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Sit Smarter: User-Centred Redesign of a Classroom Chair with Integrated Storage and Ergonomic Back Support

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Abstract
Students in Indian secondary schools spend most of the school day seated on single-piece polypropylene chairs with tubular steel legs that provide no storage, limited back support and a hard seat. This study applied a user-centred design process to redesign such a chair for upper-secondary learners. A baseline product analysis, a comparison of six commercial chairs and a student questionnaire (n = 8) identified the main problems: a hard plastic surface (62.5%), nowhere to keep a bag (62.5%) and back pain (50%). A follow-up poll (n = 48) showed that 89.6% of respondents did not want armrests. Seven concepts were modelled in CAD and scored against ten criteria; the highest-scoring concept (82/100) combined a box-frame body with an enclosed book-and-stationery locker, a side bag bay, a bottle slot and a recessed footrest. The concept was refined with a 98° seat-to-backrest angle, dimensions derived from student anthropometric percentiles, an aluminium sub-frame and over-moulded rubber glides, and high-density polyethylene (HDPE) was selected for the shell through a weighted decision matrix (4.95/5). The estimated full-scale mass is 9.9 kg, within the 10 kg carry target. A 1:3 laser-cut acrylic prototype confirmed the geometry, assembly sequence and storage function, but showed that flat-sheet construction limits seat curvature. The results indicate that integrating storage into the chair body is feasible within institutional weight and cost limits, subject to full-scale load and comfort testing.

Keywords—*school furniture; ergonomics; anthropometry; user-centred design; integrated storage; HDPE; prototyping*

I. INTRODUCTION

A. Background of the Topic

School-age students spend several hours a day seated in class, and the chair is one of the main factors shaping their sitting posture [4]. In many Indian schools the standard chair is a one-piece injection-moulded polypropylene (PP) shell riveted to a powder-coated mild-steel tubular frame with four splayed legs and plastic foot caps (Fig. 1). The design is cheap, light and stackable, but it was developed for low-cost bulk procurement rather than for long periods of sitting. It has no padding or lumbar contour, no provision for a school bag and no storage, so bags are left on the floor, where they clutter aisles and create trip hazards, and books must be carried between lessons.

A cost breakdown of this chair gives an estimated manufacturing cost of about ₹765 per unit, of which roughly ₹195 is the 2.6 kg steel frame (3 m of Ø25 mm × 1.5 mm tube), and 3.35–4.75 kWh of process energy per chair. Because the PP shell is riveted to the steel frame, the two materials are difficult to separate at end of life, which reduces recyclability.



Fig. 1. The existing classroom chair: photograph of the product in use (left) and CAD model of the existing design (right).

B. Existing Research

Studies in several countries report a persistent mismatch between classroom furniture and students' body dimensions. In Abha, Saudi Arabia, seat-height mismatch reached 75.6–84.3% and seat-depth mismatch 74.0–84.5% among 879 adolescents, and a buttock–popliteal length/seat-depth mismatch was an independent risk factor for back pain related to sitting at school [1]. A study of 432 Portuguese primary pupils found a significant mismatch between the furniture supplied and the children's anthropometry [2], and work in West Bengal, India, with 703 girls aged 10–15 found high mismatch in seat height and seat width across Classes V–X, recommending class-specific design criteria [3]. A review of ten studies published between 2004 and 2017 concluded that ill-fitting furniture contributes to poor posture and musculoskeletal complaints in pupils [4].

Bag carriage is a related problem. A critical review of 21 studies found that about 10% of body weight is the most commonly cited maximum school-bag load, yet students carried more than 15% on average, with measurable postural change and associated back pain [5]. Ergonomic chair redesigns based on anthropometric percentiles have been demonstrated for university students, producing a seat height of 44 cm and a backrest adjustable between 95° and 105° [6].

C. Research Gap

Most prior work evaluates either furniture fit (seat height, depth, desk height) or bag load in isolation. Few studies address the everyday organisation problem—where the bag, books and stationery go during the school day—together with posture, and fewer still do so for the low-cost moulded chairs common in Indian classrooms, within the weight and cost limits of institutional purchase.

D. Research Question and Objectives

This study asks: can a standard school chair be redesigned to integrate bag, book and stationery storage and improve back support, while staying under 10 kg, supporting a 120 kg load and remaining cost-effective for bulk purchase? The objectives were to (i) identify user problems through product analysis and a survey; (ii) translate them into a measurable specification; (iii) generate and evaluate design concepts; (iv) select a shell material; and (v) build and test a scale prototype.

II. METHODOLOGY

A. Baseline Product and Market Analysis

The existing chair was documented by photograph, hand sketch and a CAD model, and analysed for function, ergonomics, aesthetics, materials, cost, process energy and end-of-life impact. Six commercial alternatives priced between ₹390 and ₹11,126 per chair (SOMRAJ study chair, Nilkamal NS07SS, Flash Furniture stackable chair, Swagath classroom chair, CELLBELL C62 folding chair and Virco 9018) were compared on features, advantages and disadvantages, and improvement opportunities were listed under seven headings: ergonomics, handling, sustainability, stackability, aesthetics, safety and functionality.

B. Participants and Data Collection

Primary data were collected through an online questionnaire completed by eight students at the author's school. It asked which problems they had experienced with the chair, which single feature they most wanted, how long they sat without standing, whether the chair needed to be folded or moved outdoors, whether they preferred keeping their bag beside them or in a locker, and how important sustainability was. A second poll on armrests ($n = 48$), supported by informal interviews, was run during design refinement. Secondary data came from the Indian school-furniture standard IS 4837 [7], the educational-seating standards EN 1729 and ANSI/BIFMA X6.1 [8], [9], anthropometric tables for the target age group, and published research [1]–[6].

C. Design Specification

Survey findings, anthropometric percentiles and standards were combined into the specification in Table I. The 10 kg mass limit was derived from a safe-lift estimate of about 22% of body mass for a 55 kg upper-secondary student (12.1 kg), reduced to give a margin. A 120 kg design load was adopted as a conservative target that also covers adult visitors; formal test procedures are defined in [8], [9].

D. Concept Generation and Evaluation

Seven concepts were developed from rough sketches into Fusion 360 models with isometric, orthographic and exploded views, each with a parts list giving material, reason for choice and manufacturing method. Each concept was scored from 0 to 10 on ten criteria—ergonomics, stability/safety, storage, material suitability, manufacturability, durability, maintainability, aesthetics, sustainability and cost-effectiveness—against a four-level rubric, giving a total out of 100. Supporting comparisons were made of base type (four-legged,

three-legged, cantilever, swivel and solid) and of eight floor-glide options scored on floor protection, slip resistance, durability, replaceability, cost and ease of installation.

E. Material Selection

Eleven candidate materials were scored from 1 to 5 on ten criteria in a weighted decision matrix. Weights were long-term durability 20%; strength and impact resistance 15% each; cost, corrosion resistance and ease of cleaning 10% each; and weight, workability, aesthetics and sustainability 5% each.

F. Prototype Fabrication and Testing

A 1:3 scale prototype was built from 17 parts drawn in Fusion 360, exported as DXF files and laser-cut from 4 mm acrylic sheet. Parts were solvent-bonded in a set assembly order, and the one-piece seat-and-backrest was heated along a marked line with a heat gun and bent to 98°. Safety measures included heat-resistant gloves, goggles, fume extraction and a mask during bonding. The prototype was tested for geometry against scaled drawings, fit over three assembly cycles, edge safety, qualitative strength under small proportional loads, user feedback (n = 8 students and teachers) and resource use. A full-scale test plan was also defined: a 100 kg static seat load for 1 h, a 30–40 kg horizontal backrest load, 10,000 sitting cycles, a 5 kg drop from 0.5 m, tip tests and a seated comfort rating of at least 4/5 from 10–15 users.

III. RESULTS

A. User Needs

The most common problems were a hard plastic surface (5 of 8; 62.5%), no place to keep a bag (62.5%) and back pain (4 of 8; 50%), followed by a seat that was too high or low for the desk (25%) and instability (12.5%) (Fig. 2). When asked to choose the single most important new feature, respondents chose better back support (37.5%), a bag holder (25%), a softer seat (25%) and a book-and-stationery holder (12.5%). All respondents preferred keeping their bag beside them over storing it in a locker or cubby. No respondent found the chair too heavy, and half saw no need to fold or move it outdoors because outdoor seating had already been installed for project-based learning. Foldability, an initial assumption, was therefore dropped as a requirement.

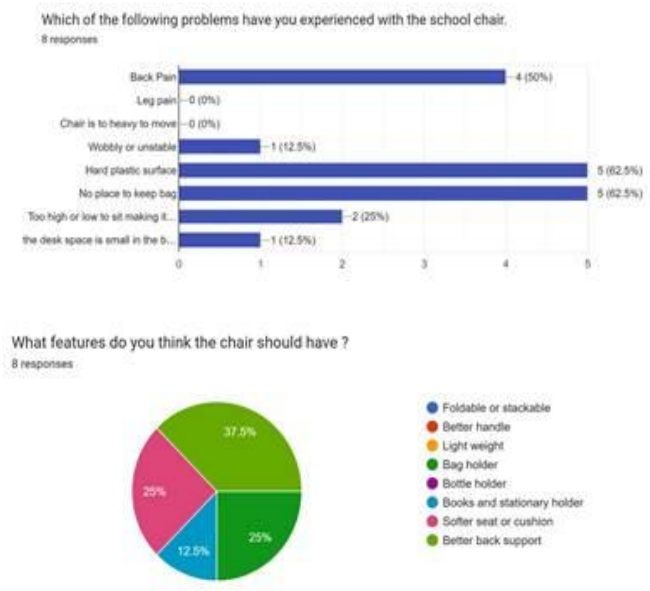


Fig. 2. Primary survey results (n = 8): problems experienced with the existing chair (left) and most-wanted single feature (right).

TABLE I
PRODUCT SPECIFICATION FOR THE REDESIGNED CHAIR

Aspect	Specification	Basis
Users	Upper-secondary students (14–17 yrs); usable by teachers	Survey; user segmentation
Functions	Bag holder; book and stationery storage; improved back support; comfort for 6–8 h use	Survey ranking

Seat height / depth	430 mm / 400 mm	Popliteal height and buttock–popliteal length (Table III)
Seat width / back height	400–450 mm / 300 mm above seat	Hip breadth and sitting shoulder height
Overall height / base width	730–780 mm / 450–500 mm	Stability and desk compatibility
Mass	≤ 10 kg (range 5–15 kg)	Safe-lift estimate, 14–17 yrs
Load capacity	≥ 120 kg	Students and adult visitors [8], [9]
Safety	Edges rounded ≥ 3 mm; tip-resistant; non-toxic finish; no exposed sharp fasteners	IS 4837 [7]; school use
Floor contact	Over-moulded rubber glides	Glide analysis (score 8.1/10, highest of 8)

B. Concept Selection

Scores for the seven concepts ranged from 79 to 82 (Table II). Concept 6 scored highest (82/100). Its box-frame body contains an enclosed storage compartment (700 × 350 × 300 mm) for books and bags, a dedicated bottle slot and a recessed heel rest, and it scored 9/10 for ergonomics, storage, durability and aesthetics (Fig. 3). Its weaknesses were an upright backrest angle, no small-item compartment, MDF panels of uncertain durability, costly stainless-steel handle rods and no floor glides.

TABLE II
CONCEPT EVALUATION SCORES (TEN CRITERIA, 0–10 EACH)

Concept	Main features	Ergon.	Storage	Cost	Total /100
1	Welded mild-steel frame, steel mesh, cushions, bag hook	8	6	7	79
2	HDPE body, wooden armrests, acrylic stationery holder, leather bag holder	9	9	6	79
3	HDPE seat on hollow aluminium frame, book and stationery storage	9	9	6	79
4	Perforated HDPE shell, removable threaded aluminium legs	8	6	7	80
5	Single bent steel sheet, under-seat storage, sliding bottle holder	7	7	8	80
6	Box-frame body, enclosed storage, bottle slot, heel rest, curved backrest	9	9	7	82
7	Aluminium shell, gel-foam cushion, compact storage	9	7	7	79

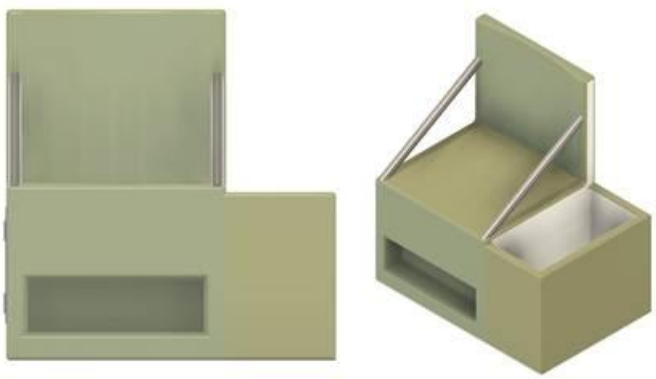


Fig. 3. Selected Concept 6 before refinement: front view (left) and isometric view showing the storage compartment (right).

C. Design Refinement

Twelve weaknesses identified in the evaluation were addressed. The seat-to-backrest angle was increased by 8° to 98°, giving a slight recline that supports the lower back while keeping students alert and upright for writing; this also suits teachers who sit for long periods. A small compartment for pens and stationery was added. The stainless-steel handle rods were removed to cut cost and assembly time, and the body was split into two pieces (main body and screw-on door). Rubber floor glides were added, and all dimensions were aligned with anthropometric percentiles for the target age group (Table III).

Armrests were reconsidered after the author noticed that they interfered with elbow placement while writing. In a poll, 43 of 48 respondents (89.6%) did not want armrests (Fig. 4). Interviewees said armrests made the classroom feel cramped, restricted changes of position, interfered with elbow placement when writing and did not suit all body sizes. Armrests were therefore removed.

TABLE III
ANTHROPOMETRIC DATA USED FOR CHAIR DIMENSIONS (MM)

Measurement	5th pct.	50th pct.	95th pct.	Used for
Stature	~1450	~1630	~1800	Overall scaling
Popliteal height	~340	~410	~460	Seat height
Buttock–popliteal length	~370	~430	~480	Seat depth
Hip breadth (seated)	~280	~330	~370	Seat width
Sitting shoulder height	~440	~510	~560	Backrest height
Thigh thickness	~100	~130	~160	Under-desk clearance

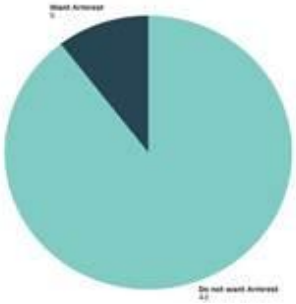


Fig. 4. Armrest poll (n = 48): 43 respondents did not want armrests and 5 did.

D. Material Selection

HDPE achieved the highest weighted score (4.95/5), followed by PP (4.60) and stainless steel (4.45) (Table IV). HDPE scored highly on impact resistance, corrosion resistance, ease of cleaning, workability and cost, and it is recyclable. The panel material was therefore changed from MDF to HDPE, with aluminium used for the internal frame.

TABLE IV
WEIGHTED MATERIAL-SELECTION SCORES (TOP SIX OF ELEVEN)

Material	Strength	Impact	Cost	Corrosion	Long-term durability	Weighted total /5
HDPE	5	5	5	5	5	4.95
Polypropylene (PP)	4	5	5	5	4	4.60
Stainless steel	5	5	2	5	5	4.45
Fibre-reinforced plastic	4	5	4	5	4	4.40
Polycarbonate	4	5	3	5	4	4.35
Aluminium	4	4	4	4	4	4.15

E. Final Design

The final design (Fig. 5 and Fig. 6) has 13 parts. A welded aluminium main frame with cross-bar reinforcement carries the loads, and a separate backrest frame is screwed to it through a 98° angle bracket with dual gusset reinforcement. HDPE claddings enclose the frame. The left cladding holds the book-and-stationery locker behind a hinged door and a bottle slot; the right side forms an open bay for a school bag; and the front cladding has a recessed footrest. Over-moulded rubber glides protect floors and reduce noise. The HDPE is made from pre-coloured pellets, so no paint is needed.

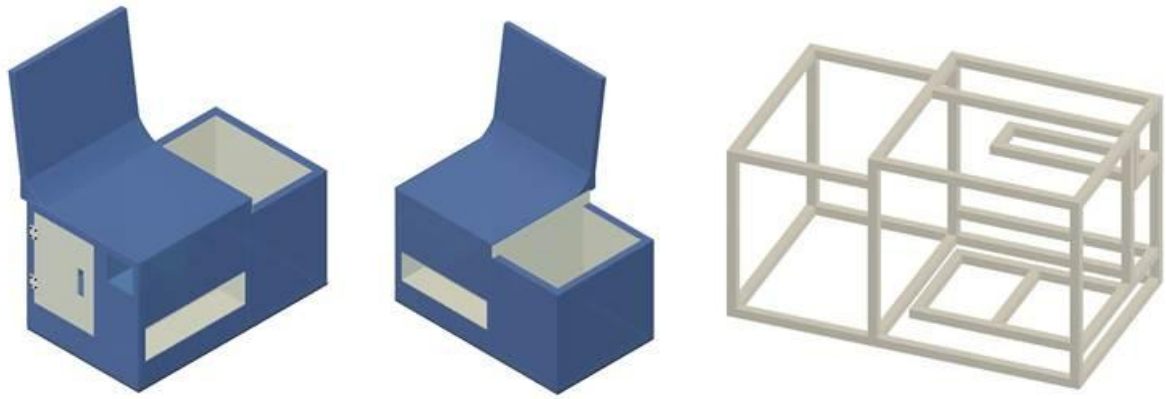


Fig. 5. Final refined design: isometric views showing the bag bay, locker door and footrest (left, centre), and the aluminium frame inside the claddings (right).

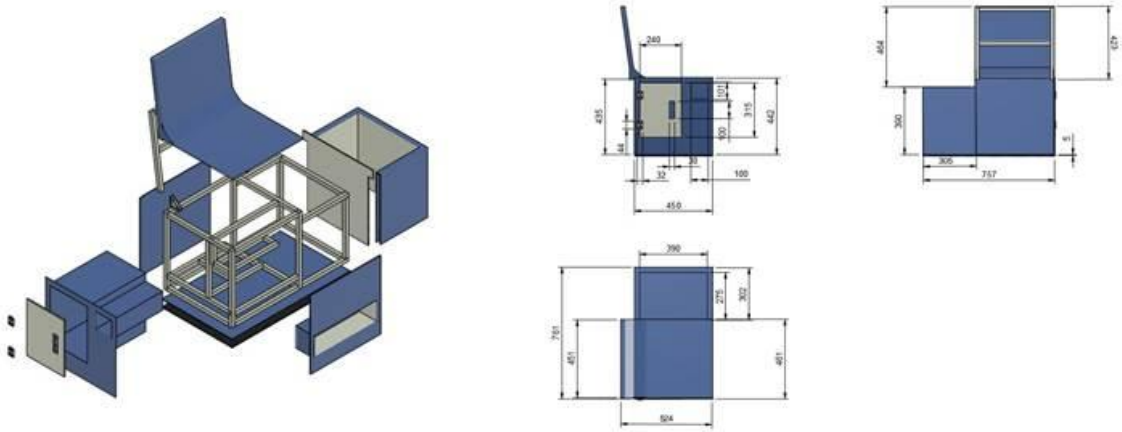


Fig. 6. Exploded view of the final design (left) and overall dimensions in mm (right).

The estimated mass, calculated from Fusion 360 volumes, is 9.91 kg (Table V), within the 10 kg target. Labour and electricity per chair are estimated at about ₹2,386 for one-off production (8.3 person-hours; 10.34 kWh) and about ₹474 in batches of 100 or more (1.83 person-hours; 2.54 kWh). Both figures exclude materials, packaging, overheads and tooling.

TABLE V
ESTIMATED MASS OF THE FULL-SCALE CHAIR

Component	Mass (kg)
Aluminium frame members	3.78
HDPE shell (seat + back)	1.14
HDPE panels (5 mm)	3.56
Fasteners, gussets, hinges (steel)	0.80
Over-moulded rubber glides	0.08
Miscellaneous (feet, adhesives)	0.05
Manufacturing allowance	0.50
Total	9.91

F. Prototype and Testing

The 1:3 prototype was cut from a single acrylic sheet and built in about 8 hours for approximately ₹1,000, within budget (Fig. 7). The planned assembly order was changed once: the back cladding was fixed before the right outer cladding, because the right cladding would not hold its position while the adhesive cured. The model matched the scaled drawings closely, and parts fitted after three assembly cycles, although small gaps appeared at some adhesive joints. Most laser-cut edges were smooth; a few needed light sanding. Under small proportional

loads the model flexed slightly but did not crack. A bag, books and a bottle fitted in their intended compartments (Fig. 8). Users liked the light, modern appearance and easy-clean surfaces, but said the surface looked hard, the edges needed rounding and the backrest needed more curvature. Table VI summarises the evaluation against the specification.



Fig. 7. Prototype fabrication and result: heat-bending the acrylic seat-and-backrest to 98° (left) and the finished 1:3 prototype from the front and above (centre, right).



Fig. 8. Functional testing of the prototype: stationery locker with door open (left), school bag in the side bay (centre) and bottle in the bottle slot (right).

TABLE VI
EVALUATION OF THE SCALE PROTOTYPE AGAINST THE SPECIFICATION

Requirement	Achieved	Evidence
Storage (bag, books, stationery, bottle)	Yes	All items fitted in their compartments (Fig. 8)
Ease of cleaning	Yes	Smooth, non-porous surfaces
Lightweight	Yes	Estimated 8.5–9.9 kg at full scale
Dimensional stability	Yes	Shape held after repeated assembly
Comfort / ergonomics	Partly	Proportions acceptable; seat and back need more curvature
Durability	Partly	Acrylic scratched; HDPE expected to perform better
Impact resistance	Not proven	Acrylic is brittle; requires full-scale HDPE test
Scratch resistance	No	Surface scratched during handling
No exposed fasteners	No	Door screws are exposed in the full-scale design

IV. DISCUSSION AND CONCLUSION

A. Interpretation

The survey showed that students' main complaints concerned comfort and organisation, not mobility. The redesign therefore treats the chair as a personal workstation: the bag is kept off the floor and within reach, and books for the next few lessons can be stored without taking up desk space. The enclosed claddings also brace the frame, which helps the chair carry the 120 kg design load at under 10 kg. The main trade-off is comfort. Cushioning was rejected because it wears and is hard to keep clean in shared classrooms, so comfort depends on geometry—the 98° recline, anthropometric dimensions and the footrest. User feedback suggests that geometry alone is not yet enough, and the flat acrylic sheets could not show the seat curvature that injection-moulded HDPE would allow. The final design also departs from the four-legged base in the specification: the box base gives storage space and stability but uses more material than a leg frame.

B. Comparison with Previous Studies

The 98° seat-to-backrest angle lies within the 95–100° range recommended by IS 4837 for classroom chairs [7] and within the 95–105° adjustable range used by Ansari et al. [6]. MRI research has shown that lumbar disc movement is least at a reclined 135° trunk–thigh angle and greatest at an upright 90° posture [10]. A 98° angle is a compromise between this finding and the upright posture needed for writing at a desk. The 430 mm seat height is higher than the 380 mm that IS 4837 gives for its largest size (statures 1445–1620 mm) [7]; the target group's median stature (~1630 mm) lies just above that range. Seat height should not exceed popliteal height plus shoe allowance, so 430 mm suits median users but is too high for the 5th percentile (~340 mm popliteal height). Given the high mismatch rates reported in [1]–[3], the recessed footrest only partly offsets this, and two height variants or measured local data would be safer. The bag bay keeps the bag off the floor but does not reduce the load students carry [5]; the locker could reduce it only if schools let students keep books at their seats between days.

C. Practical Implications

For schools, the design combines a seat, a bag hook and a small locker in one unit, which may reduce clutter and trip hazards in classrooms. For manufacturers, the HDPE-and-aluminium construction suits batch production, with a target unit cost below ₹1,500. Recycled HDPE has lower stiffness and strength than virgin HDPE, but blending in virgin material restores much of the loss [11], so blended HDPE could be used for the non-structural claddings. Using screws rather than rivets or adhesives between the aluminium frame and HDPE panels would allow the two materials to be separated and recycled, in line with design-for-disassembly practice in furniture [12].

D. Limitations and Future Research

The primary survey had only eight participants from one school, so its percentages are indicative rather than representative. The prototype was built at 1:3 scale in acrylic, which differs in stiffness and brittleness from HDPE; load capacity, tip resistance and comfort were therefore not measured. The mass estimate is based on CAD volumes, the cost figures exclude materials and tooling, and the exposed door screws do not yet meet the safety specification. Future work should (i) build a full-scale HDPE prototype and test it to EN 1729 and ANSI/BIFMA X6.1 [8], [9]; (ii) measure the anthropometry of the target students and offer two seat heights; (iii) mould curvature into the seat and backrest; (iv) conceal the door fasteners; and (v) run a multi-week classroom comfort trial with a larger, multi-school sample.

E. Conclusion

A user-centred process turned the problems students reported—a hard seat, nowhere to keep a bag and back pain—into a redesigned classroom chair with an enclosed locker, a bag bay, a bottle slot, a footrest and a 98° backrest, built from HDPE on an aluminium frame at an estimated 9.9 kg. The scale prototype confirmed that the layout and storage work. Full-scale testing of strength and comfort is the next step before the design can be recommended for classroom use.

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