table can only have practical significance in specific decision-making scenarios. Gal et al. [4] pointed out that numeracy is the comprehensive ability of adults to cope with the mathematical and statistical needs of finance, health, workplace, digital life and public affairs. The core requirements are not only computing, but also include tracing data sources, disassembling built-in "assumptions", and distinguishing the interests behind rules and critical thinking.

This critical trait is the core of interpreting "fairness" and "value". Mathematical formulas can stably execute fixed rules, but cannot independently choose their underlying "moral principle". "Equal" equal distribution, "need-based" distribution, "contribution-based" distribution, and "efficiency-maximising" distribution can all achieve mathematical self-consistency, but correspond to different beneficiary groups. Similarly, the model can estimate the value boundary of time-saving behaviours, but cannot determine whether "caregiving, fatigue, anxiety, or family obligations" are suitable for monetisation. The core of this teaching is to clarify the correspondence between personal value orientation and mathematical decision-making.

The curriculum divides "fairness" into three core dimensions: "equality" is equal quantity; "equity" takes into account individual differences in demand, burden, contribution and opportunity; "procedural fairness" emphasises the transparency of rules and information, which can be controversial. The course requires learners to clearly judge the "criterion", complete the operational implementation, predict the impact of the results, and revise the rules as needed.

2.2. Mathematical modeling as a deliberative scaffold

Mathematical modelling serves the transformation between real scenes and mathematical expression. The complete process includes defining problems, screening "variables", setting up "assumptions", building associations, calculating results, interpreting data, and verifying the reasonableness of scenarios and generalisability. Blum and Borromeo Ferri [5] pointed out that this kind of logical transformation is much more difficult than basic calculation operations.

This study defines the mathematical model as a "deliberative scaffold" rather than a single "answer-producing machine". The model guides learners to identify "stakeholders", define "variables", compare alternatives, test derived results, and retain room for questioning and adjustment throughout the whole process. Learners can independently reject weight parameters, abandon currency proxy indicators, add "constraint", or determine that efficient results do not meet the needs of equity. Therefore, the core of mathematical ability is to explain the "assumptions" relied on by operations, and to clarify the scenarios to which the decision-making does not apply.

The Fair Allocation module relies on "fair-division theory" to build a content system. Based on the "Adjusted Winner" theory, both parties can allocate 100 points to the disputed items to achieve the distribution effect of "equitable, envy-free, and Pareto-efficient" [6, 7]. The above characteristics define multiple criteria for high-quality distribution, and "strategic reporting, indivisible items, and power differences" also clarify the application limitations of the theory. Jung and Wickstrom's research [8] on the school funding model also confirms that the mathematical model carries a differentiated definition of "fairness" and social value orientation.

The Money-Time Trade-offs module relies on the core view of economics: time has "opportunity cost". Becker [9] proposed that the cost of time can be included in the same analysis system as the cost of market commodities. However, "hour before a deadline" is completely different from the regular "flexible leisure" time value, so "value of time" belongs to a "contextual" concept, and there is no unified standard.

2.3. Adult learning and the Everyday Decision Modeling Cycle

Adult learning theory emphasises that teaching should be based on real decision-making rather than on informal indoctrination. Andragogical approaches pay attention to adult life experience, learning meaning perception, problem-oriented learning preferences, and immediate practical knowledge needs [10, 11]. This course takes daily intuition as the basis for initial judgement, guiding learners to transform subjective feelings into accurate logic and complete verification.

This model is in line with the empowerment concept of Chinese community education. Zhang and Perkins [12] deeply associate community education with "lifelong learning, participation, and empowerment". For short-term mathematics courses, the core connotation of "empowerment" is to improve the ability to express preferences, question rules and participate in decision-making, rather than to achieve macro-structural transformation.

Both modules followed a five-stage Everyday Decision Modeling Cycle:

(1) Intuitive choice: make an initial decision before receiving a formula.

(2) Criteria elicitation: identify standards such as equality, preference, workload, urgency, price, time, reliability, or compensation.

(3) Mathematical representation: translate criteria into points, variables, constraints, functions, probabilities, or thresholds.

(4) Sensitivity and critique: change assumptions, observe how recommendations change, and identify omitted factors.

(5) Transfer and justification: apply the framework elsewhere and defend the choice with reference to context, assumptions, and limitations.

The process breaks the traditional "formula-example-exercise" model, puts formula learning in the middle, and integrates "critique" into the category of core mathematical competence.

3. Research context and method

3.1. Design and participants

This research adopts a practice-oriented "design-based approach", combined with curriculum development and scenario effect verification. Hoadley and Campos [13] pointed out that "design-based research" focuses on producing scenario-based design conclusions, rather than on universal laws of cause and effect.

This assessment adopts the "one-group pretest-posttest pilot" design, and 36 adults complete the whole assessment process. The sample belongs to the "bounded convenience sample" of the Xi'an project, which is not representative of the population and cannot support subgroup effect analysis. Because no "control group" is set, the difference between the pre- and post-test is only defined as a short-term improvement after module learning, and is not recognised as the sole "causal effect" of the course.

3.2. Course modules

3.2.1. Fair allocation

Two people each distributed 100 valuation points across a house, stocks, cash, and a memento. The first assigned 40, 20, 30, and 10; the second 25, 35, 25, and 15. Giving each item initially to the person who valued it more produced subjective totals of 70 and 50. If the second person then received a fraction x of the divisible cash, the two valuations were given by Equation (1):

$$V_A = 70 - 30x, \quad V_B = 50 + 25x \tag{1}$$

Equating the totals gave $x = 4/11$. The first retained 7/11 of the cash, and each valued the final personal bundle at 650/11 ≈ 59.09. Each valued the other bundle at approximately 40.91, so neither preferred to exchange. Objective wealth had not increased; allocation according to different subjective valuations increased the value each perceived in the personal share.

The module then transferred from assets to burdens such as household work, eldercare, or team responsibilities. Learners considered efficiency—who could perform a task at lower cost—and fairness—

whether repeated reliance on the most capable person required compensation, rotation, or recognition. Assignment and settlement were separated: first reduce total burden, then inspect its distribution.

3.2.2. Money-Time Trade-offs

A subway trip cost 5 yuan and was expected to take 50 minutes; a taxi cost 45 yuan and 30 minutes. The taxi cost 40 yuan more and appeared to save one third of an hour. The break-even value of time was calculated using Equation (2):

$$v^* = (45 - 5)/[(50 - 30)/60] = 120 \text{ yuan per hour} \tag{2}$$

The comparison was also represented through generalized cost (Equation (3)),

$$G = C + vT \tag{3}$$

where C is monetary cost, T is time, and v is the learner's context-dependent value of an hour.

The answer was then revised. In a teaching scenario, the subway took 50 minutes with probability 0.90 and 60 minutes with probability .10, giving an expected time of 51 minutes. The taxi took 30, 45, or 65 minutes with probabilities 0.45, 0.30, and 0.25, giving 43.25 minutes. Expected saving fell to 7.75 minutes, raising the threshold to approximately 310 yuan per hour. A 55-minute deadline and a notional late-arrival loss L = 100 were then added through Equation (4):

$$E(G) = C + vE(T) + pL \tag{4}$$

Under these assumptions, the threshold rose to approximately 426 yuan per hour. These probabilities and the loss were pedagogical assumptions, not empirical Shanghai traffic estimates. They showed that a model's answer changes with its information set and that "average faster" does not mean "more reliable".

3.3. Measures, analysis, and ethics

Six measures were used:

(1) A decision-criteria articulation task, scored 0–4 before and after instruction, assessed explicit use of preference, cost, compensation, and exchange conditions.

(2) A model-based reasoning task, scored 0–10, assessed quantification, matching, compensation, and verification.

(3) A five-point usefulness rating.

(4) A novel-scenario transfer task, scored 0–4; at least 3 was classified as successful initial transfer.

(5) A five-point negotiation-agency item concerning the ability to express preferences or costs and participate in negotiation.

(6) A one-week follow-up asking whether participants had tried at least one framework element in an actual decision.

Data analysis is mainly based on descriptive statistics, covering mean, percentage and sample volume. The relative change is calculated according to the formula "(post − pre) / pre" combined with the whole mean. Due to the lack of original distribution and variance data, this study did not report "inferential tests, confidence intervals, and standardised effect sizes".

The full text only presents aggregated and non-identifying data. Because the data comes from the evaluation of internship courses, journal submissions need to rely on the review of cooperative institutions to confirm that the "consent and ethics requirements" meet the standards of public dissemination.

4. Results

Table 1. Descriptive outcomes

Measure	Pre-module	Post-module or outcome	Interpretation
Explicit decision criteria	2.08/4	3.33/4	+1.25 points; approximately +60.1%
Model-based reasoning	5.52/10	7.60/10	+2.08 points; approximately +37.7%
Negotiation agency	2.94/5	4.19/5	+1.25 points
Perceived usefulness	—	4.56/5	34 of 36, or 94.4%, selected 4 or 5
Novel-scenario transfer	—	88.9% successful	32 of 36 scored at least 3/4
One-week real-decision attempt	—	19 of 29 respondents	65.5% of respondents; 52.8% of the original sample

The average value of the "decision-criteria" of the subjects (Table 1) increased from 2.08 to 3.33 (out of 4 points), an increase of 1.25 points, or a 60.1% increase relative to the baseline. Learners can clearly list the dimensions of comparison and no longer rely on subjective and vague judgements such as "fair" and "worth it". The score of "model-based reasoning" increased from 5.52 to 7.60 (out of 10 points), an increase of 2.08 points and a 37.7% increase. The subject's "quantification, matching, compensation, reasonableness checks are significantly enhanced. This change cannot exclude the interference of "practice effects, rubric familiarity, facilitator influence".

The average "usefulness" of the course was 4.56 (out of 5 points), and 34 out of 36 subjects gave 4-5 points. It is generally recognised that the module adapts to housework, team tasks, resource sharing, convenient consumption and other scenarios, but "perceived usefulness" is not the same as actual learning results.

In the "novel-scenario transfer task", 32 subjects met the standard (≥ 3 points), accounting for 88.9%, which only reflects short-term "near transfer" and does not represent long-term "far transfer". The score of "negotiation agency" increased from 2.94 to 4.19 (out of 5). There were 29 valid samples of follow-up visits in a week, of which 19 tried to apply the curriculum framework, accounting for 65.5% of the number of follow-up visits and 52.8% of the initial sample. The result is only an early "behavioural experimentation", which does not represent continuous change, and is subject to problems such as the form of self-reporting, missing samples, and the broad definition of "trying an element".

5. Discussion

5.1. The mathematical logic of fairness

The Fair Allocation module verifies the core logic of "criteria before calculation". "Equal division" has high transparency and adapts to some scenarios, but it defaults that "equal quantities" are equivalent to equal value and burden. Room usage rights, night care labour, implicit emotional labour and other scenarios all have the characteristics of value differentiation. It is necessary to clarify the individual differences first, and then rely on mathematical tools for quantitative analysis.

The improvement of the standard score proves that learners move from subjective intuition to "accountable statements". Reasoning logic has been upgraded from the single "half is fair" to a normative expression based

on equal rights and interests, optimal efficiency and labour compensation; task allocation no longer simply relies on individual speed, but instead can achieve the double consideration of "total time minimization + unfair burden compensation". There is no absolute standard answer to this kind of reasoning, but it is explicit and open to debate.

The course case realises the split of "objective quantity" and "subjective allocated value". The dual subject can achieve a reasonable result where personal valuation exceeds half of the total amount through independent "normalised valuation systems", while distinguishing between multi-layered core attributes: "equitability" relies on subjective total value equality, and "envy" relies on exchange verification, and "efficiency" relies on value matching and distribution.

There are obvious limitations in the framework: there are problems such as "strategic reporting", underestimation of the burden of vulnerable people, emotional obligations not applicable to monetary compensation, and "power differentials" affecting the fairness of decision-making. "Fair-division mathematics" can only be used to expose differences and build a basis for consultation, and cannot replace "consent, law, or ethical deliberation".

5.2. The mathematical logic of value

The Money–Time Trade-offs module solves the core problem of "unlike quantities comparison". The public often subjectively judges that a plan "saves time" or "costs too much", but cannot clarify the critical criteria for decision-making reversal. This study introduces the critical value "v*", measures the equilibrium point of scenario-based time value, explores the "implicit price" behind the choice, and returns the final judgement to the user.

The dynamic change of the critical value from 120, 310 to 426 yuan per hour is more meaningful for teaching than a single value. The third version of the model adopts the variable system of "point estimates", "probability distributions" and "deadline risk" in turn, and the difference in conclusion comes from "information and assumptions" being updated, not from a mathematical or logical contradiction. This principle can effectively guide the rational interpretation of "forecasts, cost-benefit analyses, and algorithmic recommendations".

The module breaks the single cognition of "time value = wages". Salary is only a reference dimension. "hour before a flight, with a child, or in flexible leisure" has a differentiated "opportunity cost", and part of the time has a "non-tradable, non-recoverable" attribute. Therefore, "threshold" is only a scenario-based "decision weight" and does not represent the absolute value of people. Standardised mathematical modelling can realise conversion logic visualisation, revision and decision-making inability.

5.3. Models, assessment, and adult learning

The experimental results verify the core design hypothesis: the value of the mathematical model is to support "deliberation" rather than final decision-making. The most significant improvement of learners is in explicit "criteria expression" ability, and the "transfer task" proof framework can realise cross-scene reuse. The teaching closed loop of intuition revelation—mathematization—verification—reality correction is highly feasible and practical.

Teaching design needs to adhere to "consequential question first", abandon decontextualised skill teaching, and strictly distinguish between "descriptive inputs" and "normative choices": traffic duration is objective data, while valuation and late loss are subjective judgement; task duration can be objectively observed, while "emotional burden" has a value attribute. All models must be included in the "sensitivity question", check the inversion conditions of the conclusion, and at the same time expand the scope of verification from basic

operations to the full-dimensional proofreading of preferences, deadlines, stakeholders and assumptions checks.

The assessment and evaluation should focus on rewarding standard combing, unified unit, explicit hypothesis, scheme comparison, sensitivity analysis, and limitation explanation, rather than just assessing the accurate numerical value "x or v*". Future research needs to improve the complete "rubrics", add multi-scorer verification, and distinguish between the accuracy of operations and the ability to use model criticism.

5.4. Mathematics equity, voice, and agency

This study maintains a rigorous definition of "mathematics equity": two-module short-term courses cannot eliminate macro "educational inequality" and do not involve resource redistribution and long-term social outcome intervention.

Teaching fairness, in a narrow sense, focuses on "access, voice, and agency": access refers to low-threshold contact with practical mathematical logic; voice refers to personal preference, burden, and fairness definitions that can be incorporated into the model; agency refers to questioning rules, revising assumptions and participating in negotiations based on the framework. The increase of the "negotiation agency" score from 2.94 to 4.19 and the practical attempt of a one-week follow-up visit can support the improvement of perceived participation.

At the same time, it is clear that the improvement of confidence is not the same as the improvement of "bargaining power". The ability to clearly explain costs and logic may still be constrained by "institutional or relational inequality". Adult critical numeracy education needs to continuously question issues of data control, goal choice and result execution.

5.5. Limitations and future research

There are many limitations of this research: small sample size, non-representative, unable to carry out subgroup analysis; single group design cannot strip "practice effects, maturation, demand characteristics, facilitator influence"; teaching and evaluation are completed by the designer, and there is a "confirmation-bias risk"; the average value does not allow for inferential statistics, confidence interval and effect analysis.

At the same time, there are shortcomings in the assessment system: the scoring standard lacks complete documents, "usefulness and agency" relies on self-reporting, "transfer task" only detects short-term recent migration, short one-week follow-up cycle, missing samples, behavioural attempts have no objective verification; the valuation table, probability and loss parameters are all "pedagogical simplifications".

Therefore, this conclusion can only confirm the feasibility of the course, the perceived suitability and the improvement of short-term structured reasoning, and cannot verify the long-term behavioural change, universality and teaching superiority.

Future research needs to expand diversified samples, set up "facilitated course, video-only version, active comparison condition" multi-group comparison; optimise task design to avoid recall bias, use blind review scoring, add delayed assessment, rely on "decision diaries" to record real scenes, analyse "framework rejection" behaviour through interviews, and verify critical ability.

6. Conclusion

The core meaning of adults mastering the mathematical logic of "fairness" and "value" is not to rely on mathematics to obtain absolutely fair distribution results or accurate time pricing, but to disassemble the

hidden criteria, incomparable quantities and unverified assumptions in daily decision-making. Mathematical modelling can fully visualise the implicit decision-making logic.

The experimental data of 36 subjects showed that the dominant decision-criteria score increased from 2.08 to 3.33, and the model-based reasoning score increased from 5.52 to 7.60, and 88.9% of the subjects reached the migration task standard; learners have a high evaluation of usefulness, and the ability of negotiation agency has been improved. There is some preliminary practical behaviour in short-term follow-up, but there is no evidence of long-term behaviour change. All conclusions are preliminary descriptive conclusions and are strictly bound by the research design.

The core value of this research is based on teaching insights, not causal verification. Adult numeracy teaching should use the model as deliberative scaffolds to help learners clarify their core demands, compare alternatives, expose implicit hypotheses, deduce the impact of results, and explain the limitations of decision-making. The real mathematics equity is not only to popularise basic computing power, but also to give the public the ability to quantitatively question, logically argue, and participate in data-making.

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