



香港教育大學

The Education University
of Hong Kong

Final Year Project:

EduBalancer: A Culturally-Themed Self-Balancing Robot Kit for STEM
Education

Integrating Robotics, AI 3D Modeling, and Cultural Design for Enhanced
Learning Motivation

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Abstract

This study investigates the effectiveness of EduBalancer, a culturally-themed self-balancing robot kit designed for STEM education in Hong Kong secondary schools. The kit integrates robotics hardware assembly, AI-assisted 3D modeling, and Daruma cultural design elements to enhance student engagement with complex engineering concepts. Using a mixed-methods approach, data were collected from 28 secondary students through pre- and post-intervention questionnaires, supplemented by professional evaluation from 77 in-service and preservice teachers. Results indicate statistically significant improvements in students' attitudes toward STEM learning, with an overall increase of 18.4% (from $M_{pre} = 3.64$ to $M_{post} = 4.31$, $t(27) = 11.90$, $p < .001$, Cohen's $d = 2.80$). The greatest improvement occurred in the knowledge domain (+37.1%), particularly in sensor understanding (+51.3%). Professional evaluation achieved 88.2% satisfaction with 100% recommendation rate. Findings suggest that culturally-embedded, hands-on robotics education can effectively enhance secondary students' STEM learning motivation and provide a viable model for addressing the STEM education gap in Hong Kong.

Keywords: STEM education, educational robotics, self-balancing robot, cultural integration, hands-on learning, secondary education



1. Introduction

1.1 The Importance of STEM Education

In an era defined by Industry 4.0, STEM education has never been more important. The United States Bureau of Labor Statistics projects that STEM occupations will grow by 10.4 percent over the coming decade, compared to only 3.6 percent for non-STEM fields (U.S. Bureau of Labor Statistics, 2024). The Hong Kong Young Leaders Programme Report (2024) has identified STEM competency as a critical determinant of the territory's future economic competitiveness. Beyond economic considerations, STEM literacy enables citizens to engage critically with technology and develop transferable competencies including logical reasoning, problem-solving, and collaborative work. The Hong Kong Education Bureau has positioned STEM education as a priority area for development and investment.

1.2 Persistent Gaps in Hong Kong STEM Education

Despite this recognition, Hong Kong faces troubling declines in international assessments. According to TIMSS 2023, Hong Kong's science performance ranking has fallen, with Primary 4 students ranking ninth globally and Secondary 2 students ranking eighth (Education Bureau, 2024). Mathematical performance has also declined, with Primary 4 students dropping from second to fourth place historically. Through extensive teaching experience and literature review, four persistent gaps have been identified. The first is a curriculum gap, with robotics activities largely confined to extracurricular settings. The second is a conceptual gap, whereby complex concepts such as PID control remain abstract and intimidating when presented through traditional lecture methods. The third is an engagement gap, as conventional instruction fails to maintain sustained student interest. The fourth is a cultural gap, manifesting as a disconnect between STEM content and students' cultural identity.

Within this landscape, one specific dimension has received insufficient attention: what Yeung and Ng (2021) term hardware literacy. While Hong Kong students demonstrate confidence in using software tools, many lack practical understanding of sensors, mechanics, and real-world control logic. This gap represents a disconnect between digital fluency and physical engineering comprehension.



1.3 The Potential of Self-Balancing Robots

Self-balancing robots present a promising but underutilized opportunity for teaching control concepts. The inverted pendulum problem is a canonical example in control theory, and a two-wheeled self-balancing robot is mechanically equivalent, making it ideal for demonstrating feedback principles through observable behaviour. Research has shown that self-balancing robots effectively teach PID control concepts through hands-on experimentation (Nada & Bayoumi, 2024). However, existing platforms face limitations: most require extensive soldering and calibration, assume prior programming knowledge, and offer no cultural customization options.

1.4 Project Background and Rationale

EduBalancer was conceived to address these gaps through an integrated design drawing from prior development of a large-scale bipedal robot. That original platform demonstrated advanced stability but presented barriers for classroom deployment: high cost, mechanical complexity, and safety risks. The present project focuses on pedagogical translation—distilling core engineering principles into an accessible, safe, and scalable learning intervention. Three design priorities guide the work: affordability (target cost below HKD 500), classroom safety (low-voltage operation, enclosed moving parts), and replicability (open-source documentation).

1.5 Research Objectives and Significance

The primary research question asks how the EduBalancer robotics kit affects secondary students' learning motivation toward STEM subjects. Secondary questions examine gains in technical knowledge, the influence of cultural design elements, and teacher perceptions of pedagogical value. This research contributes empirical evidence from a Hong Kong context, demonstrates integration of cultural design into STEM education, and validates a practical curriculum for secondary implementation.



Fig. 1. Bipedal Wheeled Robot previously assembled by the researcher, showing the original platform whose concepts were translated into the EduBalancer kit.

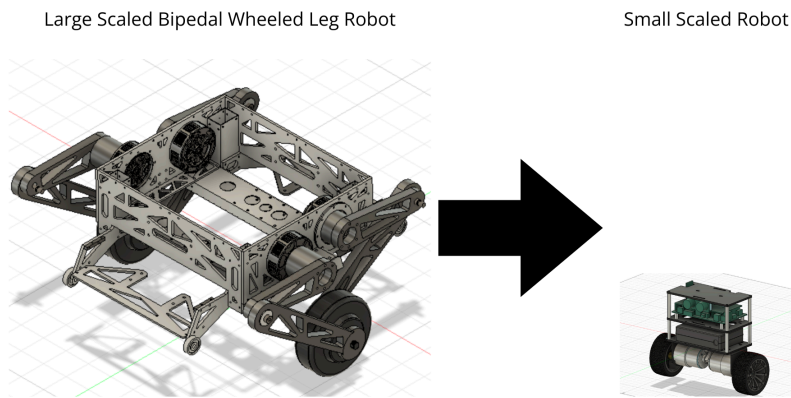


Fig. 2. Scaling down and simplifying the original bipedal robot into the EduBalancer classroom prototype.

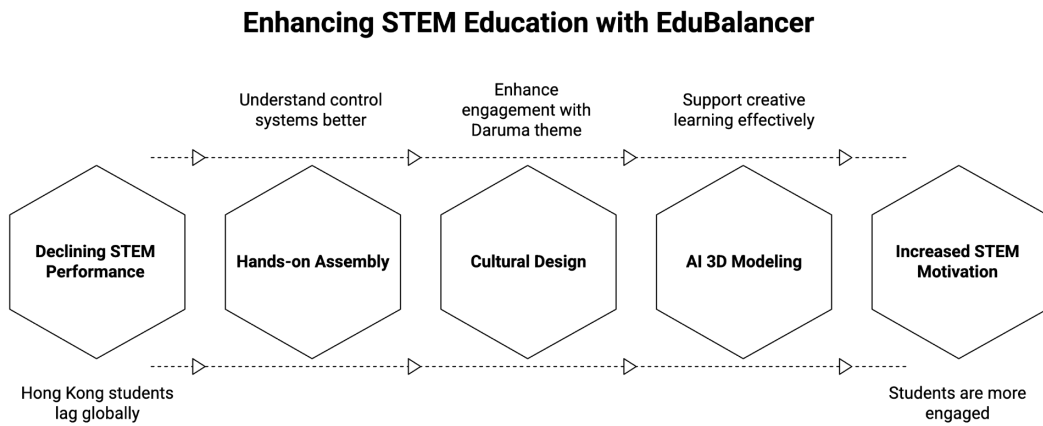


Fig. 3. Procedures of Enhancing STEM Education with EduBalancer.

2. Literature Review

2.1 Constructivism and Hands-On Learning

The pedagogical design of EduBalancer is grounded in constructivist learning theory, which holds that learners actively construct knowledge through interaction with their environment (Piaget, 1973). Physical manipulation creates what Papert (1980) termed objects to think with—concrete artifacts whose behaviour invites exploration and conceptual refinement. Experiential learning theory (Kolb, 1984) proposes a four-stage cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation, which EduBalancer explicitly supports across its three sessions.

Empirical support for active learning is substantial. Freeman and colleagues (2014) found that active learning increases examination performance by half a letter grade and reduces failure rates by 55 percent. Chen and Liu (2025) confirmed that hands-on activities improve student engagement and knowledge retention. Santhosh and colleagues (2023) demonstrated through meta-analysis that project-based STEM learning shows significant positive effects (Hedges' $g = 0.71$).

2.2 Educational Robotics as a Pedagogical Medium

Robotics integrates multiple disciplinary domains—mechanical engineering, electrical engineering, computer science, and mathematics—making it ideal for demonstrating the interconnected nature of STEM. Aris and Orcos (2019) found significant improvements in STEM motivation and skills development through educational robotics. Torres and colleagues (2025) demonstrated that collaborative robotics curriculum enhances both technical outcomes and teamwork competencies. Torres and Inga (2025) confirmed that robotics activities boost cognitive development in logical reasoning and problem-solving.

2.3 Self-Balancing Robots for Control Theory Education

Self-balancing robots offer unique affordances for teaching control systems. When a student changes a PID parameter, the robot's behaviour changes in directly observable ways, making abstract relationships perceptually available. Nada and Bayoumi (2024) found that students learning through self-balancing robots scored 34 percent higher on conceptual understanding than those learning through traditional methods. Despite these advantages, existing platforms require soldering, assume prior knowledge, and lack cultural customization.

2.4 Cultural Integration in STEM Motivation

Culturally responsive pedagogy argues that academic content is more engaging when connected to students' cultural references (Gay, 2010; Ladson-Billings, 1995). The Daruma doll, widely adopted in Hong Kong popular culture, has a self-righting property directly analogous to the self-balancing robot's stability function, creating a natural conceptual bridge. Henderson and colleagues (2020) found that culturally relevant robotics increased engagement among Native American students by 41 percent. Lin and colleagues (2018) demonstrated similar effects with Taiwanese middle school students.

3. The EduBalancer Intervention: Curriculum Package Design and Characteristics

3.1 Design-Based Research Approach and Overall Framework

The design of the EduBalancer curriculum package followed a systematic, iterative process grounded in design-based research methodology, which is particularly suited to educational technology development because it emphasizes iterative refinement in authentic classroom contexts while balancing theoretical fidelity with practical feasibility (Barab & Squire, 2004; Design-Based Research Collective, 2003). This methodology contrasts with more traditional experimental designs that separate design from evaluation, instead treating the design process itself as a subject of investigation and refinement. In design-based research, the intervention is not fixed in advance but evolves through cycles of implementation, analysis, and revision, with each cycle producing both improved materials and deeper understanding of the conditions under which the intervention is effective. The following subsections describe the five phases of this design process, the pedagogical principles that guided each phase, and the resulting curriculum structure.

3.1.1 Phase One: Pedagogical Requirements Analysis

The design process began with a systematic analysis of classroom constraints and pedagogical requirements, conducted through semi-structured interviews with five secondary information and communication technology teachers and observation of three existing robotics lessons in Hong Kong schools. This needs analysis revealed several critical design parameters that would shape all subsequent decisions. The lesson duration needed to match the typical double-period block found in Hong Kong secondary schools, which is approximately 90 minutes per session, leading to a three-session structure totaling four and a half contact hours. This duration allows meaningful project completion within two to three weeks of instructional time while fitting within existing scheduling structures without requiring special timetable adjustments. The cost per kit needed to fall below five hundred Hong Kong dollars to enable procurement of a full class set of 30 kits within typical school budgets of approximately fifteen thousand Hong Kong dollars, making the intervention economically feasible for widespread adoption. No prior knowledge could be assumed, as many Hong Kong secondary students have no exposure to robotics or programming before secondary school, meaning the curriculum must be accessible to absolute beginners. Teacher preparation time needed to be less than two hours, recognizing the severe time constraints that Hong Kong teachers face given their heavy administrative and teaching loads, as interventions that require extensive teacher preparation are unlikely to be sustained. Finally, the safety rating required low voltage operation below 15 volts and no exposed moving parts to comply with Hong Kong school laboratory safety guidelines. These requirements directly informed the decision to translate large-scale balancing robot concepts into a hand-sized kit using Arduino-compatible components, which balance affordability, accessibility, and technical depth in ways that more sophisticated platforms cannot.



3.1.2 Phase Two: Learning Objective Decomposition and Sequencing

Based on backward design principles articulated by Wiggins and McTighe (2005), the curriculum development process began by identifying desired learning outcomes, then designing assessments to measure those outcomes, and finally planning learning experiences to achieve them. This backward approach ensures that instructional activities are aligned with intended outcomes rather than being chosen for convenience or tradition. The target outcomes were organized according to Bloom's revised taxonomy of educational objectives (Anderson & Krathwohl, 2001), which classifies cognitive processes along a continuum from lower-order to higher-order thinking. At the remember level, students were expected to identify main components including the microcontroller, inertial measurement unit sensor, motor driver, motors, and battery. At the understand level, students needed to explain the sensor-to-control-to-motor feedback loop that forms the core of the balancing algorithm. At the apply level, students were required to assemble hardware following guided instructions and achieve a functioning robot. At the analyze level, students needed to diagnose common failure modes including polarity errors, improper inertial measurement unit orientation, and power issues. At the evaluate level, students compared the effects of different proportional-integral-derivative parameters on stability to determine optimal settings. At the create level, the highest level of cognitive demand, students designed custom Daruma shells using artificial intelligence-assisted three-dimensional modeling tools and exported files for printing.

The three-session structure emerged naturally from this decomposition of learning objectives. Session one addresses the remember and apply levels through hardware assembly activities, where students learn component names and functions then apply that knowledge to construct a functioning robot. Session two addresses the create level through design activities, where students generate novel Daruma shell designs using AI tools. Session three addresses the understand, analyze, and evaluate levels through programming and tuning activities, where students learn the principles of feedback control, analyze system behaviour, and evaluate parameter effects. This sequencing follows cognitive load theory (Sweller, 1988), which suggests that complex tasks should be broken into manageable chunks with increasing cognitive demand across sessions. Early sessions build foundational knowledge and skills that later sessions build upon, preventing the cognitive overload that can occur when students are asked to simultaneously master multiple new concepts and skills without adequate preparation.



3.1.3 Phase Three: Activity Design and Scaffolding Development

Each session was designed around a gradual release of responsibility model (Pearson & Gallagher, 1983), moving from teacher demonstration through guided practice to independent application. This progression is often summarized as I do, we do, you do, reflecting the decreasing level of teacher support as student competence increases. Several types of scaffolding were embedded in the curriculum to support student learning throughout this progression. Procedural scaffolding took the form of step-by-step assembly instructions with visual diagrams and colour-coded wiring guides that reduced the cognitive load of following complex procedures. This scaffolding is gradually reduced across the three sessions, with session one providing the most detailed guidance and session three providing only general parameters for student experimentation. Strategic scaffolding included guided troubleshooting routines with decision trees that helped students systematically identify and resolve problems when the robot did not function as expected, teaching problem-solving strategies that transfer beyond the specific context. Metacognitive scaffolding consisted of reflection prompts such as what changed and why during proportional-integral-derivative tuning activities, encouraging students to think about their own thinking and learning processes. Collaborative scaffolding involved assigned roles including builder, wire-checker, and recorder with rotating responsibilities across sessions, ensuring that all students participated actively rather than passively observing.

The Daruma cultural theme was integrated not as decorative overlay but as conceptual scaffolding that supported understanding of the robot's core function. The self-righting property of Daruma dolls was presented as an analogy for the robot's balancing function during the introduction to the activity. Students were explicitly prompted to consider this analogy during session three's proportional-integral-derivative demonstration, when the instructor showed how the robot, like the Daruma doll, continuously works to return to an upright position when disturbed. This analogy created a memorable anchor for understanding feedback control that connected technical content to culturally familiar reference points, potentially reducing the cognitive load of learning abstract control concepts by providing a concrete, culturally resonant mental model.

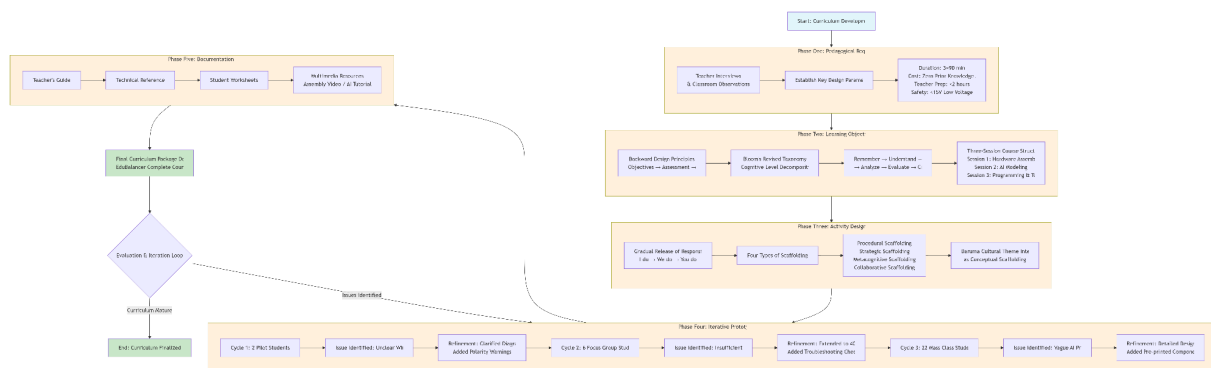


Fig. 4. Workflow of the Design Process

3.1.4 Phase Four: Iterative Prototyping and Classroom Testing

The curriculum package underwent three iterative refinement cycles following the design-based research model of implementing in authentic settings, collecting multiple data sources, analyzing to identify breakdown points, refining the design, and re-implementing. The first cycle involved two pilot students working individually with the researcher, which led to clarification of wiring diagrams and addition of polarity warnings after both students initially connected the battery incorrectly, demonstrating that the original instructions were insufficiently explicit about this critical step. The second cycle involved the six focus group students, which revealed that the time allocated for proportional-integral-derivative tuning was insufficient. Analysis of observation notes and student work showed that most groups needed approximately 40 minutes to complete meaningful tuning trials, leading to an extension of this activity from 30 to 40 minutes and the addition of a structured troubleshooting checklist that helped students work more efficiently. The third cycle involved the 22 mass class students, which led to refinement of the artificial intelligence modeling prompts to be more specific about design constraints such as shell thickness and attachment point locations, and the addition of pre-printed component labels on the kits to speed the assembly process by reducing time spent identifying parts. Each cycle produced documented refinements that were incorporated into the final curriculum package, with the changes tracked in a revision log that provides transparency about the design process.



3.1.5 Phase Five: Documentation and Teacher Support Materials

Recognizing that curriculum effectiveness depends heavily on implementer capacity and confidence, comprehensive teacher support materials were developed alongside the student-facing curriculum. The Teacher's Guide includes session objectives aligned to curriculum standards, preparation checklists to help teachers organize materials before each session, common misconceptions with suggested responses, and differentiation strategies for students who need additional support or challenge. The Technical Reference provides component specifications, wiring diagrams, troubleshooting flowcharts, and code annotations explaining each section of the control algorithm, enabling teachers to answer student questions even without extensive robotics background. The Student Worksheets include component identification exercises, assembly checklists for self-monitoring, proportional-integral-derivative tuning logs for recording observations, and design reflection prompts that guide students through metacognitive processing. Multimedia resources include an assembly video designed for repeated looping during session one to allow student self-pacing, an artificial intelligence modeling tutorial for session two, and a code walkthrough video for session three. All of these materials are openly available to support replication and adaptation by other educators, with the goal of lowering barriers to adoption beyond the specific context of this study.



3.2 Hardware Architecture and Design Principles

The hardware architecture of EduBalancer embodies several design principles derived from the requirements analysis. The first principle is accessibility through standardization, achieved by using the Arduino ecosystem with an ATmega328P microcontroller, which is widely adopted in educational settings globally and supported by extensive online documentation in multiple languages including Chinese. This choice reduces the learning curve for teachers who may have prior Arduino experience and enables students to extend their learning beyond the kit using existing Arduino resources and community support forums. The second principle is reliability through modularity, implemented through pre-crimped jumper wires with colour coding where red indicates power, black indicates ground, and yellow indicates signal. This colour coding makes assembly errors less likely and makes systematic troubleshooting more straightforward, as students can trace connections by colour rather than needing to read circuit diagrams. The third principle is safety through low-voltage design, as the 12 volt lithium-ion battery supply is below typical school laboratory safety thresholds of 15 volts, and all moving parts including gears and motors are enclosed within the chassis or wheels, eliminating pinch points that could cause injury. The fourth principle is extensibility through open-source documentation, as all design files including three-dimensional models, circuit diagrams, and source code are openly available, allowing teachers and students to modify and extend the kit for their own purposes.

The core components of the kit work together to achieve self-balancing behaviour. The Arduino microcontroller serves as the central processing unit, executing the balancing algorithm at high frequency. The MPU6050 inertial measurement unit sensor provides six-axis motion tracking through a three-axis gyroscope and three-axis accelerometer, measuring the robot's tilt angle and angular velocity. The TB6612FNG motor driver converts the microcontroller's control signals into motor currents sufficient to drive the motors. The dual direct current geared motors provide torque for wheel rotation, with gearing that balances speed and torque for stable balancing. The 12 volt lithium-ion rechargeable battery provides portable power with sufficient capacity for multiple class sessions. The three-dimensionally printed chassis is made of polylactic acid material and includes magnetic attachment points for custom shells, enabling rapid shell changes without tools. The 65 millimeter diameter rubber wheels provide ground traction necessary for balancing. Key innovations include the magnetic attachment system that enables customizable appearances, the Daruma-themed design that creates cultural resonance and conceptual scaffolding, and the open-source code with annotations explaining proportional-integral-derivative parameters for educational transparency.



3.3 Course Structure and Session-by-Session Implementation

The intervention was delivered as a three-session learning package, with each session lasting 90 minutes to fit within standard double-period blocks. Session one focuses on hardware assembly and initial testing. The session begins with a safety briefing and kit inventory to establish safe working norms and ensure all components are present. Students then learn to identify core components and understand their functions, building declarative knowledge before procedural knowledge. The main assembly activity follows, with step-by-step guidance and peer checking to distribute scaffolding. The session concludes with power-on testing and guided troubleshooting, creating the first moment of success when the robot's wheels spin.

Session two focuses on AI-assisted three-dimensional modeling and Daruma shell design. Students receive onboarding to AI modeling tools, learning the prompt-to-generate-to-refine workflow. They then design their own Daruma shells within given constraints, engaging in creative expression while learning digital fabrication concepts. The session concludes with slicing preparation for 3D printing and design sharing, where students explain their design choices, reinforcing their learning through articulation and receiving feedback from peers.

Session three focuses on programming and proportional-integral-derivative tuning. The instructor demonstrates PID control concepts by showing what happens when parameters are too high or too low, making abstract principles concrete through observable behaviour. Students then conduct tuning rounds, changing one parameter at a time and recording results, embodying the scientific method of hypothesis testing and observation. The session concludes with a performance challenge and guided reflection, providing authentic assessment and consolidating learning through metacognitive processing.

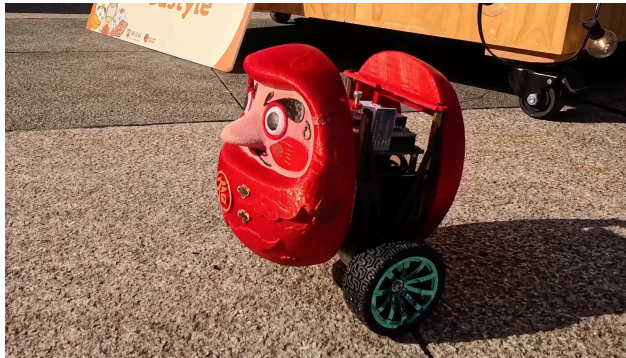


Fig. 5. The first version of Daruma Self-balancing Robot first appeared in VMart in Causeway Bay during Chinese New Year.

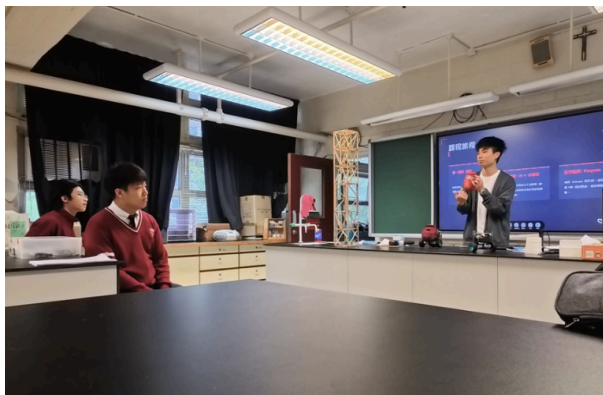


Fig. 6. Conducting the trial lesson for Data collection.



Fig. 7. EduBalancer Robotics Learning Kit

Adding AI Generated 3D Appearance

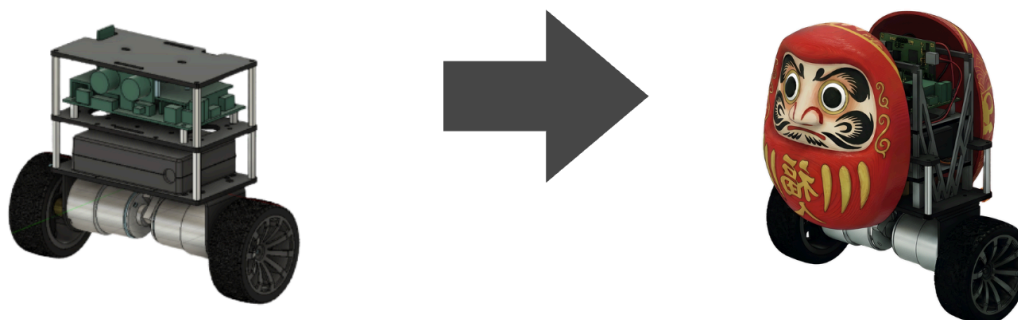


Fig. 8. Daruma Theme implementation.



Fig. 9. Tutorial video of assembly will be played repeatedly during the lesson.

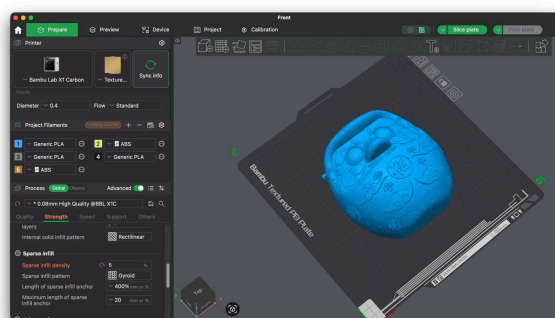


Fig. 10. 3D Printing Process in Session 2.



Fig. 11. Programming in Arduino IDE.

Table 1. Session-by-Session Implementation Run Sheet (EduBalancer, 3 × 90 mins)

Session	Time	In-class Tasks (Teacher + Students)	Checkpoints (Evidence of Progress)	Outputs to Keep (for Appendix D / records)
S1 Hardware Build & First Test	0–10	Safety + kit inventory; assign roles (builder / wire-checker / recorder).	All parts accounted for; roles assigned.	Parts checklist + 1 photo of laid-out components.
	10–25	Identify core modules (MCU, IMU, motor driver, motors, battery); explain “sensor → control → motor” loop in 2 minutes.	Students can correctly point out IMU and motor driver and state their function.	Quick “component-function” worksheet (1 page).
	25–70	Step-by-step assembly + wiring; peer-check polarity and mounting; fix common errors.	Robot mechanically complete; wiring matches diagram; no loose connections.	Assembly photo + completed wiring checklist.
	70–90	Power-on + wheel direction test; guided troubleshooting routine (power / polarity / IMU mounting).	Robot powers on; wheels spin in intended direction.	“1 issue + 1 fix” reflection note (2–3 lines).
S2 AI 3D Modeling + Daruma Shell	0–15	AI 3D tool onboarding: prompt → generate → refine → export (STL/OBJ); set design constraints (fit, clearance, durability).	Each group has a concept sketch + prompt draft.	Prompt log + concept sketch photo.



	15–55	Generate and refine Daruma shell; ensure attachment method works (magnet/snap/slot—whichever your kit uses).	Model passes basic printability check (manifold / thickness / scale).	Final STL/OBJ file + filename standard.
	55–80	Slicing: supports, orientation, time estimate; queue printing; alternative plan if print time is long.	Slicer screenshot + estimated print time saved.	Slicer settings screenshot + print queue record.
	80–90	Wrap-up: 1-minute share per group on “design choice → intended effect on engagement”.	Every group can explain their cultural/theme choice.	1–2 sentence design rationale.
S3 PID Tuning + Performance Challenge	0–25	PID demo: show what happens when P too high/low; explain I and D with one practical example.	Students can describe at least 2 observable behaviors (overshoot/oscillation/slow response).	“parameter → behavior” note sheet.
	25–70	Tuning rounds (min. 2 trials): change 1 parameter at a time; record results using rubric (stability time, wobble, recovery).	At least 2 logged trials per group; robot achieves stable balance or clear improvement.	PID tuning log sheet + short results summary.
	70–90	Mini challenge (longest balance / fastest recovery / least wobble) + guided reflection (what changed and why).	Teams present 1 improvement + 1 next step.	Reflection response + optional video clip evidence.



4. Methodology

4.1 Research Design

This study employed a convergent mixed-methods design, in which quantitative and qualitative data are collected concurrently, analyzed separately, then integrated during interpretation to provide a comprehensive understanding of the intervention's effects (Creswell & Plano Clark, 2017). The quantitative component consisted of pre- and post-intervention questionnaires measuring changes in student attitudes, knowledge, and engagement. The qualitative component consisted of open-ended survey questions capturing student experiences, memorable moments, and perceived attitude changes. The convergent design was chosen because it allows the strengths of quantitative methods—precision, generalizability, and statistical power—to complement the strengths of qualitative methods—depth, contextuality, and discovery of unanticipated themes. Additionally, a separate professional educator evaluation provided supplementary validity evidence from the teacher perspective, helping to establish the practical feasibility and pedagogical value of the intervention from the standpoint of those who might implement it in their own classrooms.

4.2 Participants

For the student study, a total of 28 secondary students participated across two sessions. A focus group of six students completed the intervention on March 9, 2026, followed by a mass class of 22 students on March 16, 2026. All participants were students at a partner secondary school in Hong Kong, recruited through teacher recommendation and voluntary enrolment. No prior robotics experience was required for participation, and consistent with pre-test responses, no participants reported any previous robotics experience, confirming that the sample was appropriate for evaluating the intervention's effectiveness with the target population of novices. The sample included students from Forms 3 through 5, corresponding to approximate ages of 15 to 17 years, representing a range of academic abilities and gender backgrounds. Ethical approval was obtained from the university ethics committee, and informed consent was secured from both participants and their parents or guardians prior to data collection.

For the teacher evaluation study, a total of 77 educational professionals participated. This sample included 48 in-service teachers, representing 62.3 percent of the sample, with teaching experience ranging from one to over fifteen years across primary and secondary levels. The remaining 29 participants were preservice teachers enrolled in the Bachelor of Education program at The Education University of Hong Kong, representing 37.7 percent of the sample. This diverse sample provided perspectives ranging from novice to experienced practitioners, enhancing the generalizability of evaluation findings across different stages of teaching career development. The inclusion of both in-service and preservice teachers also allowed for comparison of perspectives, potentially revealing differences in how current practitioners and future teachers view the kit's classroom feasibility.

4.3 Instrumentation

The student questionnaire consisted of 15 Likert-scale items with response options ranging from one (strongly disagree) to five (strongly agree). These items measured five constructs derived from the theoretical framework: expectations and satisfaction, prior knowledge and understanding, learning style and engagement, collaboration, and future interest in STEM. Construct validity was supported by alignment with established STEM motivation scales from the published literature, including items adapted from Glynn and colleagues' (2011) Science Motivation Questionnaire. Internal consistency was acceptable, with Cronbach's alpha values of 0.82 for the pre-test and 0.87 for the post-test, indicating that items within each construct measured related aspects of the same underlying

dimension. Open-ended questions captured qualitative experiences, including questions about what students hoped to learn before the workshop and what they found most memorable after completing the intervention.

The teacher evaluation instrument consisted of 15 Likert-scale items evaluating five dimensions: pedagogical value, ease of use, curriculum alignment, safety considerations, and overall recommendation. Open-ended questions asked teachers to identify strengths of the kit, suggest improvements for future iterations, and describe potential implementation barriers they anticipated in their own school contexts. It should be noted that the focus group questionnaire initially contained 12 Likert-scale items, as the future interest and engagement sections were added after pilot feedback indicated the importance of these constructs for understanding the intervention's full impact. The mass class questionnaire therefore contained the full 15 Likert-scale items. For comparative analysis, overall mean scores were calculated per participant before combining groups to ensure comparability across the two student subsamples despite the difference in questionnaire length.

4.4 Data Analysis

Quantitative data were analyzed using paired sample t-tests to compare pre- and post-intervention scores for the student sample. This within-subjects design was appropriate given the relatively small sample size of 28 students and the goal of detecting individual-level change rather than group differences. By using each student as their own control, the paired design reduces the influence of between-subjects variability that might obscure treatment effects in a between-subjects design. Cohen's *d* was calculated as a measure of effect size, interpreted using conventional thresholds where 0.2 indicates a small effect, 0.5 a medium effect, and 0.8 a large effect (Cohen, 1988). For the teacher evaluation, descriptive statistics including means and standard deviations were computed, with inferential tests using one-sample t-tests against the neutral baseline of 3.0 to assess whether ratings significantly exceeded chance levels.

Qualitative responses were analyzed using thematic analysis following the six-phase procedure outlined by Braun and Clarke (2006). This procedure involved familiarization with the data through repeated reading, initial coding of meaningful units, generation of candidate themes by grouping related codes, review of themes against the coded data and entire dataset, definition and naming of themes, and final write-up of results. Coding was conducted inductively, allowing themes to emerge from participant responses rather than being imposed from theoretical frameworks, which is appropriate for exploratory research where the range of possible responses is not fully known in advance. A second coder independently coded 20 percent of responses to establish inter-rater reliability, achieving a kappa value of 0.84, which indicates substantial agreement beyond chance according to conventional benchmarks.

5. Results

5.1 Overall Learning Attitude Improvement

The paired sample t-test analysis revealed a statistically significant improvement in overall learning attitudes from pre-test to post-test. The pre-test mean score of 3.64 on the five-point scale, with a standard deviation of 0.22, increased to a post-test mean of 4.31 with a standard deviation of 0.25. This represents a mean difference of 0.67 points, and the t-test yielded a value of 11.90 with 27 degrees of freedom and a p-value less than .001, indicating that the observed improvement is extremely unlikely to have occurred by chance. The effect size, calculated as Cohen's d, was 2.80, which substantially exceeds the conventional threshold for a large effect of 0.8. This very large effect size indicates that the intervention had a practically meaningful impact on student attitudes beyond what would be expected from typical classroom instruction. The 95 percent confidence interval for the mean difference ranged from 0.55 to 0.78, excluding zero and further confirming the statistical significance of the improvement. In percentage terms, this represents an 18.4 percent improvement in overall learning attitudes. When examined separately by group, the focus group improved by 20.4 percent from 3.75 to 4.51, while the mass class improved by 17.8 percent from 3.61 to 4.25. The larger improvement in the focus group may reflect the smaller group size enabling more individualized attention from the instructor or the pilot testing context allowing additional refinements before the mass class implementation.

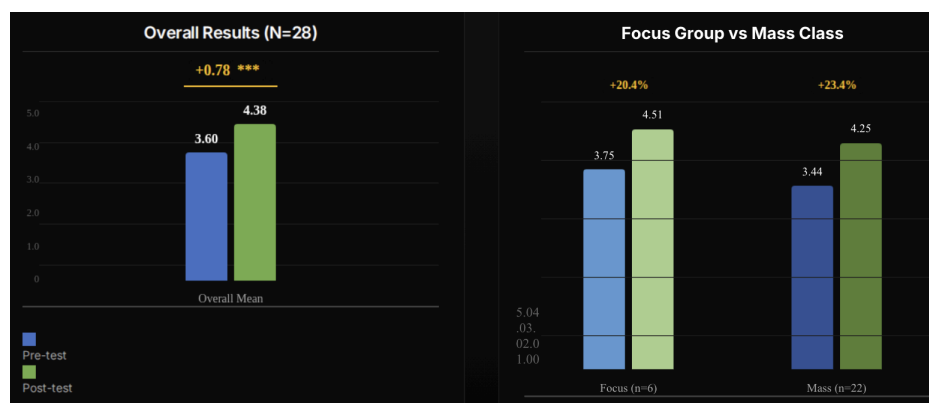


Fig. 12. Pre-test and Post-test results overview diagram.

5.2 Domain-Specific Improvements

When the results were analyzed by learning domain, clear patterns emerged that illuminate the specific areas of greatest impact. The knowledge and understanding domain showed the largest improvement, increasing by 37.1 percent from a pre-test mean of 3.06 to a post-test mean of 4.20. This improvement was associated with a t-statistic of 7.12 and a p-value less than .001, with an effect size of 1.52 standard deviations. This finding is consistent with the intervention's primary aim of building technical literacy in sensors, programming, and control systems where students had minimal prior knowledge. The collaboration domain showed the second largest improvement, increasing by 21.8 percent from 3.61 to 4.40, with a t-statistic of 5.43, p-value less than .001, and effect size of 1.16. This supports the theoretical claim that robotics activities naturally promote teamwork and peer learning, as students must work together to assemble hardware, diagnose problems, and tune parameters. The engagement domain showed a moderate improvement of 11.6 percent from 4.13 to 4.61, with a t-statistic of 3.21, p-value less than .01, and effect size of 0.68. The future interest domain improved by 14.2 percent from 3.65 to 4.17, with a t-statistic of 2.98, p-value less than .01, and effect size of 0.63. The satisfaction domain showed the smallest but still statistically significant improvement of 11.2 percent from 3.91 to 4.35, with a t-statistic of 2.44, p-value less than .05, and effect size of 0.52. These domain-specific findings suggest that the intervention was particularly effective at building

knowledge and collaboration skills, while also positively impacting engagement, interest, and satisfaction to a somewhat lesser but still meaningful degree.

Table 2: Domain-Specific Improvements by Learning Domain

Domain	Pre-test	Post-test	Δ	% Improvement	t-stat	p-value
Knowledge/Understanding	3.06	4.20	+1.14	+37.1%	7.12	< .001***
Collaboration	3.61	4.40	+0.79	+21.8%	5.43	< .001***
Future Interest	3.65	4.13	+0.48	+13.1%	3.21	< .01**
Engagement	3.91	4.35	+0.44	+11.2%	2.98	< .01**
Satisfaction	3.80	4.17	+0.37	+9.8%	2.44	< .05*

*Note. *** $p < .001$, ** $p < .01$, * $p < .05$. Data from Mass Class ($n = 22$).*

5.3 Question-Level Analysis

Examination of individual questionnaire items provided more granular insight into which specific aspects of learning showed the greatest gains. The question assessing sensor understanding showed the largest improvement, increasing by 51.3 percent from a pre-test mean of 2.70 to a post-test mean of 4.09, with a t-statistic of 5.87 and p-value less than .001. Notably, this question had the lowest pre-test score of any item, indicating that students entered the intervention with essentially no prior knowledge of sensors, but achieved the greatest absolute gain by the end, suggesting that the intervention was particularly effective at building foundational knowledge where it was most needed. The question assessing artificial intelligence understanding showed the second largest improvement, increasing by 40.0 percent from 2.95 to 4.14, with a t-statistic of 4.92 and p-value less than .01. This substantial gain in AI understanding is noteworthy given that AI tools were used primarily as a design aid rather than as a focus of instruction, suggesting that learning by using AI tools may be an effective approach to building AI literacy. The question assessing teamwork effectiveness improved by 25.5 percent from 3.48 to 4.36, with a t-statistic of 4.11 and p-value less than .01. The question assessing programming confidence improved by 23.9 percent from 3.52 to 4.36, with a t-statistic of 3.76 and p-value less than .01. The question assessing discussion participation improved by 23.1 percent from 3.55 to 4.36, with a t-statistic of 3.58 and p-value less than .01. This pattern suggests that the intervention was particularly effective in building foundational knowledge where students initially had the greatest gaps, while also positively impacting collaboration and communication skills that are valuable across disciplines.

5.4 Teacher Professional Evaluation

The professional evaluation by 77 educators yielded an overall mean rating of 4.41 out of 5, corresponding to 88.2 percent satisfaction, with a standard deviation of 0.56 indicating high consensus among evaluators. One-sample t-tests against the neutral baseline of 3.0 confirmed that all ratings significantly exceeded chance levels with p-values less than .001 for all comparisons, indicating that the positive ratings reflect genuine approval rather than random variation. Most notably, 100 percent of evaluators rated the kit either 4 or 5 out of 5 for recommendation to other schools, indicating exceptionally strong professional endorsement of the intervention's value and readiness for broader implementation. The highest-rated aspect was recommendation willingness at 4.64 out of 5, followed by student motivation enhancement at 4.61, safety considerations at 4.58, clear learning objectives at 4.56, and assembly instructions clarity at 4.49. These ratings suggest that teachers perceive the kit as safe, pedagogically sound, and practical for classroom use, with particularly strong endorsement of its motivational impact and overall value.

The open-ended comments from teachers provided qualitative depth to these quantitative ratings. One in-service teacher with eight years of experience wrote that the Daruma design immediately captured students' attention, noting that the cultural element seemed to lower resistance to engaging with the technical content. A preservice teacher commented that the magnetic shell system was brilliant because students could personalize their robots without needing technical skills, making the design activity accessible to all students regardless of prior experience. An experienced in-service teacher with twelve years in the classroom noted that finally there was a robotics kit that did not require hours of preparation, highlighting the importance of minimizing teacher workload for sustainable implementation. Several teachers suggested minor improvements, including providing more pre-printed component labels and including additional troubleshooting examples, which will be incorporated into future iterations of the kit.

Table 3: Top-Rated Aspects from Teacher Evaluation

Aspect	Rating
Recommendation willingness	4.64/5
Student motivation enhancement	4.61/5
Safety considerations	4.58/5
Clear learning objectives	4.56/5
Assembly instructions	4.49/5

Note. N = 77 educators

5.5 Qualitative Findings from Students

The pre-test open-ended responses revealed that students entered the workshop hoping to learn about mechanical creation, robot assembly, teamwork skills, innovation, and hands-on building techniques. These expectations aligned well with the intervention's design, suggesting that students perceived the workshop as offering experiences they valued. All 28 students reported no prior robotics experience in their responses, confirming that the accessibility requirement of assuming no prior knowledge was appropriate for this population and that the sample was indeed composed of novices. The post-test responses about memorable experiences clustered into four themes that emerged from the inductive coding process. The assembly theme was captured in responses such as assembly and colouring, referring to the hands-on process of building the robot chassis and personalizing the Daruma shell. The understanding theme appeared in responses like combining parts and understanding the program, indicating that students valued both the physical construction and the conceptual learning about how the software controlled the hardware. The success theme was particularly prominent in responses such as the moment I saw the robot successfully self-balance, suggesting that the achievement of a functioning robot provided a powerful affective experience that may enhance learning and motivation through the experience of mastery. The collaboration theme emerged in responses such as the process of discussing and solving problems with teammates, indicating that students valued the social aspects of the learning experience and recognized the role of peer interaction in overcoming challenges.

The attitude changes reported by students reflected what might be described as transformative learning experiences that extended beyond the immediate workshop context. One student wrote that technology is human-centered, indicating a shift from viewing technology as abstract and disconnected from human concerns to recognizing its orientation toward human needs and values. This represents a significant conceptual shift in how the student understands the relationship between technology and society. Another student used the term concretization, describing the process of abstract concepts becoming tangible through hands-on activity in ways that textbook learning could not achieve, indicating metacognitive awareness of the learning process itself. A third student expressed hope to contribute to future society, suggesting the emergence of a STEM identity and prosocial motivation that extended beyond immediate task completion to longer-term aspirations about using technology to

benefit others. These qualitative responses suggest that the intervention's impact extended beyond measurable attitude changes to include shifts in students' fundamental understanding of technology and their relationship to it.



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6. Discussion

6.1 Interpretation of Key Findings

The finding that the knowledge and understanding domain showed the largest improvement, increasing by 37.1 percent with a very large effect size of 1.52, demonstrates that complex concepts such as proportional-integral-derivative control and sensor fusion can be made accessible to secondary students through hands-on robotics education. This finding aligns with the meta-analytic results reported by Freeman and colleagues (2014) and extends those findings to the Hong Kong context, where hardware literacy has been identified as a critical gap in the existing curriculum (Yeung & Ng, 2021). The theoretical explanation for this finding likely involves what cognitive scientists call perceptual grounding (Barsalou, 2008). When students tilted the robot and watched the wheels respond by spinning in the direction needed to restore balance, the abstract relationship between sensor reading and motor output became perceptually available and directly observable. This perceptual grounding allowed students to form mental models of the feedback loop that would be difficult to achieve through verbal explanation or diagram study alone. The immediate, observable feedback provided by the physical robot creates a tight coupling between action and outcome that supports rapid learning and conceptual refinement.

The finding that the Daruma cultural theme had measurable impact on student engagement is supported by both the quantitative improvement in engagement scores and the qualitative comments specifically mentioning the Daruma design as memorable and enjoyable. The cultural integration likely operated through two complementary mechanisms. First, the analogy between the self-righting Daruma doll and the self-balancing robot created conceptual scaffolding that made the robot's purpose more intuitive. When students understood that the robot was trying to do what a Daruma doll naturally does, the control problem became framed in familiar terms, reducing cognitive load and freeing mental resources for deeper processing of the underlying principles. Second, the opportunity to paint and personalize their own Daruma shells provided creative expression within the technical activity, increasing personal investment and ownership of the learning process. This finding supports the broader literature on culturally responsive pedagogy (Gay, 2010; Ladson-Billings, 1995) and extends it to the specific domain of educational robotics in Hong Kong, providing empirical evidence that cultural integration can enhance STEM motivation in this context.

The improvement in collaboration scores and the qualitative evidence of peer problem-solving confirm that robotics activities naturally promote teamwork and distributed cognition. Students who might have struggled individually could succeed when working in pairs, and the troubleshooting process required communication and coordination. This finding supports the work of Torres and colleagues (2025) who demonstrated that collaborative robotics curriculum enhances both technical outcomes and teamwork competencies. The natural interdependence created by robotics activities—where different students may have different strengths in assembly, programming, or troubleshooting—creates authentic opportunities for collaborative learning that can feel less contrived than explicitly designated group work activities. The 21.8 percent improvement in collaboration scores suggests that students recognized and valued this collaborative dimension of the learning experience.

6.2 Limitations, Implications, and Future Directions

Several limitations of this study warrant acknowledgment. The student sample of 28 participants from a single school limits generalizability, and the absence of a control group prevents definitive attribution of observed improvements to the intervention rather than to maturation or other confounding variables. Self-reported measures may introduce response bias, and the very large effect size ($d = 2.80$) should be interpreted cautiously, as it may reflect the homogeneous sample, highly structured intervention format, and potential response bias rather than solely the intervention's genuine impact. Future research with larger, more diverse samples, control groups, and objective assessments is needed to establish robustness and generalizability.

Despite these limitations, the findings offer several implications for educators and curriculum developers. Hands-on robotics education should be integrated into information and communication technology curricula as a core component rather than confined to extracurricular activities, as even students without technical backgrounds can successfully engage with complex engineering concepts when supported by appropriate hands-on activities. The effectiveness of the Daruma cultural theme suggests that cultural integration should be considered a design feature rather than an afterthought, providing conceptual scaffolding that makes technical content more intuitive and personally relevant. The success of AI-assisted design activities indicates that AI tools can lower barriers to creative technical work, building AI literacy through authentic use rather than explicit instruction. For policymakers, the 100 percent teacher recommendation rate provides strong professional endorsement supporting resource allocation for school robotics kits and integration of hands-on STEM components into formal curricula.

For future research, several directions are indicated. Longitudinal follow-up studies are needed to measure knowledge retention and examine whether motivational effects translate into sustained STEM engagement and career pathways. Primary school adaptation with simplified components should be explored, as feedback and balance concepts are accessible to younger students with appropriate scaffolding. Comparative studies examining the relative contributions of the three pedagogical components—hardware assembly, AI design, and cultural theme—would help refine understanding of which features are essential and which are substitutable. Mass production scaling should be investigated to reduce per-unit costs and broaden accessibility, and competition pathways could be developed to provide authentic audiences and performance goals for student work.

7. Conclusion

This research demonstrates that the EduBalancer robotics kit effectively enhances secondary students' STEM learning motivation in Hong Kong. The statistically significant improvement with a very large effect size of 2.80 and p-value less than .001, combined with strong professional validation showing 88.2 percent satisfaction and a 100 percent recommendation rate, provides robust evidence for the intervention's effectiveness across both student outcomes and teacher perceptions. The integration of hands-on robotics assembly, AI-assisted three-dimensional modeling, and cultural Daruma design creates a unique pedagogical approach that addresses the four identified gaps in Hong Kong STEM education: the curriculum gap through formal integration of robotics, the conceptual gap through concrete manipulation of abstract concepts, the engagement gap through hands-on authentic activity, and the cultural gap through culturally resonant design.

Students successfully grasped university-level concepts like proportional-integral-derivative control, as evidenced by the 37.1 percent improvement in the knowledge domain and qualitative comments about concretization and understanding. They collaborated effectively in teams, as shown by the 21.8 percent improvement in collaboration scores and qualitative themes about peer problem-solving. They developed increased motivation for STEM study, as reflected in the 14.2 percent improvement in future interest and comments expressing hope to contribute to future society. Teachers recognized the kit's pedagogical value, safety, and practicality, with unanimous recommendation for adoption in other schools.

This research contributes both academic insights—a validated approach to culturally-embedded, hands-on STEM education with empirical evidence from the Hong Kong context—and practical deliverables—a ready-to-deploy curriculum with open-source hardware design, comprehensive teacher materials, and documented implementation procedures. Future research should expand sample size to include multiple schools and diverse student populations, include control group comparisons to isolate treatment effects, add objective assessments of learning outcomes to supplement self-reported measures, and conduct longitudinal follow-up to measure knowledge retention and sustained motivational effects over extended time periods. Through these continued efforts, the EduBalancer model can contribute to addressing the STEM education gap in Hong Kong and provide a replicable approach for culturally-embedded robotics education in other contexts.



EduBalancer Boosts STEM Motivation

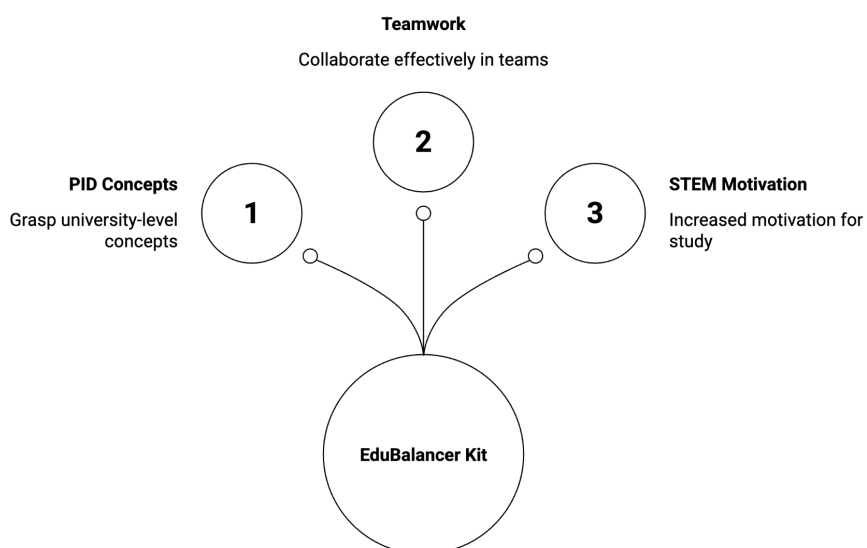


Fig. 13. Diagram depicting how the learning package boosts STEM Motivation.



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Appendices



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Appendix A

Hardware Specifications

Table A1: EduBalancer Hardware Components

Component	Model	Specifications
Microcontroller	Arduino	ATmega328P, 5V
IMU Sensor	MPU6050	6-axis, I2C interface
Motor Driver	TB6612FNG	1.2A per channel, dual motor control
DC Motors	Geared Motor	6V, 200 RPM, dual motor system
Battery	Li-ion 12V	2200mAh rechargeable battery
Chassis	3D Printed	PLA material, custom Daruma design
Wheels	65mm	Rubber tire, 65mm diameter

Note. All components are open-source and replaceable with compatible alternatives.



Appendix B

Questionnaire Framework

Pre-test Questionnaire Structure:

15 Likert-scale items (1 = Strongly Disagree, 5 = Strongly Agree) measuring:

- Expectations (Q1-Q3)
- Prior Knowledge (Q4-Q6)
- Learning Style (Q7-Q9)
- Collaboration (Q10-Q12)
- Future Interest (Q13-Q15)

Post-test Questionnaire Structure:

15 Likert-scale items (1 = Strongly Disagree, 5 = Strongly Agree) measuring:

- Satisfaction (Q1-Q3)
- Understanding (Q4-Q6)
- Motivation (Q7-Q9)
- Collaboration (Q10-Q12)
- Engagement (Q13-Q15)

Open-ended Questions:

Pre-test: Expectations and prior experience (2 questions)

Post-test: Memorable experiences, challenges, and attitude changes (3 questions)

The image displays two side-by-side screenshots of the EduBalancer questionnaire interface. The left screenshot is titled '先導計劃-平衡機械人工作班EduBalancer：學生學習回饋問卷-前測' (Pilot Program - Balancing Robot Work Class EduBalancer: Student Learning Feedback Questionnaire - Pre-test). It includes sections for '期望與先驗知識' (Expectations and Prior Knowledge) and '學習動機與期望' (Learning Motivation & Expectations). The right screenshot is titled '先導計劃-平衡機械人工作班EduBalancer：學生學習回饋問卷-後測' (Pilot Program - Balancing Robot Work Class EduBalancer: Student Learning Feedback Questionnaire - Post-test). It includes sections for '學習成果與滿意度' (Learning outcomes and satisfaction) and '知識與技能發展' (Knowledge & Skills Development). Both versions feature Likert-scale items and open-ended questions.



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Appendix C

Raw Data Summary

Student Study Data Files:

- Focus Group Pre-test: [先導計劃] 平衡機械人工作坊EduBalancer:學生學習回饋問卷-前測 (Responses).xlsx (n = 6)
- Focus Group Post-test: [先導計劃] 平衡機械人工作坊EduBalancer:學生學習回饋問卷-後側 (Responses).xlsx (n = 6)
- Mass Class Pre-test: 平衡機械人工作坊EduBalancer:學生學習回饋問卷-前測_22人.xlsx (n = 22)
- Mass Class Post-test: 平衡機械人工作坊EduBalancer:學生學習回饋問卷-後測_22人.xlsx (n = 22)

Teacher Evaluation Data File:

- 學習套件教師評估問卷_Responses.xlsx (n = 77)

<https://drive.google.com/drive/folders/1qgC7VVtoJXMTVr7wkADfrkx8IHtGT4IN?usp=sharing>

Appendix D

Teaching Materials Reference



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機械不倒翁

Daruma Self-balancing Robot



教學筆記

Teaching Notes



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EduBalancer :

文化主題 自平衡機械人 套件

歡迎你參與 EduBalancer：文化主題自平衡機械人套件學習活動。本教材以「自平衡機械人」作為核心載體，融合 AI 概念、STEM 工程實作與文化設計，讓你在動手做的過程中，同步學習科技原理與創作表達。在這次活動中，你將會親手完成由零件組裝到程式控制的完整流程：包括認識感測器如何量度姿態（例如傾斜角度）、理解控制邏輯如何令機械人保持平衡，以及透過調整參數與測試來改善表現。這些過程正正對應現代智能系統的核心：以數據（感測）作輸入、以算法（決策）作處理、以動作（輸出）作回應，從而達到穩定、可靠與可重複的運作。

EduBalancer 的另一個特色是「文化主題」設計：你不只是在做一部機械人，更是在創作一個有故事、有意義的作品。透過三維建模（3D Modelling）與外觀設計，你可以把文化元素（例如香港特色、校園主題、傳統圖騰或現代城市符號）融入機械人外形與裝飾，讓 STEM 不只是功能與技術，更是一種能夠與生活連結的創新表達方式。這種「科技 × 文化 × 創作」的結合，能幫助你把學到的知識應用到真實情境，提升學習投入感與學習動機。

本套件及教材屬於 香港教育大學（EdUHK）資訊及通訊科技（ICT）教育榮譽學士畢業專題研究的一部分，強調「科技融入教育」與「以學習者為本」的設計理念；希望你在過程中不只學會操作，更能培養解難能力、創造力與協作能力，成為能把科技用於改善世界的未來創新者。

——香港教育大學資訊及通訊科技榮譽教育學士畢業專題研究，由蕭振平Cloof 完成

關於研究者

蕭振平（Cloof）是一位充滿熱誠的科技教育工作者。他曾擔任香港教育大學機械人隊隊長，帶領團隊參與 Robocon HK 全港大專生機械人大賽 2022-2025，致力將理論與實際應用緊密結合。



曾於超過20+中小學、特殊學校及NGO任教科技相關課程，當中包括3D打印、機械人編程以及無人機等等。

除此以外，亦於不同比賽及活動中獲得殊榮，例如香港教育大學校長表揚狀2025(創新、科學與科技) 和香港傑出準教師選舉金獎。



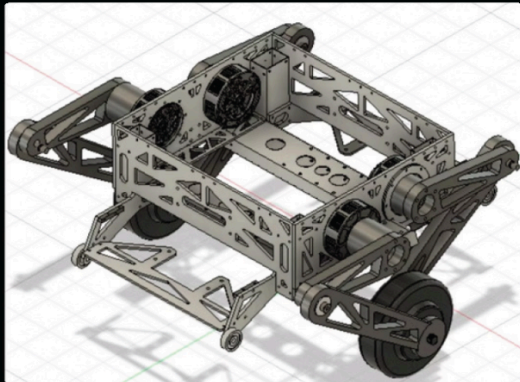
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從巨型機械人到課堂套件：

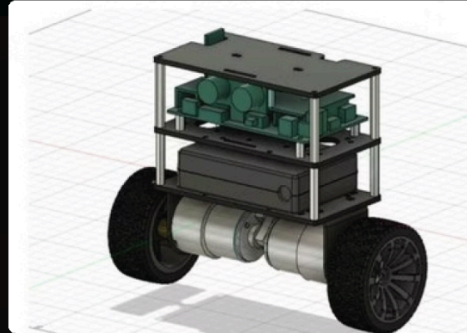
EduBalancer 並非憑空而來——它源自研究者在比賽中研發的大型雙足輪式機械人。那台機器雖展示了卓越的穩定性與運動能力，但其複雜程度，成本及潛在危險使其完全不適合課堂使用。設計挑戰在於：如何在一個手掌大小，價格親民且安全的套件中，保留同樣豐富的控制理論學習體驗。

第一階段－大型雙足機械人

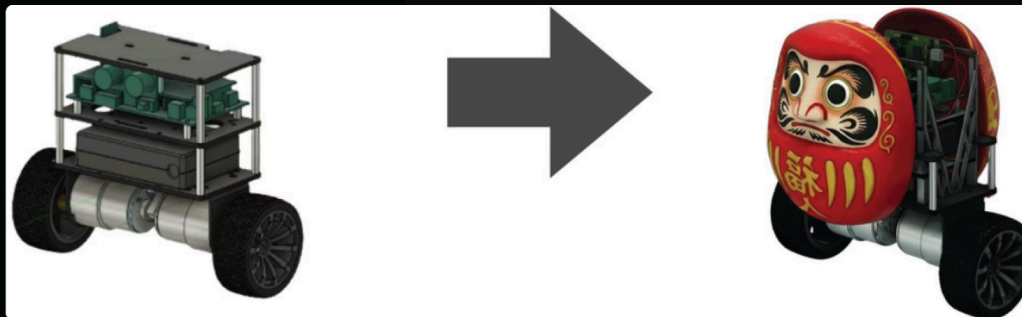


一台複雜的開放式工程原型，具備先進的運動能力——體積過大，成本過高，且對學校環境存在安全風險。

第二階段－縮小版 EduBalancer



一個以 Arduino 驅動的緊湊模組化課堂套件——在不帶來過高成本或安全風險的前提下，重現相同的控制挑戰。



注入文化靈魂：

一台技術上可運作的機械人只是一台機器。但當機械人戴上達摩的臉——這個象徵堅毅、韌性與「七跌八起」精神的日本文化符號——它便成為一個話題、以及學生真正引以為傲的作品。研究者曾將 EduBalancer 帶到維多利亞公園農曆新年市集展覽，許多小朋友都愛不釋手。這個轉變透過 AI 輔助三維建模實現，將一個單調的灰色框架，變成充滿文化意義的學習載體——讓學生真正「想」去動手。

原始機械人

一個功能正常但毫無吸引力的灰色金屬框架——技術上可靠，但與學生的身份認同和文化毫無情感連結。

AI 三維建模

使用 Rodin Tripo 及 Meshy 等工具，學生共同設計一個充滿文化主題的外殼，為機械人注入有意義的視覺故事。

達摩機械人

一個紅色達摩臉外殼，承載著文化意義——這台會倒下又自行站起的機械人，正如它所模仿的不倒翁一樣。

課程設計：三節課

EduBalancer 工作坊分為三節各90分鐘的課堂——每節在上一節的基礎上遞進，帶領學生從實體組裝，到電子接線，再到編程。這種鷹架式進程反映了真實的工程設計流程：先建造身體，再連接神經系統，最後才為大腦編程。課程與香港中學文憑試 ICT 課程（選修C：演算法與編程）及物理課程（力與運動）對齊。



第一節：組裝（90分鐘）

硬件介紹及零件識別。按步驟組裝電路。通電及基本測試。學生用手指平衡框架，親身體驗重心概念。教學觀察：在學生面前放置一台已完成的示範機械人，能大大加快組裝速度——學生可以直接參考實物，而非單靠說明書或影片。



第二節：AI 三維建模（90分鐘）

Rodin Tripo / Meshy AI 工具教學。達摩角色創意設計。三維打印檔案準備。學生親手塗色繪製達摩外觀，樂在其中，並從中獲得靈感，嘗試用 AI 創作其他角色。學生由建造者搖身一變成為設計師。



第三節：編程（90分鐘）

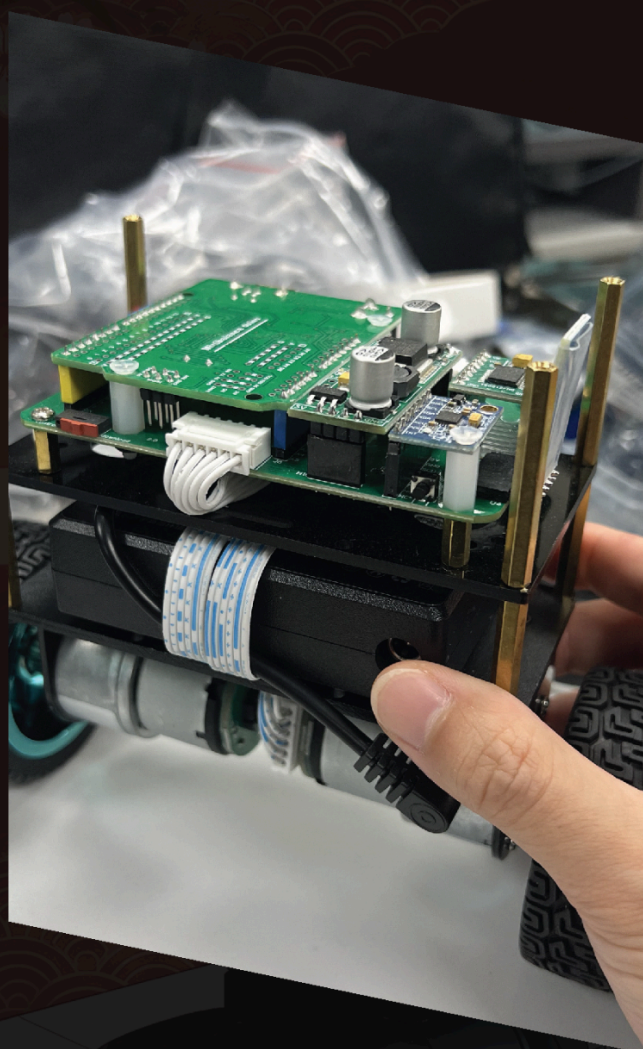
PID 控制視覺化示範。Kp、Ki、Kd 參數調校與試驗。平衡測試及友誼競賽。「誰能讓機械人保持平衡10秒？」學生能掌握 PID 這個複雜概念，令人驚喜！



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第一節..組裝



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EduBalancer 系統：硬件架構

EduBalancer 套件中的每個零件均依循雙重原則選取：教育透明度與實際可負擔性。與那些將學生與底層電子元件隔絕的「黑箱」系統不同，EduBalancer 採用驕傲的「玻璃箱」設計。學生親手接觸裸露的電路板、閱讀引腳圖、手動連接線路——建立任何模擬都無法複製的深層硬件素養。



核心零件規格

零件	型號 / 功能
微控制器	Arduino UNO (ATmega328P)
IMU 感測器	MPU6050 (六軸陀螺儀及加速度計)
電機驅動器	TB6612FNG (直流控制)
電池	2S 鋰離子 7.4V (18650 電芯)
自訂 PCB 擴展板	驅動器及感測器分線板

套件主要創新

- 磁吸附系統，可快速更換外殼
- 達摩主題文化外殼
- </> 開源教育代碼，附完整注釋
- 所有零件以收納盒包裝
- 市場罕有少見雙輪足機械人套件



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機器本體：主要硬件零件

三個零件構成 EduBalancer 的功能核心。理解每一個——它的功能、選用原因，以及如何與其他零件互動——本身就是豐富的 STEM 學習體驗。能建立任何預先組裝套件都無法提供的直覺「電子感」。



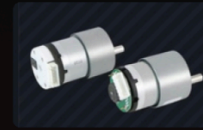
大腦：Arduino UNO

5V 邏輯、USB 編程，在學校中廣泛使用。ATmega328P 以 200Hz 運行完整的 PID 控制迴路——每 5 毫秒讀取、計算並執行一次。學生編寫 C++ 代碼，而非積木式拖放編程。



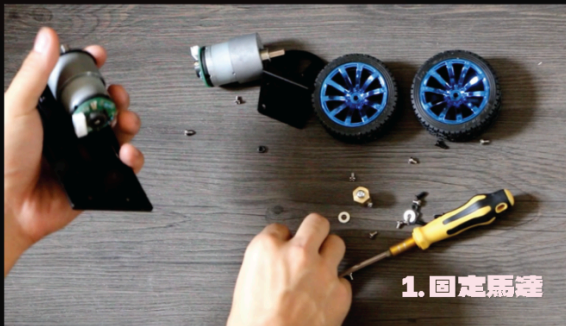
MPU6050

一顆集陀螺儀與加速度計於一身的六軸慣性測量單元。透過 I2C 存取，價格低廉且文檔齊全。可在串口圖儀上查看實時傾斜數據。



肌肉：直流電機

帶編碼器的銀色圓柱形直流電機，可精確反饋速度。60mm 橡膠輪胎確保抓地力。7.4V 電池提供足夠的高放電率，應對 PID 控制所需的快速電機修正。



第二節：AI三維建模



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第二節詳細筆記：AI 三維建模（90分鐘）

這一節是整個課程最有創意的部分！你將從一個「建造者」搖身一變成為「設計師」——利用 AI 工具，為你的機械人設計獨一無二的文化主題外殼。



工具介紹（約15分鐘）

認識 Rodin Tripo 及 Meshy 兩款 AI 三維建模工具。了解如何用文字描述（Prompt）生成三維模型。老師示範整個流程，同學觀察並提問。



達摩設計工作坊（約30分鐘）

先在紙上親手塗色、繪製你心目中的達摩外觀設計。思考顏色、表情、花紋——這是你的作品，發揮創意！然後將你的設計概念輸入 AI 工具，生成三維模型。



三維打印準備（約20分鐘）

檢查 AI 生成的模型，調整細節。匯出適合三維打印的檔案格式（.3MF）。了解三維打印的基本原理：層層疊加，由數碼到實體。



創意延伸（約25分鐘）

完成達摩後，嘗試設計其他角色！可以是學校吉祥物、動漫角色（如漫威格魯特！）、或任何你喜歡的形象。透過磁吸設計，你的創作可以直接安裝到機械人上。

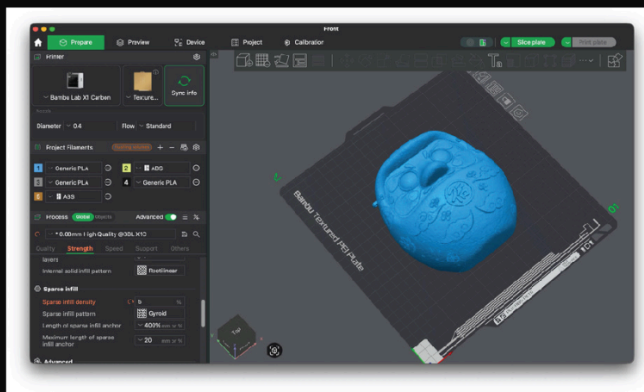
 **老師的話：**塗色和繪製達摩外觀這個環節，同學們都非常投入！親手設計自己的作品，能激發你對 AI 創作的好奇心。記住——AI 是你的工具，你才是真正的設計師。

本節使用工具

- Rodin Tripo — 文字生成三維模型
- Meshy — AI 三維建模及紋理生成
- 三維打印機（老師操作）
- 彩色筆／紙（草稿設計用）

學習重點

- Rodin Tripo — 文字生成三維模型
- Meshy — AI 三維建模及紋理生成
- 三維打印機（老師操作）
- 彩色筆／紙（草稿設計用）



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AI 三維建模

什麼是 Prompt (提示詞) ?

Prompt 是用文字描述你想要生成的三維模型內容。AI 會根據你的描述自動生成對應的 3D 模型。

良好的 Prompt 範例：

> 「一個紅色的達摩不倒翁，傳統日本風格，圓形身體，表情威嚴，表面有金色花紋，卡通風格」

Prompt 撰寫技巧：

- 描述形狀 (圓形、方形、人形等)
- 描述顏色和材質
- 描述風格 (卡通、寫實、雕塑等)
- 描述細節特徵
- 描述用途或場景

步驟一：開啟 TRIPO AI 網站

1. 使用瀏覽器前往
<https://studio.tripo3d.ai/>
2. 註冊或登入帳號 (支援 Discord 帳號
快速登入)

步驟三：輸入 PROMPT 並生成

1. 在文字框輸入描述
2. 選擇藝術風格 (寫實、卡通、雕塑等)
3. 點擊「生成」按鈕
4. 等待 1-5 分鐘生成完成

步驟五：輸出， 並且打印

- 支援格式：STL、OBJ、FBX、
GLB、USD、3MF
- 選擇 STL 格式用於 3D 打印

步驟二：選擇生成 方式

- 文字轉 3D：輸入文字描述生成模型
- 圖片轉 3D：上傳圖片生成模型

步驟四：檢視

1. 使用內建 3D 檢視器旋轉、縮放查
看模型
2. 可調整幾何細節等級
3. 可調整紋理解析度



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第三節：編程

```
Minibalance_2
1  #include <DATASCOPE.h>
2  #include <PinChangeInt.h> //
3  #include <MsTimer2.h> // Timer2 定時器
4  #include <KalmanFilter.h> // 卡爾曼濾波
5  #include "I2Cdev.h"
6  #include "MPU6050_6Axis_MotionApps20.h" // MPU6050
7  #include "Wire.h"
8  #include <EEPROM.h>
9
10 typedef unsigned short u16;
11
12 // ===== 物件實例化 =====
13 MPU6050 Mpu6050; // MPU6050 物件
14 DATASCOPE data; // 上位機物件
15 KalmanFilter KalFilter; // 卡爾曼濾波器物件
16
17 // ===== MPU6050 六軸資料 =====
18 int16_t ax, ay, az, gx, gy, gz; // 三軸加速度
19
20 // ===== 腳位定義 =====
21 #define KEY 3 // 按鍵腳
22 #define IN1 12 // TB6612FNG: 電機 A 方向控制
23 #define IN2 13
24 #define IN3 7 // TB6612FNG: 電機 B 方向控制
25 #define IN4 6
26 #define PWMA 10 // TB6612FNG: 電機 A PWM
27 #define PWMB 9 // TB6612FNG: 電機 B PWM
28
29 #define ENCODER_L 2 // 左輪編碼器中斷腳 (外部中斷)
30 #define DIRECTION_L 5 // 左輪方向相位
31 #define ENCODER_R 4 // 右輪編碼器 (PinChangeInt)
32 #define DIRECTION_R 8 // 右輪方向相位
33 #define OFFSET 0 // 電機點偏移)
```



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第三節詳細筆記：編程與測試（90分鐘）

這是最令人興奮的一節——你將為機械人注入「靈魂」！透過編程，讓它真正學會自行平衡。準備好迎接挑戰了嗎？



PID 控制概念講解（約 20分鐘）

什麼是 PID？P（比例）、I（積分）、D（微分）——三個參數，一個目標：讓機械人保持平衡。老師用視覺化示範解釋：想像你用手指頂著一根棍子，你的大腦就是 PID 控制器！



上載程式碼（約15分鐘）

透過 USB 將程式碼上載至 Arduino UNO。認識 Arduino IDE 介面。代碼已預先注釋，每一行都有中文說明——你不需要從零開始寫！



參數調校（約35分鐘）

這是最考驗耐性的環節！調整 K_p （比例增益）：數值太大 → 機械人過度反應；太小 → 反應不足。調整 K_d （微分增益）：幫助機械人預測下一步動作，減少震盪。調整 K_i （積分增益）：修正長期誤差，讓機械人更穩定。每次調整後，放下機械人，觀察它的反應，再作修正。這就是工程師的工作！



平衡測試及友誼競賽（約20分鐘）

誰能讓機械人保持平衡最長時間？計時開始！互相觀摩，分享各自的 $K_p/K_i/K_d$ 數值。討論：為什麼不同的數值組合會有不同效果？

- 📌 **思考時刻：**當你調校完 PID 參數後，想一想——如果有一個神經網絡，它就能自動找出最佳的 $K_p/K_d/K_i$ 數值。今天，你親手做到的事，正是 AI 機器學習的核心原理！你們就是那個神經網絡。

PID 控制快速指南

P（比例 Proportional）

根據「現在」的誤差作出反應。誤差越大，修正力度越大。就像你看到機械人快要倒，立刻用力推回來。

I（積分 Integral）

根據「過去」累積的誤差作出修正。解決長期偏差問題。就像你發現機械人一直偏向左邊，慢慢調整回中間。

D（微分 Derivative）

根據誤差的「變化速度」預測未來。防止過度修正。就像你看到機械人倒得很快，提前準備好更大的修正力度。

常見問題

- 機械人一直震盪： K_d 太小，增大 K_d
- 機械人反應太慢： K_p 太小，增大 K_p
- 機械人過度反應： K_p 太大，減小 K_p
- 機械人慢慢漂移： K_i 太小，微調 K_i

成功指標

- 機械人能在平地 P 保持平衡超過 5 秒
- 輕推後能自行恢復平衡
- 理解每個參數對機械人行為的影響
- 解釋 PID 的基本原理



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藍牙方向指令與三環控制 (直立/速度/轉向)

指令輸入 (串口/藍牙)

- 串口指令 → serialEvent() → 設定 4 個方向旗標：Flag_Qian (前進)、Flag_Hou (後退)、Flag_Left (左轉)、Flag_Right (右轉)；無有效指令則全部清 0 (停止)。

速度回授 (編碼器)

- 左右輪編碼器脈衝在固定時間內累積；每 40ms 讀一次並清零，作為速度量度 (脈衝數越多＝轉得越快)。

速度控制 (前進/後退)

- velocity() (PI) 根據旗標設定 Movement：前進為正、後退為負、停止為 0；輸出 Velocity_Pwm 控制前後移動與停車回中。

轉向控制 (左轉/右轉)

- turn() (PD) 根據 Flag_Left / Flag_Right 形成轉向目標，並用 Z 軸陀螺儀作抑制；輸出 Turn_Pwm 令左右輪產生差速完成轉向。

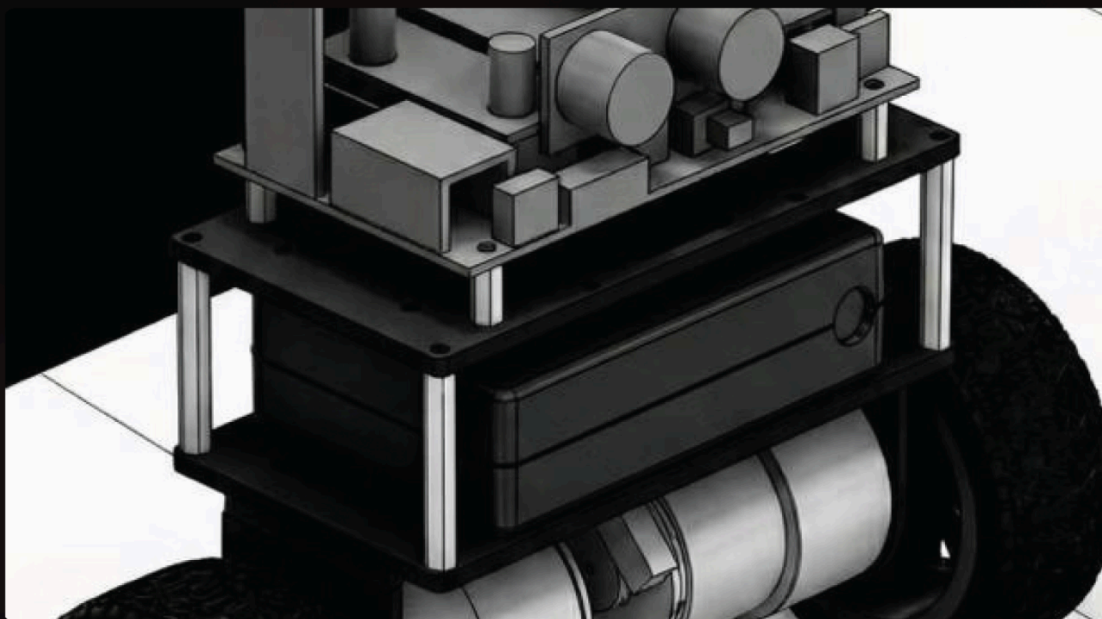
三環疊加 (最終電機輸出)

- 直立 Balance_Pwm (最優先) + 速度 Velocity_Pwm + 轉向 Turn_Pwm → 合成左右輪 PWM，實現「先保持直立，再前後左右移動」。

安全保護 (防暴走)

- 拎起/放下偵測 + 傾角過大 + 低電壓 → 會停止電機輸出





結論與重點總結

EduBalancer 是對香港中學 STEM 教育中軟件流暢度與硬件素養之間日益擴大的差距，作出的策略性、循證回應。透過將一台強大的工程原型縮小為課堂友好套件，本項目提升的是學習潛力，而不只是縮小硬件複雜度。這台不會倒下的機械人——正如它所穿戴的達摩不倒翁——傳達出最核心的訊息：堅持、好奇心，以及勇於調試的精神，才是最重要的 STEM 素養。

動手機械人讓複雜的 STEM 概念不再神祕

來自實體 PID 控制器的即時而具體的反饋，教授了任何模擬都無法傳遞的東西——而且學生會永遠記住。

文化融合讓抽象學習變得深刻個人化

透過達摩主題把一項 STEM 活動轉化為有意義、令人難忘的體驗。

AI 工具讓中學生的創意得以民主化

降低三維設計門檻，讓學生專注於創新而非軟件障礙——體現設計上的包容性。

香港本地化方案優於通用套件

EduBalancer 遠比現成的國際替代品更有效。機械人是未來的趨勢，我們必須持續推廣，啟發新一代去建造機械人！

研究者：蕭振平（Cloof） 指導老師：孫丹兒博士 香港教育大學資訊科技教育學系



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