

**AI-POWERED MOBILE AUGMENTED REALITY
EDUCATIONAL SYSTEM FOR PRIMARY SCHOOL
STUDENTS:
GEOMETRY AND ENGLISH LITERACY LEARNING
INDIVIDUAL THESIS**

Component 2: 2D NET CORRECTION AND VIRTUAL SLICING

Adaptive Scaffolding for Interactive Augmented Reality Geometry Learning

Research Project: R26-IM-005 | Product: GeoLex AR

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in Information Technology, Specialization in Interactive Media.

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ABSTRACT

Spatial geometry learning can be difficult when children must infer how flat geometric nets relate to three-dimensional (3D) objects and how solids are partitioned into fractional parts from static diagrams. This thesis presents Component 2 of GeoLex AR, a mobile augmented reality (AR) educational system for primary-school learners. The contribution combines error-specific two-dimensional (2D) net guidance with interactive Virtual Slicing of validated 3D solids. The finalized correction design operates before 3D generation: an invalid net identified by Component 1 is highlighted, explained using child-oriented guidance, and returned for learner revision. The Virtual Slicing workflow supports Cube, Cuboid, Triangular Prism, Tetrahedron, and Cylinder; Vertical, Horizontal, and Angled directions; and $1/2$, $1/3$, $1/4$, and $3/4$ fraction choices. The learner traces a displayed guideline to reveal separated pieces for inspection in an AR environment. The implementation used Unity 2022.3 LTS, C#, AR Foundation, and the ARCore XR Plugin, with event and session data recorded for research. Within the final pilot, 25 learners aged 9–12 participated in the geometry cohort. The Virtual Slicing activity was completed successfully in 20 of 25 recorded sessions (80%); mean logged task duration was 6.40 seconds (SD 1.91 seconds). Reported group mean scores increased from 5/10 to 9/10, a descriptive four-mark change. These results support the feasibility of the slicing workflow but do not independently quantify the effectiveness of net correction or establish a causal learning effect. The thesis documents design decisions, integration, evaluation boundaries, and responsible directions for further investigation.

Keywords: Adaptive Scaffolding; Augmented Reality; Geometric Net Correction; Spatial Visualization; Virtual Slicing.

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TABLE OF CONTENTS

1 INTRODUCTION	1
1.1 Overall project context	1
1.2 Individual component context	1
1.3 Problem statement	1
1.4 Research gap	2
1.5 Aim and objectives	2
1.6 Research questions	3
1.7 Scope, limitations and assumptions	3
1.8 Individual contribution	4
1.9 Thesis structure	4
2 LITERATURE REVIEW AND RELATED WORK	5
2.1 Review method and scope	5
2.2 Domain and theoretical foundations	5
2.3 Augmented reality and geometry research	6
2.4 Sketch understanding, representations and feedback	6
2.5 Existing systems, alternatives and differentiation	7
2.6 Research gap synthesis and conceptual framework	7
3 RESEARCH METHODOLOGY	8
3.1 Research design	8
3.2 Participants and study materials	8
3.3 Experimental and activity procedure	9
3.4 Measures and evaluation metrics	9
3.5 Data structure and descriptive analysis	10
3.6 Ethics, privacy, security and responsible practice	11
3.7 Reproducibility and research artifacts	11
4 PRODUCT AND SOLUTION DESIGN	12
4.1 Requirements and design constraints	12
4.2 Component architecture and integration boundary	13
4.3 Design alternatives and scope revision	13
4.4 Detailed design of 2D net correction	13
4.5 Shape-specific instructional design	15
4.6 Virtual Slicing interaction design	15
4.7 User interface states and educational accessibility	17
4.8 Research identity and export design	18
5 IMPLEMENTATION, INTEGRATION AND TESTING	19
5.1 Development environment and technologies	19
5.2 Implementation of slicing and correction states	19
5.3 Integration with Component 1 and shared application	20
5.4 Trace validation, retries and control behavior	20
5.5 Session logging, export and data protection	21
5.6 Software verification and regression safeguards	22
6 RESULTS AND VALIDATION	23
6.1 Overall C2 pilot results	23
6.2 Slicing performance by geometric solid	23
6.3 Slicing performance by direction	24

6.4 Slicing performance by fraction	25
6.5 Learning outcomes and assessment interpretation	26
6.6 User validation and engagement evidence	27
6.7 Integration evidence and boundaries	27
6.8 Summary of principal findings	28
7 DISCUSSION	29
7.1 Interpretation of findings	29
7.2 Comparison with literature and alternative learning forms	29
7.3 Individual research contribution and novelty	29
7.4 Product contribution and research logging	30
7.5 Limitations and threats to validity	30
7.6 Implications for teaching and future evaluation	31
8 COMMERCIALISATION AND SUSTAINABILITY	32
8.1 Value proposition and target users	32
8.2 Market alternatives and differentiation	32
8.3 Business and sustainability model	32
8.4 Intellectual property, compliance and accessibility	33
8.5 Sustainable Development Goal contribution	34
9 CONCLUSION AND FUTURE DIRECTIONS	35
9.1 Conclusion	35
9.2 Achievement of objectives	35
9.3 Individual research and product contributions	36
9.4 Future directions	36
REFERENCES	37
GLOSSARY	38
APPENDICES	39
Appendix A: Research evidence and reproducibility register	39
Appendix B: Illustrative event-to-session trace	39
Appendix C: Acceptance and final-code verification checklist	40
Appendix D: Academic integrity and AI-use disclosure	40
Appendix E: Proposed controlled Net Correction evaluation instrument	41

LIST OF FIGURES

Figure 4.1	Component boundary and C2 internal architecture.	13
Figure 4.2	Adaptive 2D net correction and revalidation flow.	14
Figure 4.3	AR Virtual Slicing activity workflow.	17
Figure 5.1	Session and event logging relationship.	21
Figure 6.1	Recorded Virtual Slicing sessions by solid.	24
Figure 6.2	Completion by slicing direction.	25
Figure 6.3	Completion by selected fraction.	26
Figure 6.4	Geometry-cohort pre-test and post-test means.	27

LIST OF TABLES

Table 1.1 Research boundaries and evidence status	4
Table 2.1 Literature positioning	7
Table 3.1 Evaluation design and denominators	8
Table 3.2 Variables in the documented C2 session record	10
Table 4.1 Functional and non-functional requirements	12
Table 4.2 Shape-specific instructional focus	15
Table 4.3 Supported cutting interactions	17
Table 5.1 Main implementation subsystems	19
Table 5.2 End-to-end and regression test matrix	22
Table 6.1 Aggregate outcomes for the C2 pilot	23
Table 6.2 Observed counts by geometric solid	24
Table 6.3 Breakdown by direction	25
Table 6.4 Breakdown by fraction	26
Table 7.1 Evidence strength and validity threats	31
Table 8.1 Commercialisation assumptions and validation needs	33
Table 9.1 Objective achievement and supporting evidence	36
Table A.1 Reproducibility and source-evidence register	39
Table B.1 Sample event sequence (illustrative, not participant data)	39
Table E.1 Planned fault-correction observation sheet (not completed data)	41

LIST OF ABBREVIATIONS

Abbreviations used throughout the thesis

Abbreviation	Definition
2D / 3D	Two-Dimensional / Three-Dimensional
APK	Android Package Kit
AR	Augmented Reality
ARCore	Google ARCore augmented reality framework
C1 / C2	Research Component 1 / Research Component 2
CSV	Comma-Separated Values
DSR	Design Science Research
IEEE	Institute of Electrical and Electronics Engineers
SD	Standard Deviation
SDG	Sustainable Development Goal
SLIIT	Sri Lanka Institute of Information Technology
UI / UX	User Interface / User Experience
UAT	User Acceptance Testing
XR	Extended Reality

1 INTRODUCTION

1.1 Overall project context

GeoLex AR is an integrated mobile educational system for primary-school learners that connects learner-generated inputs with computational processing, instructional feedback and three-dimensional or augmented reality reinforcement. It addresses geometry and English literacy through separate but related educational pathways. Component 1 validates learner-created geometric nets, Component 2 supports correction of invalid nets and exploration of solids by slicing, Component 3 recognizes camera-tracked air-written letters, and Component 4 connects child-generated object sketches with vocabulary activities and AR rewards. The existence of four components does not mean that they apply a common artificial intelligence classifier. Their common contribution is the repeatable instructional interaction cycle in which interpretation takes place before reinforcement [1], [2].

1.2 Individual component context

The individual component combines two instructional functions: 2D Net Correction and Virtual Slicing. The first responds to incorrect geometric relationships by locating the problematic aspect of a net and presenting visual guidance. The second provides an interactive way for learners to inspect the partitioned parts of validated 3D objects. Taken together, these functions serve successive phases of spatial learning. A child first becomes attentive to how a solid is constructed from connected surfaces; after a correct representation is available, the child can examine the solid and investigate the effect of selected cuts.

1.3 Problem statement

A static 2D diagram often does not allow a primary-school learner to inspect the consequences of moving an edge, changing face adjacency or intersecting a 3D solid with a plane. Learners may correctly identify a familiar solid by name but still struggle to reason about the spatial relationships that make its unfolded net valid. When an educational tool responds only with “incorrect,” it does not convey which relationship is wrong or how the learner could revise the representation. In the same way, showing

an intact 3D object does not necessarily clarify why cuts at different positions and orientations produce distinct cross-sections.

The individual research problem is therefore to design an accessible mobile AR geometry activity that offers informative corrective guidance for learner-created invalid nets and a controllable Virtual Slicing experience for exploring internal geometric structure. This problem is educational as well as technical: the guidance must be understandable to children, the geometry must be coherent with the selected solid, and the interaction must support repeated attempts without obscuring research evidence.

1.4 Research gap

Recent investigations of AR geometry demonstrate the potential of manipulable 3D representations to support visualization and geometric reasoning [3]–[7]. Yet an activity that begins with a predefined correctly formed cube cannot determine whether a student understands which 2D face arrangements will form that cube. Research on sketch interpretation and sketch-to-3D representation demonstrates how user-created input can be computationally analyzed [8]–[10], but recognition or reconstruction alone does not constitute fault-specific instructional guidance. Work on intelligent AR tutoring similarly suggests a need to distinguish instructional feedback from visually attractive presentation [6].

1.5 Aim and objectives

The aim is to design, implement and descriptively evaluate a mobile AR geometry-learning component that guides learners toward correct 2D geometric constructions and supports exploration of corresponding 3D solids through Virtual Slicing. This aim is operationalized through five objectives: (O1) define the interface from rule-based validation to corrective guidance; (O2) offer understandable visual highlighting, dotted suggestions and retry; (O3) provide five-solids slicing across supported orientations and fractions; (O4) preserve session-level identity and event-level research logging without disrupting the AR interaction; and (O5) evaluate completion and timing in the pilot while reporting evidence limitations accurately.

Each objective addresses a different aspect of the proposed learning artifact. O1 and O2 concern conceptual construction and formative feedback; O3 concerns 3D interaction; O4 concerns research observability; and O5 concerns evidence rather than development alone. Completion of a feature and an observed educational benefit are intentionally treated as different kinds of conclusions.

1.6 Research questions

The primary evaluated research question is: How reliably can the developed C2 Virtual Slicing activity be completed by primary-school learners aged 9–12 across its supported solids, directions and fractions? A design-oriented question is: How can invalid C1 geometry states be translated into child-friendly fault indications and opportunities for revision before 3D reinforcement? A third question addresses operational reliability: How should user choices, trace attempts, retries and session completion be preserved in research records while allowing repeated exploration?

1.7 Scope, limitations and assumptions

The component supports the five final solids and selected slicing controls on compatible Android hardware. The 2D correction process is initiated by an invalid net identified by C1, so C2 does not claim ownership of the foundational foldability classifier. AR placement depends on environmental scanning and a detectable physical plane. The slicing interaction depends on a displayed guideline and interpretation of touch tracing. Prepared separated meshes may present the outcomes of supported combinations; no physical cutting of a real object is implied.

The pilot contains 25 C2 sessions from the geometry cohort. It is not a benchmark of the full combinatorial space of every shape-direction-fraction configuration, nor is it a randomized comparison with textbook teaching. Gravity-driven falling of pieces was part of the later development specification, but a specific physics implementation was not independently verified by the final quantitative log. These restrictions keep the thesis aligned with observed evidence.

1.8 Individual contribution

The researcher responsible for C2 worked on the adaptive geometry guidance and Virtual Slicing interaction, including AR interface development, control progression and the component-specific evaluation and logging requirements. The contribution should not be described as development of C1's entire net classifier or of the two literacy components. At the project level, C2 makes the geometry learning pathway more than a simple valid/invalid test: it offers a correction route and an exploratory slicing route after an accepted model is available.

Table 1.1 Research boundaries and evidence status

Element	Supported status	Reporting boundary
2D net highlighting and guidance	Final component design / implementation described	No separate effectiveness statistic
Five-shape Virtual Slicing	Implemented and evaluated activity	25 recorded sessions
Trace attempts and retries	Research logging requirement	Detailed total not in published aggregate
AR plane detection / placement	Working architecture	Not a benchmark of tracking robustness
Gravity and falling pieces	Later specification / development work	Do not claim experimentally verified physics
Pre-post change	Reported aggregate group means	Descriptive; no paired scores or significance

1.9 Thesis structure

Chapter 2 reviews the relevant educational and technical literature. Chapter 3 presents the research design, participant cohort, data and analysis approach. Chapter 4 defines the product architecture and the revised 2D correction and slicing workflows. Chapter 5 documents implementation, integration and verification principles. Chapter 6 reports the final quantified outcomes and interprets their denominators. Chapters 7 and 8 discuss the contribution, validity threats, adoption and sustainable development. Chapter 9 concludes with objective achievement and prioritized future research; references and appendices provide an evidence and reproducibility register.

2 LITERATURE REVIEW AND RELATED WORK

2.1 Review method and scope

The literature review adopts a focused narrative synthesis of publications relevant to four intersecting areas: primary-school spatial geometry, educational augmented reality, adaptive corrective feedback, and manipulation of 3D shapes through slices and cross-sections. It begins with the literature cited in the final integrated research paper and the individual March 2026 proposal, prioritizing peer-reviewed work and recent syntheses where available. The purpose is conceptual positioning rather than claiming the completeness of a systematic database search with a preregistered screening protocol.

2.2 Domain and theoretical foundations

Spatial reasoning includes the capacity to relate different representations of an object, anticipate effects of rotation and folding, and infer sections of a volume. A geometric net is a 2D arrangement of connected faces that, under suitable structural constraints, can be assembled into a 3D solid. A net's validity is not determined merely by its area or number of visible polygons; adjacency, compatibility, orientation and closure matter. This makes invalid nets useful formative learning inputs because the location of an error can expose an underlying misconception about the solid [3]–[5].

Scaffolding refers here to temporally situated instructional support: the system indicates a problematic relation, presents an understandable example or visual hint, and invites the learner to try again. It should not simply complete the answer on behalf of the child. The degree of guidance can vary by task state—for example, initial error highlighting followed by an optional dotted-line hint. Because this implementation does not report a validated adaptive learner model, the term “adaptive” is used in the practical sense of guidance contingent on the detected error and learner action, not as evidence of a personalized predictive tutoring algorithm.

Cross-sections introduce a second representational demand. A learner must understand both the original solid and the geometry of the pieces produced by an imagined or visible plane. Virtual Slicing can expose an internal face that is invisible in an intact object, but the display must keep fraction selection, slice orientation and resulting solid

pieces conceptually coherent. The device's ability to overlay the object onto a physical desk can support embodied inspection without replacing the need for explanation or teacher-mediated discussion [6], [7].

2.3 Augmented reality and geometry research

Nadzeri et al. study AR applications for primary pupils' spatial visualization; Tarnag and colleagues examine improvements in elementary geometry understanding; and Wu et al. consider geometric thinking, cognitive load and flow in AR mathematical picture-book activities [3]–[5]. Together, these studies motivate the use of interactive geometric representations but cannot be read as direct validation of the present C2 correction logic. Their interventions, populations, designs and outcome definitions are not identical to the present pilot.

2.4 Sketch understanding, representations and feedback

Sketch2Model demonstrates the feasibility of moving from freehand 2D representation toward 3D modeling, while recent sketch-recognition work explores learned features that identify the intended category or structure of drawn input [8]–[10]. C2 occupies a different position. It does not claim that one general CNN classifies or fixes the geometry; C1 performs a deterministic rule-based net validity decision, and C2 provides an instructionally meaningful response to invalid geometry states. This division ensures that a perceived picture similarity does not automatically stand in for proof of foldability.

A simple correct/incorrect message represents a low-information response. A fault-specific correction step is more useful when it connects the failed property—such as adjacency, orientation or a missing connection—with an observable part of the 2D drawing. A dotted correct edge or highlighted face should function as a hypothesis that the learner tests, not as an uninterpreted decorative overlay. The feature is therefore presented as an interaction design for active revision. Demonstrating that it improves learning would require a future controlled comparison of children who do and do not receive this guidance.

2.5 Existing systems, alternatives and differentiation

The practical alternatives considered in the original problem definition include textbook drawings, physical paper nets, plastic or cardboard geometric models, touchscreen learning applications and AR viewers of prepared solids. Paper nets are inexpensive and physically tangible, but repeated construction and revision can be time-consuming; physical models provide tactile feedback but do not inherently explain every error. An AR viewer can make a 3D object visible yet may not accept and analyze the child's own incorrect construction. The current component does not render these alternatives obsolete; it aims to complement them in teacher-led and supervised practice.

Table 2.1 Literature positioning

Related strand	Established contribution	Boundary of C2
Primary AR geometry [3]–[5]	Manipulable shapes can support geometric learning	Learner-created net fault response emphasized
Intelligent AR tutoring [6]	Pedagogically organized feedback in AR	No independently measured tutor benefit here
Representation comparison [7]	Effects vary with modality and task	Mobile AR is a design choice, not guaranteed superiority
Sketch interpretation [8]–[10]	Hand-drawn input can be processed	C1 rule-based validity before C2 guidance
Design Science Research [11], [12]	Develop and evaluate an artifact in context	Separate implementability from educational causal claims

2.6 Research gap synthesis and conceptual framework

The synthesis identifies two separable needs that can be addressed in one component: support for the child who has made a geometrically invalid 2D representation, and opportunities to investigate interior 3D sections once a valid solid has been established. The first need is formative and error-oriented; the second is exploratory and spatial. The proposed conceptual framework therefore progresses from learner construction, through validity-dependent feedback and possible revision, to a 3D/AR state and user-controlled Virtual Slicing.

3 RESEARCH METHODOLOGY

3.1 Research design

The research follows Design Science Research (DSR), in which a technological artifact is designed, developed, demonstrated and evaluated against a practical problem [11], [12]. The artifact examined in this thesis is the C2 correction-and-slicing component embedded in GeoLex AR. The research cycle included literature review and problem definition, initial correction/slicing designs, iterative Unity implementation, integration with the C1 geometry pathway, device testing, pilot evaluation and reflection on limitations. The result is both a working set of learning interactions and an evidence-bound assessment of the task that was quantitatively logged.

3.2 Participants and study materials

The integrated pilot involved 50 unique primary-school learners divided into two age-specific cohorts. The geometry cohort comprised 25 learners aged 9–12 who evaluated both C1 and C2. A different cohort of 25 learners aged 6–8 evaluated the literacy components. Consequently, C2 had 25 participant-linked Virtual Slicing records, not 50 independent C2 learners and not 100 unique overall participants. The same child may appear in the C1 and C2 component datasets because the geometry cohort was shared, but component observations are not independent participants.

Table 3.1 Evaluation design and denominators

Study element	Geometry C2 evidence	Interpretive note
Participants	25 learners, ages 9–12	Same cohort also evaluated C1
Sessions	25 slicing sessions	The primary technical/workflow denominator
Learning assessment	Group means: 5/10 before; 9/10 after	No retained paired participant score table
Correction efficacy	No isolated experimental sample	Qualitative design/implementation only
Ethical participation	Guardian consent and learner assent obtained	Data anonymized for reporting

3.3 Experimental and activity procedure

The intended learner journey begins with a login or entry activity, during which the child enters a nonempty name and receives a unique session identity. In a geometry learning activity, the learner produces a 2D net that C1 validates. Invalid nets can be routed into C2 for targeted highlighting, optional guidance and retry; a valid representation permits the correct 3D object to be displayed. The Virtual Slicing workspace is a separate but connected stage in which the environment is scanned for a suitable AR plane, a shape is selected and placed, and the child chooses a direction and fraction before tracing the guideline.

The slice operation occurs only when the trace is accepted by the interaction logic. Unsuccessful or incomplete tracing is a meaningful action: the learner should receive feedback and may attempt the trace again without losing all context. After a successful operation, separated pieces are displayed for inspection, while reset and change-shape controls enable further exploration. The documented evaluation measured the outcomes of 25 such slicing sessions rather than systematically randomizing the order of all combinations. The final paper does not publish a complete individual procedural timing protocol; no fictitious session script is treated as observed fact here.

3.4 Measures and evaluation metrics

The primary C2 technical outcome is binary successful completion of the intended Virtual Slicing workflow. Its observed rate is computed as 20 successfully completed sessions divided by 25 recorded sessions, multiplied by 100, producing 80%. Additional descriptive variables include slicing direction (Vertical, Horizontal, Angled), fraction choice ($1/2$, $1/3$, $1/4$, $3/4$), selected geometric solid, task duration and, as an implementation requirement, trace attempts and retry activity. These variables provide more context than a single completion rate, although the published category counts remain small.

Mean task duration of 6.40 seconds (SD 1.91) and observed range 3.02–9.78 seconds are reported from the finalized dataset. They are not claimed to capture total lesson duration, plane-scanning time or every interaction from initial login. Learning assessment was reported separately as an increase from 5/10 to 9/10 in group means.

This is four points on a ten-point scale, or 40 percentage points relative to the maximum score. It is not a 40% relative increase over the baseline; the distinction matters for accurate research reporting.

3.5 Data structure and descriptive analysis

The development defined two complementary levels of research record. Event-level logging captures meaningful choices and actions as they occur: session start, successful login, scanning, plane detection, object selection, direction and fraction changes, guide display, trace attempts, completion, reset and exit. Session-level data summarizes the run using the same unique Session ID and includes the learner identifier or entered name, selected configuration, number of attempts, completion state and duration. The final pre-existing CSV/database schema should be preserved during changes to login or UI behavior.

The original research data convention used anonymized Student IDs of the form ST0001–ST0025, but the current application login accepts any nonempty name. Where backward compatibility requires reuse of an existing StudentID column, an entered display name may be recorded there while a distinct automatically generated SessionID links events and sessions. Because names may be personally identifying, analysis and publicly shared data should use anonymized labels or aliases rather than exposing actual children’s names. A name must not be treated as a unique session key: two learners can enter the same text and one learner can begin multiple sessions.

Table 3.2 Variables in the documented C2 session record

Record area	Representative contents	Analytical purpose
Identity	Entered name / participant alias; unique SessionID	Link records without using names as keys
Context	Selected solid; direction; fraction	Describe the attempted task
Interaction	Repeated choices, trace attempts, retry events	Study process instead of final result only
Outcome	Successful slice; completion state	Compute completion denominator
Time	Start, end, duration	Describe observed task performance
Export	Events CSV and sessions CSV	Preserve inspectable research evidence

3.6 Ethics, privacy, security and responsible practice

The participants were minors. The completed final study reported institutional ethics procedures, informed consent from parents or guardians, assent from the learners and anonymization of recorded study data. These completed actions should be expressed in past tense; prospective provisions from the March proposal should not be substituted for final ethics statements. The use of demonstration images, real child-user photographs or voice/video clips in a future exhibition or publicly shared thesis must remain within the consent granted for that purpose.

The revised name-entry requirement improves usability but increases the need for data minimization. A child's entered name should not be included in public figures, research tables, screenshots or external datasets. An operational local export may contain an identifier for internal linkage, but researchers should produce a separate anonymized analysis copy, restrict access to raw files, and avoid unintended copying of personal data into demonstration materials. The supplied records do not establish a final encryption method, cloud synchronization policy or data-retention schedule; such technical controls require inspection of the actual release and ethics documentation.

3.7 Reproducibility and research artifacts

A reproducible evaluation package should specify the Unity version, Android build profile, installed AR packages, device model, selected shapes, task procedures, event schema, output files and validation criteria. The C2 development context identifies Unity 2022.3.62f3 LTS, C#, AR Foundation, the ARCore XR Plugin and a Xiaomi Redmi Note 9 Pro used in mobile tests. Shape-specific controllers, UI management, a trace detector and the research logger/exporter were part of the development history. Exact present script names may have changed during integration, so they should be copied from the final repository before code-level diagrams or signatures are finalized.

4 PRODUCT AND SOLUTION DESIGN

4.1 Requirements and design constraints

The educational requirements arise from the problems of net validity, corrective explanation and spatial sectioning. When a learner has a geometric error, the interface must make the relevant part visible and offer an actionable hint. After valid model generation, controls must let the learner choose a supported solid, slicing orientation and fraction, display an appropriate trace guide and see the result of a successful trace. For a primary-school audience, the interface must use readable wording, adequate contrast and large touch controls. The learner must be able to retry a failed interaction without unnecessary navigation complexity.

Operational requirements are equally important. Slicing should occur only after an appropriate 3D model and AR environment are available. A scan-to-plane state must not silently permit an unsupported placement. The event logger must associate all actions in one run with the same SessionID, and changes to names, icons or screen layouts must not inadvertently break CSV export or shape controllers. The final choice of fraction should not erase earlier selections; such changes are part of the learner interaction record.

Table 4.1 Functional and non-functional requirements

Requirement	Required system behavior	Rationale
FR-01	Consume C1 invalid net state and selected solid	Link validation and guidance
FR-02	Show error indication, optional dotted hint and retry	Support learner revision
FR-03	Provide five supported solids	Maintain research geometry scope
FR-04	Provide three directions and four fractions	Enable exploratory slicing controls
FR-05	Check slicing trace before presenting a result	Avoid unearned result progression
FR-06	Record repeat actions and unique SessionID	Preserve research event provenance
NFR-01	Child-readable, touch-friendly UI	Suit ages 9–12
NFR-02	AR plane placement on compatible Android	Connect model to physical context
NFR-03	Preserve existing controllers and CSV schema	Reduce regression risk

4.2 Component architecture and integration boundary

Figure 4.1 positions Component 2 between the C1 geometric decision and the slicing-based reinforcement activity. C1 determines validity from shape-specific geometric rules; if invalid, C2 receives the erroneous construction state and presents a guided corrective interaction. The learner can revise and resubmit the net for C1 validation. This feedback loop terminates in valid generation only when the underlying geometry passes the validation criteria. After the valid state, the model becomes available for AR viewing and for selection of a slicing task.

The component contains separable internal responsibilities. A correction-guidance responsibility interprets the faulty relation and renders highlighting or a dotted alternative. A model-inspection responsibility displays a valid 3D solid and supports viewpoint changes. A slicing-interaction responsibility handles shape selection, direction and fraction state, the visible guide and the trace acceptance. An outcome renderer displays the corresponding separated result. Logging cuts across the workflow rather than existing only at the final completed state.

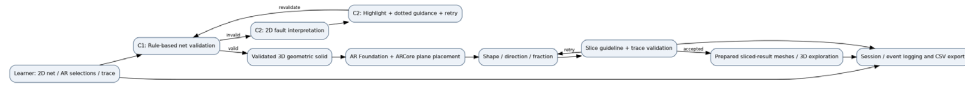


Figure 4.1 Component boundary and C2 internal architecture.

4.3 Design alternatives and scope revision

The March proposal emphasized comparing an incorrect generated 3D shape with a transparent ghost reference model. Supervisor feedback moved the main error-comparison process earlier to the 2D net stage. This revision improved conceptual alignment with the validation dependency: an invalid net should not first be materialized as if it were a valid solid merely to demonstrate its defect. Comparison of face positions, adjacency and missing or incompatible edges can be presented directly on the child's own net before 3D generation.

4.4 Detailed design of 2D net correction

The correction process begins with a validated invalid state, not with a guess based only on visual similarity. Examples of faults that guidance may address include an incorrectly positioned face, a missing connection, an incompatible edge, an incorrect

orientation or a configuration that cannot close into the required solid. The display should connect feedback to the actual position of the problematic geometry. An error highlight directs attention; a short message explains the kind of problem; and an optional dotted line provides a possible corrective relation. “GUIDE” and “TRY AGAIN” are two explicit learner choices in the finalized design.

The pedagogical effect depends on avoiding premature answer revelation. A single correct overlay that is always shown can turn the activity into copying, whereas progressive assistance gives the child an opportunity to revise independently. The system may first highlight a faulty edge and subsequently reveal a dotted target location. Once the learner adjusts the 2D sketch, C1 validates it again. Only after a valid state is reached does the model-generation phase proceed. Figure 4.2 presents this intended loop; it should be read as an explanatory process diagram, not a benchmarked step-by-step log of every child correction.

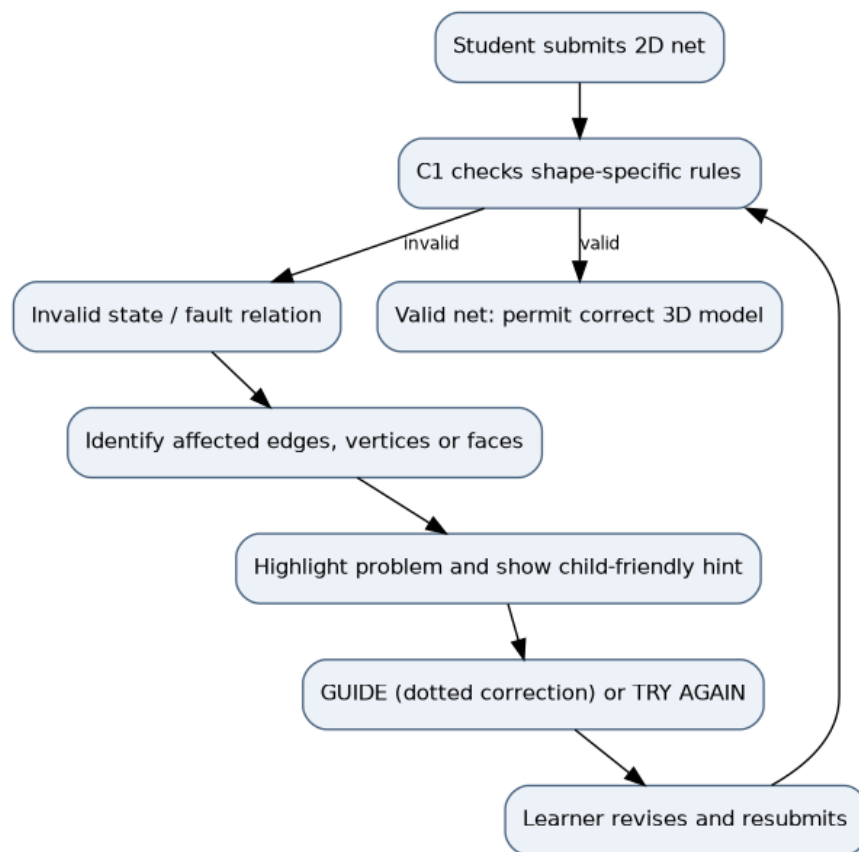


Figure 4.2 Adaptive 2D net correction and revalidation flow.

4.5 Shape-specific instructional design

The five supported solids impose different geometric expectations. The cube requires six compatible square faces arranged so that the net closes without conflicting overlaps. A cuboid uses compatible rectangular faces with correctly matched opposite dimensions. A triangular prism combines rectangular lateral faces and compatible triangular ends; a tetrahedron comprises four triangular faces capable of closing into one solid. A cylinder requires two equal circular ends and a compatible lateral surface. Component 1 is responsible for recognizing whether the submitted net satisfies the relevant constraints, while C2 provides the child-facing explanation if a relation is unacceptable.

These differences also shape the slicing outcome. A cut through a prism can produce sections that are unlike a similarly oriented cut through a cylinder. A child may need to rotate a model to recognize what remains the same and what changes when direction or fraction selection is modified. The component supports 360-degree inspection and zoom after a valid model is available. Because the final study has only two cylinder sessions and three tetrahedron sessions, the educational design of each shape cannot be ranked statistically by the observed aggregate outcomes.

Table 4.2 Shape-specific instructional focus

Final solid	Net / 3D concept	Exploratory slicing question
Cube	Six connected square faces / edge relationships	How does orientation change section shape?
Cuboid	Compatible rectangle dimensions	What does a fraction of a longer dimension mean?
Triangular Prism	Triangular ends and rectangular sides	How do cuts relate to triangular ends?
Tetrahedron	Four triangular faces	Why do different cuts reveal different polygons?
Cylinder	Circular ends and curved lateral surface	How do horizontal and vertical cuts differ?

4.6 Virtual Slicing interaction design

The Virtual Slicing interface uses a staged selection strategy to reduce cognitive load. First, the AR environment detects a suitable plane and the learner selects and places a supported shape. Next, the learner chooses a direction. Then the fraction is selected.

The application displays a trace line or guideline representing the intended slicing action; the learner traces the path using touch input. An incomplete or off-target trace should lead to retry feedback rather than immediately displaying a successful cut. This input sequence corresponds to a task-state machine, and each state can be described independently for testing and logging.

Fractions and directions are visible conceptual labels, not proof that every prepared mesh has an exact mathematically measured target volume. In reporting formal educational results, “fraction selection” means that the user selected a task configured for the fraction. The outcome renderer displays separated mesh pieces intended to communicate the corresponding division; a geometric mass or volume conservation test would require additional mesh-level evidence. In particular, one third and three quarters are not inherently equivalent to an equal division by a single arbitrary plane. The research should not claim that the fraction labels were numerically verified in each 3D mesh without such tests.

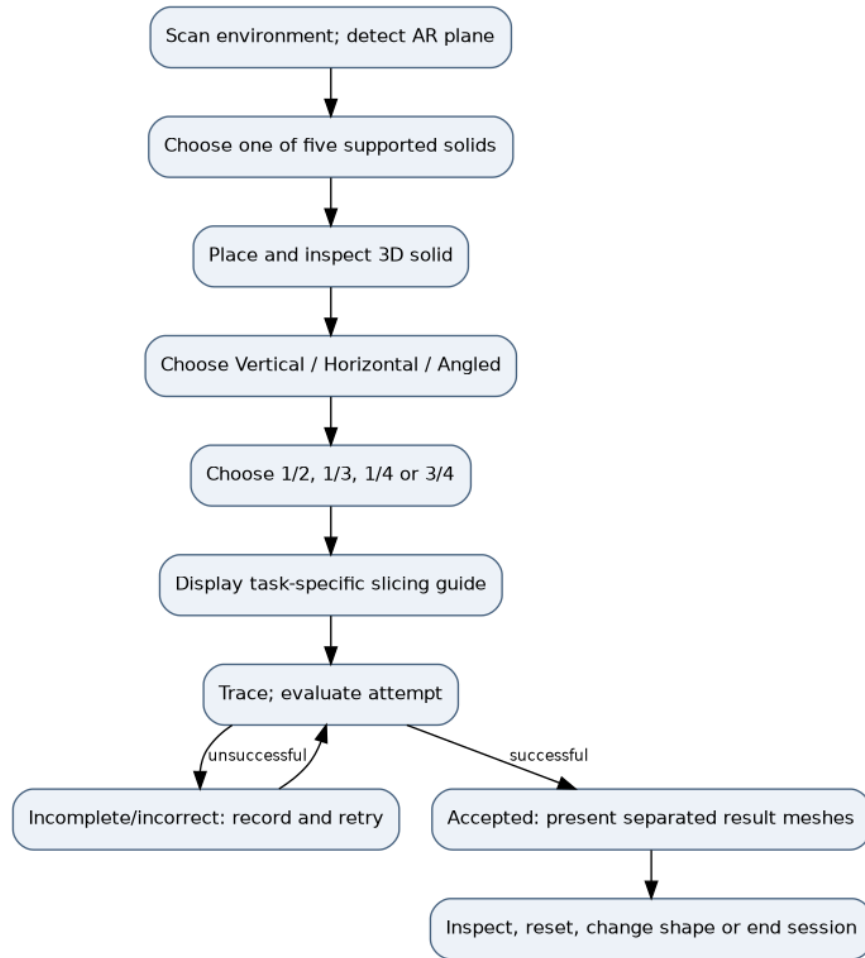


Figure 4.3 AR Virtual Slicing activity workflow.

Table 4.3 Supported cutting interactions

Dimension	Options	Recorded role
Solid	Cube; Cuboid; Triangular Prism; Tetrahedron; Cylinder	Shape choice and final per-shape count
Direction	Vertical; Horizontal; Angled	Direction selected and slice state
Fraction	1/2; 1/3; 1/4; 3/4	Each selection, including changes, is meaningful
Trace	Accepted; failed; incomplete	Repeated attempts should be retained
Outcome	Separated result / restart / reset	Session completion and exploration

4.7 User interface states and educational accessibility

The component was developed with several UI stages, including a start or welcome area, learner name entry, scanning, shape selection, model placement, slicing choices,

result inspection and export or session completion. Earlier prototype panels also included sketch, error, guide and 3D model views. Exact screen names varied during development, but the stable conceptual sequence remained unchanged. A UI redesign adopted colorful child-friendly illustrations and labeled controls; in a thesis, design claims should still be checked against screenshots from the actual final APK rather than replaced with fictional generated application screens.

User interaction must respect ordinary mobile input constraints. The typed name should appear within the same text-entry field as its placeholder and not in a separate displaced area. Clear button hit targets reduce accidental changes; a consistent back or reset path makes retries less frustrating. An information hierarchy that foregrounds “Choose Direction,” “Choose Fraction” and the displayed guide keeps the child focused on the next action. Color should reinforce meaning rather than be the only carrier of correctness information.

4.8 Research identity and export design

Research logging is a crosscutting service that begins before the first slicing action and continues through completion or exit. The chosen learner name is presentation or local identification data; the SessionID is the stable machine key linking event-level records. The interface may accept “Student A” or a conventional personal name, but the dataset should not assume that these strings are globally unique. A unique session key is generated on each start, including when two learners enter identical names. The historic ST0001-style participant aliases remain suitable for anonymized analysis and are separate from login validation.

Event log entries should preserve repeated fractions, directions and traces, enabling a researcher to reconstruct the sequence of choices rather than merely the last selected state. Session summaries should report the final selected shape and result, duration and available counts. The master file resides in Unity persistent storage; the export action copies data to an accessible Android Download/C2_ResearchData location when supported by device permissions. The exact storage APIs and modern Android scoped-storage behavior must be inspected in the final code before claiming universal export compatibility.

5 IMPLEMENTATION, INTEGRATION AND TESTING

5.1 Development environment and technologies

The development used Unity 2022.3.62f3 LTS with C# scripts, AR Foundation and the ARCore XR Plugin for Android. Early work used an XR Device Simulator for desktop interaction testing; later APK builds were run on an Android handset, including a Xiaomi Redmi Note 9 Pro. This combination supports camera-based plane detection, 3D object placement and touch interaction without requiring a dedicated AR headset. It also imposes device-specific constraints in camera permission, tracking quality, placement precision and available processing resources.

The runtime can be divided into screen/navigation management, AR session and placement, the geometry slicing controller, touch-trace interpretation and the research logging/export subsystem. Shape-specific controllers allow the project to represent different geometric outputs without forcing all solids through an identical mesh operation. The documented working functionality includes all five final solids, but exact present source filenames and package revisions should be reproduced from the final source repository before compiling a definitive code manifest.

Table 5.1 Main implementation subsystems

Subsystem	Representative scripts or systems	Responsibility
Navigation	C2_AppUIManager.cs and UI panels	Screen progression and choices
AR placement	C2_ARPlacementManager.cs / AR managers	Plane acquisition and solid placement
Tracing	C2_SliceTraceDetector.cs	Trace handling and acceptance
Slicing	Shape-specific controllers	Supported slice outcomes by solid
Session management	C2_StudentSessionManager.cs / C2_SessionManager.cs	Unique SessionID and run lifecycle
Data logging	C2_ResearchDataLogger.cs / C2_DataLogger.cs	Event/session records
Export	C2_CSVExportManager.cs	Preserve and copy CSV records

5.2 Implementation of slicing and correction states

The Unity component implements interaction as a progression of valid states. The geometry correction route begins only after an invalid 2D result exists, ensuring that

the explanatory overlay can be grounded in a specific relation rather than a generic failure. The learner may request more guidance or retry; once corrected, validity must be checked again. This arrangement preserves C1 as the source of truth for geometric validity and C2 as the consumer of fault information and the renderer of educational guidance.

5.3 Integration with Component 1 and shared application

Component 1 and Component 2 form a direct dependency. C1 first checks the learner-created net using shape-specific geometric constraints. Invalid constructions do not proceed to a misleading “correct” 3D object. Instead, C2 can highlight an incorrect edge, face or connection and offer guidance. This route must maintain consistent shape identity, avoid stale previous errors, and support revalidation once the child changes the net. The geometry components share the five-solid scope but have distinct evaluation metrics: 25/25 validation agreement belongs to C1, whereas 20/25 completed slicing sessions belongs to C2.

5.4 Trace validation, retries and control behavior

Trace validation is a necessary gate in the instructional sequence. It should distinguish a completed intended trace from an incomplete attempt and should avoid promoting accidental touch gestures into a successful slice. Some development requirements also considered incorrect starting positions and tolerance windows; these are useful design possibilities, but their exact thresholds are not documented in the final published evaluation. The thesis therefore presents trace validation as a working interaction check without claiming particular unverified geometric formulas or acceptance percentages.

Controls such as Try Same Slice, Reset Choices, Restart AR and Change Shape serve different learner intentions. Try Same Slice repeats the existing configuration; Reset Choices returns direction and fraction state to a neutral selection; Restart AR restarts placement or scanning; Change Shape returns to the solid selection. Each transition should be handled without leaving old result meshes or guides obstructing the next activity. For research quality, a retry must also be represented as a new event rather

than replacing the original failed trace. A repeat selection of 1/2 after another fraction has been chosen is meaningful interaction history.

5.5 Session logging, export and data protection

Figure 5.1 shows the relationship between event entries and a unique session identifier. Event records capture the path through shape selection, guide display, failed and accepted tracing and result inspection. The session summary consolidates outcome and duration. Both kinds of record are needed: events support analysis of process and retries, while a summary offers a clean denominator for calculating completion at the session level. These data should be written consistently even when a learner changes the direction or leaves before completing a cut.

The final component requirements specify local CSV storage in Unity persistent data, with exports copied to an accessible Downloads/C2_ResearchData folder where available. Typical logical files include C2_Events.csv and C2_Sessions.csv; historical builds also referenced C2_TestResults.csv. A copying export preserves the internal master instead of moving or deleting it. Before a formal release, the final APK should be checked for actual storage permission behavior on the target Android version, because path visibility and scoped-storage requirements vary across devices.

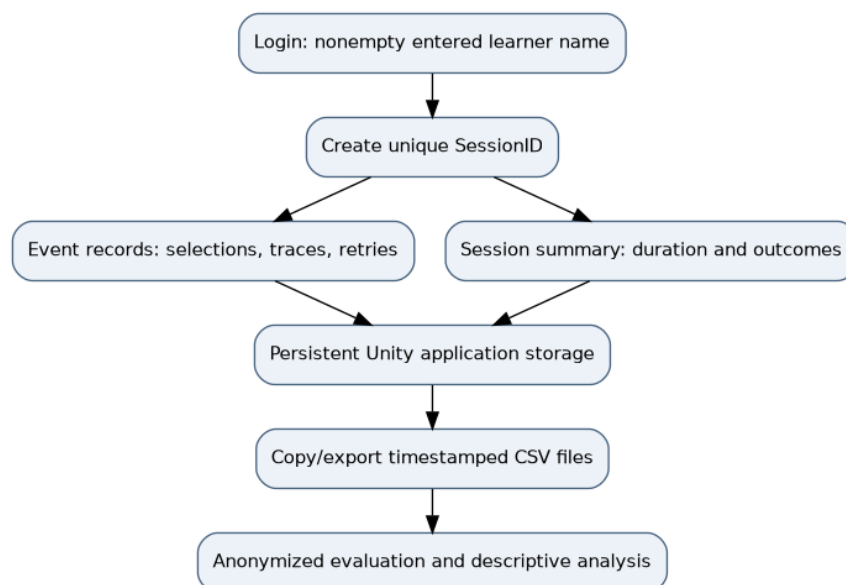


Figure 5.1 Session and event logging relationship.

5.6 Software verification and regression safeguards

The verification strategy should test each complete interaction path rather than only the visible final mesh. At the correction boundary, an invalid net must not accidentally produce a successful AR object and a corrected net must be returned for validation. For Virtual Slicing, every supported shape should be selectable; plane detection and placement should precede tracing; each direction and fraction should generate the expected guide state; invalid traces should be recoverable; and reset should remove stale objects or prior selection highlights. Regression checks should be repeated after UI or login changes because such changes often have unforeseen links to event subscriptions and panel visibility.

A particularly important development rule is preservation of working functionality. An adjustment to the login text field should not replace geometry controllers; a change to UI art should not alter CSV headers or SessionID generation; and an export-path change should not rewrite slicing logic. The source supplied for review should always be the actual current, compiled script rather than an older assistant-generated version. After any source edit, the project should compile with no red Console errors, show valid Inspector references and be tested in Play Mode and on the Android device where relevant.

Table 5.2 End-to-end and regression test matrix

Test area	Input / situation	Expected outcome
Correction	Invalid C1 net	Highlight / guide; no accepted model
Revalidation	Corrected net	Return to C1 check before generation
Plane detection	No AR plane	Do not permit meaningful placed slicing
All shape options	Select each of five solids	Correct model/guide state
Direction / fraction	Change options repeatedly	Current display updated; all events retained
Trace failure	Incomplete guide tracing	Feedback, no successful sliced result
Trace acceptance	Valid intended trace	Corresponding result becomes inspectable
Repeated session name	Same name on different runs	Different SessionID each run
CSV export	Export from Android build	Master remains; copy readable
Restart/reset	Retry or change shape	Clean state; no stale results

6 RESULTS AND VALIDATION

6.1 Overall C2 pilot results

The final pilot recorded 25 Component 2 Virtual Slicing sessions from learners aged 9–12. Twenty sessions met the recorded successful-completion condition, corresponding to 80% of sessions; five were unsuccessful. Mean task duration was 6.40 seconds with a standard deviation of 1.91 seconds, and the observed duration ranged from 3.02 to 9.78 seconds. These statistics characterize the activity as evaluated, not every possible AR setup and slice configuration. The report does not supply a secondary C2 accuracy metric for fault-specific net correction.

The result is educationally relevant because it demonstrates that most recorded learners were able to complete the intended guided slicing interaction in the test context. Yet the 80% figure cannot be treated as geometric mesh accuracy, trace-classification sensitivity, fault-detection accuracy or direct learning improvement. Those would require different reference labels and evaluation protocols. The distinction is essential when comparing C2 with the other components, whose reported percentages measure different outcomes.

Table 6.1 Aggregate outcomes for the C2 pilot

Measure	Final reported value	Interpretation
Number of recorded sessions	25	Geometry learners aged 9–12
Successful sessions	20	Completed slicing workflow
Unsuccessful sessions	5	Not completed in logged sample
Session completion rate	80%	20/25 (not correction accuracy)
Mean task duration	6.40 seconds	Observed recorded task
Duration standard deviation	1.91 seconds	Session-to-session spread
Observed range	3.02–9.78 seconds	Not total lesson time
Net Correction accuracy	Not independently quantified	No standalone controlled dataset

6.2 Slicing performance by geometric solid

The final dataset includes all five target solids, but session counts were uneven. Cube contributed three sessions, Cuboid eight, Triangular Prism nine, Tetrahedron three and Cylinder two. This distribution demonstrates coverage of the final supported shape list; it does not demonstrate an equal level of testing for each solid. In particular,

observations for a solid with only two or three records are insufficient to support a stable ranking of user difficulty or reliability.

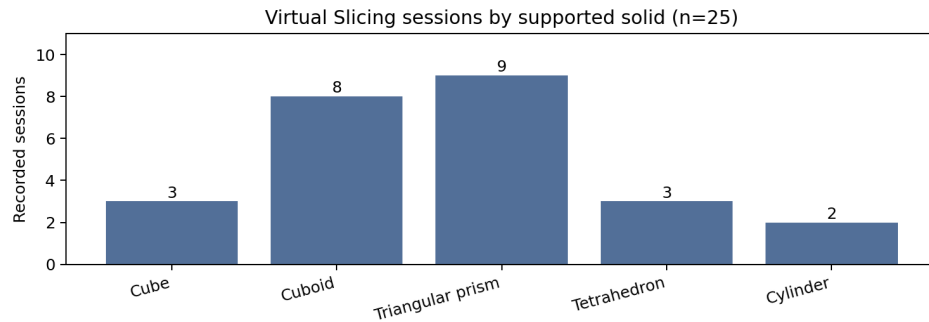


Figure 6.1 Recorded Virtual Slicing sessions by solid.

Table 6.2 Observed counts by geometric solid

Solid	Sessions	Share of all C2 sessions
Cube	3	12%
Cuboid	8	32%
Triangular Prism	9	36%
Tetrahedron	3	12%
Cylinder	2	8%
Total	25	100%

6.3 Slicing performance by direction

Vertical slicing succeeded in all five recorded Vertical sessions. Horizontal slicing succeeded in eleven of fourteen, and Angled slicing succeeded in four of six. The direction-specific completion proportions are therefore 100%, approximately 78.6% and approximately 66.7%, respectively. Figure 6.2 shows successful and unsuccessful counts rather than only percentages, because the unequal denominators make percentage-only comparisons misleading.

The results may suggest that angled tracing presented additional practical difficulty for some learners; however, the sample was small and configurations were not balanced. Direction was not isolated from participant, selected fraction, solid or order of activity. Consequently, the study cannot establish a causal effect of slicing orientation on completion, and the observed vertical success rate should not be generalized to future learners or different solids.

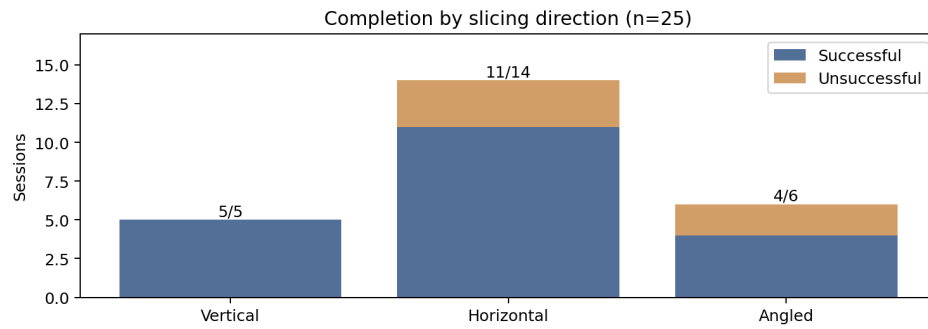


Figure 6.2 Completion by slicing direction.

Table 6.3 Breakdown by direction

Direction	Successful	Total	Observed rate
Vertical	5	5	100.0%
Horizontal	11	14	78.6%
Angled	4	6	66.7%
All directions	20	25	80.0%

6.4 Slicing performance by fraction

For selected fraction tasks, $1/2$ succeeded in four of five sessions, $1/3$ in three of four, $1/4$ in six of seven and $3/4$ in seven of nine. The reported proportions are 80.0%, 75.0%, 85.7% and 77.8%, respectively. These labels refer to configured learning options and observed completion; they do not prove that the output of each slice possessed an exact corresponding volumetric proportion measured independently from its mesh geometry.

Figure 6.3 presents the actual observed counts. The small sample for the $1/3$ option, coupled with unequal usage of the four choices, makes fine-grained inferential comparisons inappropriate. A future protocol should explicitly define the targeted fraction representation for each solid and slicing direction, then separately assess whether learners can interpret the resulting section rather than recording only whether the software progressed to the result state.

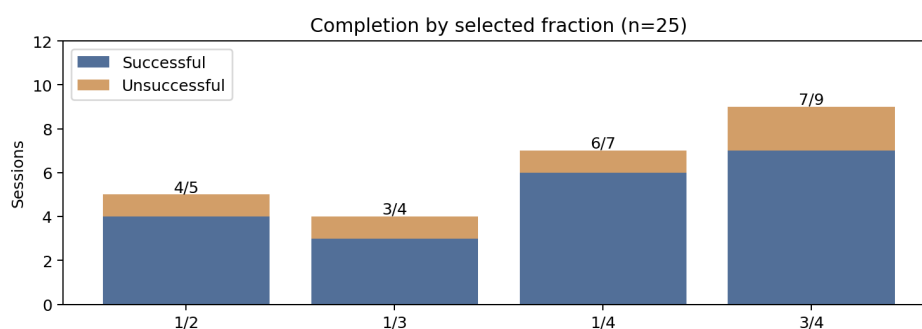


Figure 6.3 Completion by selected fraction.

Table 6.4 Breakdown by fraction

Selected fraction	Successful	Total	Observed rate
1/2	4	5	80.0%
1/3	3	4	75.0%
1/4	6	7	85.7%
3/4	7	9	77.8%
All fractions	20	25	80.0%

6.5 Learning outcomes and assessment interpretation

The geometry cohort's reported mean C2 learning assessment score increased from 5 out of 10 before interaction to 9 out of 10 after interaction. The absolute difference is four marks. The same geometry group also evaluated C1, whose aggregate pre-/post-test means were reported as 5/10 and 9/10. Figure 6.4 places the two aggregate geometry component outcomes side by side for context but does not imply that their improvements were causally independent.

The published final paper retained aggregate means rather than the participant-level paired scores. It therefore did not report a validated distribution of individual gains, a paired t-test, a Wilcoxon result, confidence intervals for learning gains or a causal comparison with conventional instruction. An increase in the average observed scores is encouraging as a descriptive finding, but it cannot be promoted into proof that C2 was superior to all traditional methods or that the effects will persist after several weeks.

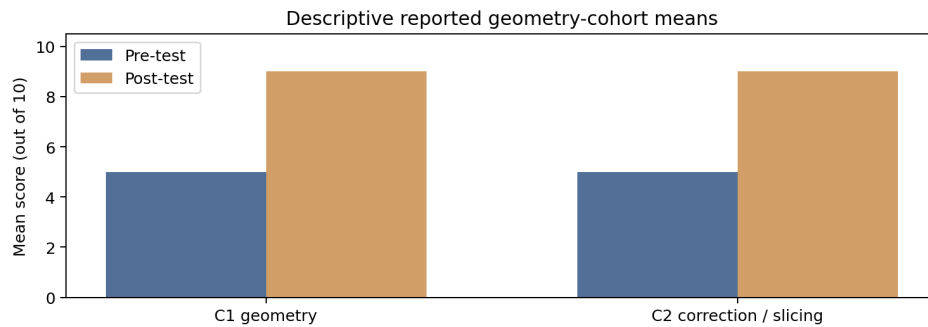


Figure 6.4 Geometry-cohort pre-test and post-test means.

6.6 User validation and engagement evidence

The children completed practical interactive activities using the application, and real testing footage and photographs were recorded for the final group study. The paper also reports session timing and completion information, which provide indirect evidence of whether the workflow could be followed. These observations are consistent with the feasibility of a mobile learning activity for the target age group. They do not substitute for a validated child usability questionnaire or observational coding scheme that would establish detailed findings about ease of use, comfort or preference relative to non-AR materials.

In a future C2-specific evaluation, observations should be recorded with a structured protocol addressing whether a child understands the error highlight, can explain why a net is invalid, can independently select the intended cut and can state what the resulting pieces mean. Teacher interpretation could also be included. Such methods would make it possible to evaluate scaffolding quality rather than only task completion, while protecting children's privacy and avoiding unsupported claims about motivation.

6.7 Integration evidence and boundaries

C2's integration with C1 is supported by the documented validity-to-guidance design and by the final group paper's description of invalid states being routed for correction. C1's separate outcome was 25/25 agreement with expected net validity labels: twenty valid and five invalid cases. That result helps establish why a correction branch is needed, but it does not prove that C2 successfully corrected all invalid examples. The

amount of correction attempted, number of hints requested and accuracy of post-guidance revisions were not independently summarized in the final quantitative record.

6.8 Summary of principal findings

The pilot provides four bounded findings. First, the final five-shape slicing workflow was used in a child-user evaluation with twenty successful completions among twenty-five sessions. Second, completion varied descriptively across chosen orientations and fractions, with limited denominators. Third, the reported aggregate geometry mean increased by four marks after interaction but cannot support inferential or causal claims. Fourth, the revised 2D correction mechanism is an important implemented design contribution whose independent effect remains unmeasured in the published dataset.

These findings answer the evaluated slicing question at a descriptive level and frame the next research step. Improvements to evidence quality should prioritize balanced trials, direct measurement of fault-specific correction performance, and explicit assessment of what children understood about cross-sections and fractions, not merely further visual polish of the AR screens.

7 DISCUSSION

7.1 Interpretation of findings

The C2 result supports the practical possibility of presenting a guided Virtual Slicing activity within a mobile AR geometry experience for primary-school learners. The reported 80% completion indicates that most participants finished the configured activity, even though some did not. This finding is a task-workflow measure. A student may complete a cut without being able to verbally justify its fractional meaning, and a student may fail a trace through an input-control difficulty while still understanding the geometry. Educational interpretation must preserve this distinction between interacting successfully and demonstrating mastery of an underlying mathematical concept.

The direction and fraction breakdown is useful for improving design but is not a controlled difficulty study. For example, a lower observed completion rate in Angled slicing could reflect visually complex tracing, the selected solid, fraction positioning or device handling. The final report does not separate those explanations. The appropriate response is to identify hypotheses for further testing rather than assume an algorithm is faulty or claim a verified cognitive difference.

7.2 Comparison with literature and alternative learning forms

AR geometry studies support the importance of making 3D representations interactive, but also show that learning outcomes are sensitive to instructional design, learner age and the chosen comparison condition [1]–[7]. The current thesis is consistent with this direction by emphasizing learner action—constructing, correcting, selecting and tracing—rather than using AR only to display a completed shape. Its distinctive role is to connect formative representation correction with exploration of the solid’s internal structure. It does not claim stronger statistical efficacy than the cited studies because designs, scales and outcome measures differ.

7.3 Individual research contribution and novelty

The principal individual contribution is an educational progression from invalid 2D net to fault-oriented guidance, valid 3D representation and interactive slicing. The 2D

correction stage addresses where and how the learner can revise a representation. The slicing stage addresses how a valid object can be explored through different sections. Both stages depend on the child supplying meaningful input and receiving a response relevant to that input. The contribution is therefore a design and integration approach with a piloted slicing interaction, not an independently proven novel mesh-fracture theorem.

The scope revision itself is analytically important. Moving comparison to the 2D sketch level aligns feedback with the artifact that the child can actually revise. It also preserves C1's validity gate so an erroneous net does not become a misleading 3D teaching object. A 3D ghost model may still be valuable as a reference after the solid is known to be correct; in that role it supports inspection rather than error classification.

7.4 Product contribution and research logging

C2's product contribution includes a selectable five-solid AR learning workspace, supported slicing directions and fractions, a tracing interaction, result inspection and repeat actions. The research logging layer makes the activity suitable for more than an exhibition demonstration: individual choices and attempts can be associated with a session, permitting a future researcher to investigate how users reached an outcome. Such process data may reveal a repeated misunderstanding even when the final state is successful.

Preserving the existing code architecture matters for product maturity. Separate shape controllers, the trace detector, UI state management and the export service reduce the risk that a change to one educational task damages another. Nevertheless, architectural modularity should not be equated with proved software reliability; a source-audited set of regression results, performance measurements and anonymized release artifacts would be required for a stronger operational claim.

7.5 Limitations and threats to validity

The main threats concern sample size, missing individual-level educational data and uneven task configuration. There are only 25 slicing sessions, distributed unequally across shapes, directions and fractions. Without randomization or an appropriate control condition, the pre-/post-test change may reflect familiarity, assistance, other

learning during the session or assessment effects. The final available file does not retain paired learner scores, so inferential analysis would be speculation. The session duration also pertains to a recorded task interval rather than necessarily including all AR scanning and instructional setup time.

Net Correction is not measured as an independent controlled outcome. No ground-truth set of corrected fault cases, time-to-correction distribution or before/after error-identification test is reported. An exact dynamic mesh-cutting method or falling-piece physics evaluation is not available from the final paper. These omissions are limitations to acknowledge, not reasons to modify the historical results. Interpretation remains sounder when every claim is tied to a specific observation or documented implementation stage.

Table 7.1 Evidence strength and validity threats

Claim	Available support	Limitation
Learners completed slicing	20/25 final logs	25 sessions; limited distribution
Some configurations harder	Category-specific observed counts	Not controlled or balanced
Learning scores increased	Reported 5/10 to 9/10 mean	No participant-level paired analysis
Net errors can be guided	Documented feature workflow	No isolated quantitative test
Physics fall is correct	Later development requirement	No published independent verification
Device compatibility	Android development and testing	No broad hardware benchmark

7.6 Implications for teaching and future evaluation

For instruction, the component is best positioned as a supplementary exploratory aid used alongside conventional explanation and practical manipulation. A teacher can ask children to predict the cross-section before selecting a direction, then compare the prediction with the result. During correction, children can be encouraged to explain what changes in a net and why. These activities provide a way to check whether a child is reasoning about geometry rather than merely interacting successfully with a touch guide.

8 COMMERCIALISATION AND SUSTAINABILITY

8.1 Value proposition and target users

The C2 module contributes to GeoLex AR's proposed educational value by connecting construction feedback with an interactive view of solid partitions. Primary users are children in the geometry learning age band, assisted by teachers and guardians. Schools, tutoring centers and educational institutions are potential organizational adopters, but their willingness to pay was not measured in the pilot. The component's relevant value proposition is the ability to explore common classroom solids without manufacturing a separate physical set for every example, while also receiving visual guidance that identifies specific errors in an attempted net.

This proposition should remain an adoption hypothesis until it is supported by stakeholder evidence. Teachers still need explanations, curricula still define the target concepts, and some students benefit from tactile manipulatives that an AR application cannot replace. A carefully designed classroom pilot could determine whether the component saves teacher preparation time, improves a specific geometry assessment or complements physical teaching materials effectively.

8.2 Market alternatives and differentiation

Relevant alternatives include print-based geometry workbooks, paper-net kits, manipulable classroom solids, existing mobile geometry applications and AR viewers of predefined 3D objects. Price and availability vary, so a final commercialization plan should rely on an actual market scan rather than dated proposal estimates. The distinguishing educational workflow is error-contingent 2D net correction followed by learner-controlled virtual cutting across a fixed set of primary-school solids. The narrowness of the supported set can be a strength during evaluation because it allows more consistent tasks and validation rules.

8.3 Business and sustainability model

Potential commercialization approaches include a school license for a curriculum-aligned GeoLex AR package, a freemium mobile application with optional learning modules, or institutional partnerships to support devices and teacher training. These

are future options, not existing revenue streams. Development costs can be contained through the use of Unity and AR-compatible Android hardware already available to the team, but ongoing maintenance, content checking, testing, privacy support and teacher onboarding would still require resources.

The March 2026 individual proposal contained an early illustrative development budget and commercialization assumptions. Those figures should not be represented as audited expenditure or validated demand. A responsible next step is to build a resource model based on actual developer time, deployment device cost, localization, software maintenance and user-support requirements. School trials should also evaluate whether app use is practical without stable internet access, whether export functionality meets privacy rules, and whether accessible alternatives are available for students without compatible phones.

Table 8.1 Commercialisation assumptions and validation needs

Proposed value or plan	Evidence available	Required next verification
Mobile classroom learning aid	Prototype and Android testing	Broader school device audit
Five-solid spatial learning scope	Implemented supported models	Curriculum and teacher alignment
Reduced use of physical kits	Plausible use case only	Cost/learning comparison
School or parent licensing	Commercial proposal option	Customer interviews and pricing test
Privacy-safe school analytics	Research logging architecture	Data protection and retention audit
Scalable deployment	Unity Android platform	Support, localization and QA plan

8.4 Intellectual property, compliance and accessibility

The integrated product combines original interaction design and source code with external technologies and prepared assets. Commercial distribution therefore requires an inventory of license terms for Unity packages, third-party 3D meshes, fonts, illustrations and any additional libraries. Ownership should be confirmed against university rules, contributor agreements and the circumstances of shared development. It would be inappropriate to describe a patent as awarded or any copyrighted asset as cleared without corresponding formal evidence.

Privacy and accessibility are core adoption requirements because the intended users are minors. Identifiable login text, recorded sessions and photos need data minimization, consent boundaries and appropriate security controls. Accessibility

should include readable instructions, sufficient contrast, forgiving touch targets, clear error feedback and the ability to use classroom activities without excessive physical movement. An AR-only interaction must not be assumed accessible to every learner; teacher-led physical or screen-only alternatives may be necessary.

8.5 Sustainable Development Goal contribution

The project is aligned with SDG 4: Quality Education because it investigates an additional interactive way to support primary-school geometric understanding. The intended benefit is to make abstract representations more visible and to let children test their own ideas through accessible controls. The pilot evidence supports technical feasibility in a limited participant group, but it does not demonstrate improved national educational equality, sustained learning outcomes or reduced teacher workload at scale.

Future adoption should be assessed for possible negative consequences as well as benefits, including unequal access to AR-compatible devices, privacy risks arising from child data, distraction during unsupervised camera use and overreliance on animations instead of conceptual explanation. The responsible measure of sustainability is not the number of 3D effects shown but whether the teaching context can support equitable, safe and demonstrably useful learning.

9 CONCLUSION AND FUTURE DIRECTIONS

9.1 Conclusion

This thesis documented the design, implementation context and pilot evaluation of Component 2, 2D Net Correction and Virtual Slicing, in the integrated GeoLex AR primary education project. The finalized approach treats invalid 2D nets as opportunities for fault-specific guidance before 3D generation, then enables learners to investigate a validated solid through AR placement, direction and fraction selection, touch tracing and inspection of separated pieces. The correction and slicing functions represent two linked but distinct stages of geometry learning.

The final recorded evidence shows successful completion of 20 of 25 Virtual Slicing sessions (80%), mean task duration of 6.40 seconds and descriptive improvement in the reported geometry assessment mean from 5/10 to 9/10. These observations support feasibility of the sampled workflow; they do not establish statistically significant learning gain, independent Net Correction efficacy or verified volume-conserving physical mesh behavior. The component's value is therefore a coherent instructional artifact with promising pilot completion and well-defined questions for further validation.

9.2 Achievement of objectives

The design and integration objectives are supported to different degrees. The C1-to-C2 invalid-net relationship and 2D correction interface are documented in the final architecture, but improvement caused by those hints was not isolated. All five final solids and three slicing directions and four fraction choices formed the implemented activity scope. A pilot evaluation was completed with the appropriate 9–12 age band, and the published result quantified slicing success and time. The logging and export behavior was developed as a research-supporting system, while exact deployed field names and storage permissions need final source inspection for reproduction.

This differentiated objective assessment is preferable to a binary “all objectives achieved” statement because scientific confidence depends on evidence type. A complete interface is not itself proof of educational effectiveness; conversely, a small

pilot should not be dismissed because it cannot answer questions that require a larger controlled study. The component established a reusable basis for subsequent testing.

Table 9.1 Objective achievement and supporting evidence

Objective	Assessment	Supporting evidence
O1 C1-to-C2 correction interface	Design / implementation supported	Invalid geometry routed for 2D guidance
O2 Visual correction support	Implemented; efficacy unmeasured	Fault highlighting, hint and retry architecture
O3 Five-solid AR slicing	Pilot demonstrated	20/25 completed sessions across supported solids
O4 Event and SessionID research logging	Development design supported	Documented session and export pipeline
O5 Quantitative evaluation	Descriptively achieved	Completion/time and aggregate learning means

9.3 Individual research and product contributions

The individual research contribution is the adaptation of a previously ghost-centered AR feedback proposal into a 2D fault-guidance workflow aligned with rule-based net validation and a separately evaluated AR Virtual Slicing activity. The product contribution includes five-solids selection, orientation and fraction controls, trace-validation-based progression, 3D result inspection and session-aware logging designed to retain a learner's retry history. The integrated geometry experience thereby links correct construction with exploratory analysis of the resulting volume.

9.4 Future directions

The first research priority is a controlled and independently labeled evaluation of 2D Net Correction. A study should sample known fault types, record whether the system located the correct error, distinguish hints requested from hints given automatically, and measure attempts and time to valid revalidation. The second priority is a balanced Virtual Slicing protocol covering each selected solid, fraction and orientation with clear geometric criteria for what a correct displayed result means. The third is a stronger educational evaluation using paired participant-level tests, suitable comparison activities, delayed retention tasks and child-appropriate usability instruments.

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GLOSSARY

Terms specific to the C2 research component

Term	Meaning in this thesis
Adaptive Scaffolding	Error-contingent visual hints intended to support revision, not autonomous tutoring efficacy.
2D Geometric Net	Connected arrangement of faces that may fold into a supported solid.
Net Correction	Highlighting/explaining a problematic 2D relation and offering learner revision.
Trace Validation	Interaction check determining whether a displayed slicing guide was followed sufficiently.
Virtual Slicing	Digital representation of a configured cut through a validated 3D geometric solid.
Cross-Section	Two-dimensional shape where a slicing plane intersects a solid.
SessionID	Unique session identifier linking event-level and session-level records.
Prepared Result Mesh	Predefined or prepared geometry used to represent a supported slicing outcome.
Task Completion Rate	Fraction of recorded activity sessions meeting the intended successful end state.

APPENDICES

Appendix A: Research evidence and reproducibility register

The available evidence bundle consists of the March 2026 Component 2 proposal, the overall Topic Assessment Form, the final IEEE-style integrated paper, the consolidated component development context, the university formatting guide and the individual report template. The pilot statistics reported in this thesis are based on the final integrated paper and consolidated research context. Source code, the full final APK, complete raw CSV files, original individual pre-/post-test scores and separate net-correction trial labels were not provided as a complete audited package; no fictional records have been created to replace them.

Table A.1 Reproducibility and source-evidence register

Evidence item	Use in this thesis	Verification still needed
Final ICAC/IEEE group paper	Final pilot numbers and component descriptions	Check accepted manuscript version
Component 2 March proposal	Initial scope and design alternatives	Do not present ghost-based plan as final
C2 development master context	UI, sessions, CSV, controller history	Confirm final script versions
Final Unity project and APK	Runtime implementation evidence	Attach signed release identifiers
Original anonymized CSV	Recreate each descriptive statistic	Preserve unchanged historical logs
Guardian consent and learner assent	Completed ethics statement	Verify photograph/publication scope
SLIIT formatting standards	A4 margins, typography, section style	Final institutional review

Appendix B: Illustrative event-to-session trace

The following sequence illustrates how a logger would preserve repeated choices in one run. It is not a row from an actual participant and must not be cited as observed user-testing data. A production record would include timestamps and existing schema fields as defined in the final project source. The example avoids child names and demonstrates why events and summaries are different evidence levels.

Table B.1 Sample event sequence (illustrative, not participant data)

Sequence	Example event	Research significance
1	Session started (new SessionID)	Begin unique run
2	Plane detected; Cube selected	Context established

Sequence	Example event	Research significance
3	Direction Vertical; Fraction 1/2 selected	First configuration
4	Fraction changed to 1/3	Record transition, not only final choice
5	Fraction changed back to 1/2	A repeated choice remains observable
6	Trace attempt incomplete	Failure/attempt captured
7	Trace repeated; accepted	Successful attempt distinct from failure
8	Slice displayed; session ended	Session summary records final state

Appendix C: Acceptance and final-code verification checklist

Before release or submission, verify the following against the real Unity repository: selection of all five solids; no Sphere option in the final research workflow; correct Triangular Prism terminology; correction at the 2D net level; blocked 3D generation after invalid C1 state; fraction and direction event histories; AR plane acquisition before slicing; trace failure/acceptance separation; clean reset and retry; automatic unique SessionID; acceptance of a nonempty login name; visibility of typed text within the actual input field; CSV copies exported without deleting the internal master; and no red compilation errors on the final Android target.

When replacing or editing scripts, use the actual currently working source and preserve its public method contracts, Inspector references, event schema and export behavior. No exact Unity API calls, numeric touch tolerances or mesh-generation formulas are fabricated in this checklist. Their verification requires inspecting the final compiled implementation.

Appendix D: Academic integrity and AI-use disclosure

This editable thesis was prepared using automated drafting and document-formatting assistance based on the research materials supplied for Project R26-IM-005. This assistance supported structure, narrative synthesis, tables, charts, diagram layout and Word formatting. The researcher must verify every statement against original sources, check the completeness and accuracy of references, confirm the precise final implementation in the Unity project and independently review the paper before signing

the candidate declaration. AI-assisted material must be disclosed in the manner required by the SLIIT research module and its current policy.

Appendix E: Proposed controlled Net Correction evaluation instrument

To close the primary evaluation gap, a future C2-specific test should distinguish whether a learner can independently locate a geometric fault, whether the application highlights the correct location, whether a requested dotted guide is intelligible, and whether a revised net subsequently passes the original C1 validity check. Each condition should be evaluated with a predefined expected fault description and independent review. This is a proposed instrument only: no new participant observations or correction-success counts are attributed to the completed pilot.

Table E.1 Planned fault-correction observation sheet (not completed data)

Variable	Planned observation or coding
Geometry case	Solid and predefined valid/invalid net identifier
Expected fault	Reference edge, face or adjacency relation
Displayed feedback	Highlight and optional dotted guide state
Learner action	Revision count, retries and hints requested
Outcome	Corrected net accepted by C1 or unresolved
Experience	Brief age-appropriate explanation of what changed

The next evaluation could compare outcomes across a guided condition and a carefully matched no-hint or alternative-hint condition, while preserving informed consent and the learner’s right to stop. Reporting should distinguish correction detection accuracy, completion after guidance and conceptual explanation quality. A study of this type would directly test the adaptive scaffolding contribution that the final slicing-session dataset could not quantify.