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Case-based learning in paediatric cardiology training

Kate O'Halloran[1] and Colin J. McMahon[1,2]

[1]Department of Pediatric Cardiology, Children's Health Ireland, Crumlin, Dublin, Ireland and [2]School of Medicine, University College Dublin, Dublin, Ireland

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Corresponding author:
Colin J. McMahon;
Email: cmcmahon992004@yahoo.com

Abstract

Background: Case-based learning (CBL) is increasingly used across health professions education to promote clinical reasoning and professional competencies. In paediatric cardiology, rapid advances in diagnostics, interventions, and multidisciplinary care have intensified the need for educational approaches that integrate complex knowledge with real-world problem-solving. *Methods:* This narrative review outlines the theoretical foundations of CBL and examines the available literature on its implementation and effectiveness in medical education generally and paediatric cardiology specifically. Emerging applications of CBL, including simulation, virtual reality, and international collaborative case conferences, were also reviewed. Key design principles for effective CBL were explored, including case selection, alignment with competency-based curricula, faculty development, and assessment strategies. *Results:* Evidence suggests that CBL enhances clinical reasoning, knowledge integration, learner engagement, and the development of professional competencies. In paediatric cardiology, CBL supports the application of complex diagnostic and management principles within authentic clinical contexts. Emerging technology-enhanced approaches and international collaborative learning initiatives further expand opportunities for interactive and multidisciplinary education. However, challenges remain, including significant time and resource requirements, digital inequities, and the need for more rigorous evaluation of educational outcomes. *Conclusion:* Well-designed CBL appears to be a powerful educational strategy for preparing paediatric cardiology clinicians to deliver increasingly complex, team-based care. Future directions include greater integration of technology-enhanced learning, simulation-based approaches, and global educational networks to support trainees and practitioners across diverse practice settings while strengthening evidence for educational effectiveness.

Introduction

Paediatric cardiology is a rapidly evolving field characterised by complex congenital and acquired heart disease, sophisticated imaging and interventions, and long-term multidisciplinary follow-up. Training programmes must therefore cultivate not only factual knowledge but also advanced clinical reasoning, communication, and systems-based practice. Traditional lecture-based teaching alone often fails to develop these higher-order skills or to mirror the complexity of real clinical practice.

Case-based learning uses authentic or simulated patient cases as the primary vehicle for teaching. It engages learners in analysing data, generating differential diagnoses, and formulating management plans while integrating pathophysiology, evidence, and contextual factors. Conceptual papers and facilitator guides describe case-based learning as an active, learner-centred approach that sits between problem-based learning and didactic lectures, with more structure than the former and more interactivity than the latter.[1]

Across undergraduate and postgraduate medical education, case-based learning has been associated with improved academic performance, learner satisfaction, and perceived relevance compared with traditional methods.[2] This provides a strong rationale for embedding case-based learning within paediatric cardiology curricula, where complex decision-making, uncertainty and longitudinal care trajectories are central.

Educational foundations of case-based learning

Case-based learning is grounded in several educational theories. First, constructivist learning theory emphasises that learners actively build knowledge through interaction with problems and prior experience. In case-based learning, students link basic and clinical science to specific patient narratives, thereby constructing more durable mental models of disease. Adult learning theory (andragogy) highlights the importance of relevance, autonomy, and problem-orientation; cases provide immediate clinical relevance and a clear sense of purpose.

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Figure 1. Educational framework for case-based learning (CBL) in paediatric cardiology training. CBL uses authentic or simulated clinical cases to facilitate active learning, clinical reasoning, and integration of knowledge. Core components include clinical cases, facilitated discussion, predefined learning objectives, feedback, and assessment. Educational principles underpinning CBL include adult learning theory, contextual learning, active learning, scaffolding, reflection, and integration of basic and clinical sciences. CBL may be delivered through small-group discussion, conference-based teaching, simulation, and digital learning platforms. Expected outcomes include improved clinical reasoning, knowledge retention, procedural competence, decision-making, teamwork, communication, and learner engagement.

Recent work has sought to better characterise how and why case-based learning actually works.[3,4] A protocol for a realist review of case-based learning in undergraduate medical education aims to examine which design features are most effective for different learner groups and contexts.[4] Systematic reviews indicate that case-based learning improves examination scores and self-reported skills across disciplines, although heterogeneity in study design and outcomes remains a challenge.[2]

Case-based learning can be delivered in various formats: small-group discussions, flipped classrooms with pre-reading, online asynchronous modules, or blended models combining in-person and digital activities.[5] A scoping review of online case-based learning in medical education emphasised its flexibility and scalability but also noted the importance of structure, facilitator presence, and clear learning objectives.[6] These principles are highly relevant for paediatric cardiology, where trainee numbers may be small and geographically dispersed.

Case-based learning in paediatric cardiology training

Integration into structured curricula

Our paediatric cardiology training curricula in Dublin explicitly incorporate case-based discussions as a core assessment and teaching modality (Figure 1), often alongside workplace-based assessments such as mini clinical evaluation exercise and direct observation of procedural skills.[7] For example, we have conducted several case-based learning sessions designed to push trainees within the zone of proximal development on topics such as heart failure, using cases building in complexity from left-to-right shunts to myocarditis/cardiomyopathy and the failing transplant patient. Case-based discussions are used not only to evaluate clinical reasoning but also to explore professionalism, communication, and systems issues.

Beyond formal assessments, case-based learning has been used to structure resident "academic half-day" teaching in cardiology and other subspecialties. In one report, paediatric residents participated in dedicated cardiology sessions built around representative cases, allowing uninterrupted interaction with subspecialty faculty and targeted bridging of knowledge gaps.[8]

At the subspecialty level, an interactive multimodal curriculum for paediatric cardiology fellows combined case-based conferences, imaging review, and board-style questions. Fellows reported improved engagement and knowledge, and pre-/post-testing suggested learning gains.[9]

A particularly notable development is the integration of clinical pathways with case-based learning in paediatric cardiology residency training. In a recent controlled study from China, trainees exposed to a combined clinical pathway–case-based learning model showed higher test scores, improved skills and greater satisfaction compared with traditional lecture-based teaching.[10] In this study, trainees were guided through cognitive reasoning steps reflective of real-world clinical practice, e.g., combining medical history and diagnostic test results to determine treatment approach (e.g., intervention versus surgery) and indications. In the CP-case-based learning group, 37.5% of trainees scored >90 points in the summative assessment, versus 4.3% of trainees in the traditional training group, highlighting this as a successful strategy to prepare trainees for clinical practice.

Simulation-enhanced case-based learning

Simulation has become central to paediatric and congenital cardiology education. Narrative reviews and curricula in congenital cardiology emphasise the value of simulation for rare, high-risk scenarios and for team training.[11] When simulation scenarios are explicitly framed as cases with pre-briefing, structured debriefing

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and linkage to evidence, they function as a powerful form of experiential case-based learning.

In a study embedding patient simulation within a paediatric cardiology curriculum, fellows participating in scenario-based simulations reported increased confidence and demonstrated modest improvements in clinical reasoning compared with traditional teaching.[12] Similarly, simulation-based courses have been used to teach communication skills, such as delivering serious news in paediatric cardiology, using scripted cases and structured feedback to enhance competence in high-stakes conversations.[13]

More recently, virtual reality-based simulation has been introduced for interprofessional education in paediatric cardiology. A 2025 study reported that virtual reality scenarios improved learners' self-reported understanding of CHD anatomy, interprofessional communication and procedural workflows.[14] When combined with facilitated case discussion, these technologies extend the reach of case-based learning into immersive, interactive environments.

Global and online case-based initiatives

Paediatric cardiology has also pioneered international case-based collaborations. The "Cardiology Across Continents" initiative, for example, hosts regular interactive sessions centred on challenging cases from resource-limited settings, connecting clinicians across institutions and countries.[15] These sessions highlight context-specific diagnostic and management dilemmas, broaden participants' perspectives on health systems and resource constraints, and support capacity building.

Such programmes align with broader evidence that online case-based learning can support distributed learners and continuing professional development, provided that cases are well curated and facilitation is active.[16] For paediatric cardiology, where expertise is concentrated in relatively few centres, online case conferences and digital case repositories can help democratise specialist knowledge.

Evidence for effectiveness

Although paediatric cardiology-specific case-based learning studies are fewer than in broader medical education, the emerging data are encouraging. The clinical pathway–case-based learning study in paediatric cardiology training demonstrated statistically significant improvements in written test performance, procedural skills and learner satisfaction compared with traditional teaching.[10] Multimodal case-based curricula for fellows have shown knowledge gains and high ratings for relevance and engagement.[9] Simulation-embedded case-based learning has been associated with increased confidence and improved performance in scenario-based assessments.[12]

Evidence for case-based learning in cardiovascular imaging

In relation to cardiovascular imaging, case-based approaches help trainees integrate image interpretation with clinical decision-making. Paediatric cardiology imaging training frameworks emphasise progressive exposure to CHD imaging cases, supervised interpretation, and demonstration of competency across echocardiography, cardiac MRI, and CT, recognising that expertise develops through guided interpretation and clinical integration rather than case numbers alone.[17]

Evidence for case-based learning in cardiac catheterisation and electrophysiology

Procedural simulation training is an exciting area for advancement of the case-based learning model, with the potential to enhance both knowledge acquisition and technical skills for cardiology trainees. In one prospective study, cardiology trainees underwent a teaching protocol facilitated by simulated cases over 18 months. Compared with controls, the intervention cohort had higher scores on the post-simulator written assessment, transvenous pacing wire skills assessment, and intra-aortic balloon pump skills assessment.[18] The direct literature on case-based learning specifically in EP fellowship training is comparatively sparse, leaving opportunities for further research.

Evidence for case-based learning in cardiac intensive care unit

Direct cardiac intensive care unit-specific case-based learning studies are limited; however, critical care education literature supports case-based learning when paired with simulation for improving teamwork, crisis management, and applied clinical reasoning.[19] Combining case-based learning with simulation training in a cardiac intensive care unit setting is an area for future development.

These findings are consistent with systematic reviews across health professions, which generally show moderate effect sizes favouring case-based learning over traditional lectures for knowledge and skills, as well as positive impacts on motivation and satisfaction.[2] Studies comparing blended models, such as case-based learning combined with task-driven learning or flipped-classroom approaches, suggest that integrating case-based learning with other active methods may further enhance outcomes.[20]

However, substantial heterogeneity remains in outcome measures, follow-up duration, and study quality. Long-term impacts on clinical performance, patient outcomes and systems-level indicators in paediatric cardiology are largely unknown and represent a key research gap.

Design considerations for effective case-based learning in paediatric cardiology

Based on the broader case-based learning literature and speciality-specific experience, several design principles emerge:

1. **Authentic, appropriately complex cases:** Cases should reflect the spectrum of paediatric cardiology practice, from common lesions (e.g., ventricular septal defects) to complex single-ventricle physiology, arrhythmias and cardiomyopathies. Progressively complex case series can scaffold learning across training levels.
2. **Alignment with competency-based curricula:** National and regional paediatric cardiology curricula emphasise competencies such as imaging interpretation, peri-operative management and lifelong follow-up. Mapping each case to specific competencies and entrustable professional activities ensures coherence and facilitates assessment.[21]
3. **Structured facilitation and faculty development:** Successful case-based learning requires skilled facilitators who can guide discussion, maintain psychological safety, and link cases to evidence and guidelines. Facilitator guides and faculty development programmes have been proposed to support this role.[1]

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4. **Integration with simulation and technology:** Pairing case discussions with echo and MRI image review, catheterisation tracings, or simulated procedures can deepen understanding. Virtual reality and high-fidelity simulation offer additional opportunities, particularly for rare emergencies and interprofessional collaboration.[12]
5. **Robust assessment and feedback:** Case-based assessments (e.g., structured case discussions, written cases, and OSCE-style stations) can evaluate reasoning and decision-making. Workplace-based assessments tied to real cases provide feedback in authentic settings.
6. **Attention to equity and global relevance:** International case-sharing initiatives illustrate how case-based learning can highlight resource-sensitive decision-making and ethical dilemmas.[15] Including cases from low- and middle-income settings helps prepare trainees for diverse practice environments.

Challenges and limitations of case-based learning

Implementing case-based learning at scale in paediatric cardiology faces several barriers:

1. **Time and workload:** Developing high-quality cases, facilitator materials, and assessments is resource-intensive. Faculty with clinical and research responsibilities may find it challenging to commit sufficient time.
2. **Faculty expertise and variability:** Not all experts are effective facilitators. Without training, discussions may revert to mini-lectures or lack sufficient structure, diluting the benefits of case-based learning.[1]
3. **Assessment alignment:** If high-stakes examinations emphasise factual recall over reasoning and application, learners may perceive case-based learning as less useful and consequently reduce their engagement.
4. **Technology and access:** Online and simulation-enhanced case-based learning require infrastructure, technical support, and reliable connectivity. In some settings, low-tech approaches (e.g., paper-based cases) may be more feasible, but this can limit interactivity and reach.[16]
5. **Evidence gaps:** Many studies are single-centre, use surrogate outcomes (test scores, self-reported confidence) and lack long-term follow-up. Robust, multi-centre evaluations in paediatric cardiology are still relatively scarce.

Addressing these challenges will require institutional support, faculty recognition for educational work, and collaboration across training programmes.

Future directions of case-based learning

Several trends suggest promising directions for case-based learning in paediatric cardiology:

1. **Hybrid and longitudinal case curricula:** Designing longitudinal case series that follow patients from fetal diagnosis through adolescence could help trainees appreciate the entire care continuum, including transition to adult congenital services.
2. **Integration with learning analytics and AI:** Digital case-based learning platforms can capture patterns of learner responses and reasoning. In the future, AI-supported systems might provide adaptive cases, tailored feedback, and automated scoring of written reasoning, while maintaining human oversight.
3. **Global case repositories and shared curricula:** International societies, training consortia and platforms such as Heart University are well placed to curate open-access case libraries, including imaging and procedural data, with annotations tied to competencies and guidelines.[22]
4. **Interprofessional and family-centred cases:** Cases involving cardiologists, intensivists, nurses, surgeons, psychologists and allied professionals can better reflect real practice. Including parent and patient perspectives, especially in communication and decision-making cases, may enhance empathy and shared decision-making skills.[11,13]
5. **Rigorous educational research:** Future studies should employ robust designs, including randomised or stepped-wedge trials where feasible, and track outcomes beyond knowledge such as clinical performance, team functioning and patient-centred metrics.

Conclusion

Case-based learning aligns closely with the cognitive and professional demands of paediatric cardiology. By situating knowledge within authentic patient narratives and encouraging active problem-solving, case-based learning can enhance clinical reasoning, integration of imaging and haemodynamic data, and communication within multidisciplinary teams. Emerging evidence from clinical pathway–case-based learning models, simulation-embedded curricula and international case conferences supports its effectiveness and acceptability among trainees.

To fully realise the potential of case-based learning in paediatric cardiology, programmes must invest in faculty development, curricular alignment, and high-quality case design, while leveraging technology to extend reach and interactivity. Collaborative research and shared case resources across institutions will be crucial. As the complexity of paediatric cardiovascular care continues to grow, well-implemented case-based learning offers a flexible, patient-centred and evidence-informed approach to preparing the next generation of paediatric cardiologists.

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