The Perceived Effectiveness of Various Forms of Feedback on the Acquisition of Technical Skills by Advanced Learners in Simulation-Based Health Professions Education

by

Julia Micallef

A thesis submitted to the
School of Graduate and Postdoctoral Studies in partial
fulfillment of the requirements for the degree of

Master of Health Sciences in Health Informatics

Faculty of Health Sciences

University of Ontario Institute of Technology (Ontario Tech University)

Oshawa, Ontario, Canada

AUGUST 2023

THESIS EXAMINATION INFORMATION

Submitted by: **Julia Micallef**

Health Informatics in **Health Sciences**

Thesis title: The Perceived Effectiveness of Various Forms of Feedback on the Acquisition of Technical Skills by Advanced Learners in Simulation-Based Health Professions Education

An oral defense of this thesis took place on August 2nd, 2023 in front of the following examining committee:

Examining Committee:

Chair of Examining Committee	DR. NICK WATTIE
Research Supervisor	DR. ADAM DUBROWSKI
Examining Committee Member	DALE BUTTON
Thesis Examiner	DR. BERNADETTE MURPHY

The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

Simulation-based health professions education is valuable for healthcare professionals to develop technical skills. However, little research has explored the effectiveness of augmented versus intrinsic feedback for advanced learners. This thesis aimed to determine what feedback type is perceived to be most effective by advanced care paramedics airing intraosseous access skills using simulation. Following the Design-Based Research framework, design-thinking and Delphi methods were used to generate a list of augmented feedback. In the test phase, paramedics received the augmented feedback and compared it to their intrinsic feedback while using the simulator, and in the evaluate phase, they ranked the feedback types. The results indicate that knowledge of performance was perceived as most effective, followed by intrinsic, and knowledge of results was perceived as least effective. This research provides insights into augmented and intrinsic feedback in simulation-based health professions education, but further work is needed to assess their actual learning effects.

Keywords: simulation; health professions education; augmented feedback; intrinsic feedback; technical skill acquisition

AUTHOR'S DECLARATION

I hereby declare that this thesis consists of original work of which I have authored. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I authorize the University of Ontario Institute of Technology (Ontario Tech University) to lend this thesis to other institutions or individuals for the purpose of scholarly research. I further authorize University of Ontario Institute of Technology (Ontario Tech University) to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research. I understand that my thesis will be made electronically available to the public.

The research work in this thesis was performed in compliance with the regulations of Durham College Research Ethics Board under **REB Certificate number 241-2122.**

Julia Micallef

JULIA MICALLEF

STATEMENT OF CONTRIBUTIONS

Part of the work described in both Chapter 4 and Chapter 5 have been published or accepted in Cureus as:

Micallef, J., Button, D., Uribe Quevedo, A., McClatchey, C., King, L., & Dubrowski, A. (2023). Defining the Nature of Augmented Feedback for Learning Intraosseous Access Skills in Simulation-Based Health Professions Education. *Cureus*, *15*(7): e41869. doi:10.7759/cureus.41869

Micallef, J., Button, D., Uribe Quevedo, A., McClatchey, C., King, L., & Dubrowski, A. [in press]. The Perceived Effectiveness of Various Forms of Feedback on the Acquisition of Technical Skills by Advanced Learners in Simulation-Based Health Professions Education. *Cureus*, (): e. doi:10.7759/cureus.

I performed the majority of the synthesis, testing, and writing of these manuscripts.

ACKNOWLEDGEMENTS

First and foremost, I have to thank my supervisor, Dr. Adam Dubrowksi. I have come a long way since just being "Artur's girlfriend" when I joined maxSIMhealth many years ago – and this is all thanks to your guidance and support. During this time, you have allowed me to develop into my own person, leader, and researcher by pushing me to do things that I didn't think I was even capable of, and for that, I am extremely grateful. It has truly been an honor and privilege to learn from you, and I cannot wait to continue to do so in my doctoral studies. I can only hope that one day I may have the same impact that you have on your students! I would also like to thank my committee member, Dale Button, who helped guide me in the world of paramedicine. I am very thankful to have a committee member who was so supportive and willing to help over these past two years. I must also thank the Faculty of Health Sciences at Ontario Tech University and the Natural Sciences and Engineering Research Council of Canada (NSERC) for believing in me and allowing me to pursue my research. Additionally, I want to thank The Region of Durham Paramedic Services for your help in completing this work.

I must also express my overwhelming gratitude to my friends and family. To my parents, Keith and Antonella, and my brothers, Anthony and Daniel, thank you for listening to me complain, encouraging me when I felt like giving up, and for your endless love and support – I love you all very much! To Krystina and Dania, you guys were at the front line of this with me and I am so grateful to have met you both in this crazy world of academia. Neither of you ever let me get away without taking the time to celebrate the little (and big) milestones – I am forever grateful for your kindness and friendship. To my friends Chelsea, Melissa, and Sofia, your unwavering faith in me since we met in kindergarten has given me the drive and confidence to do anything I set my mind to. You have all shaped me into the person I am today, and I am so lucky to have you all in my life. Finally, I must thank the person who introduced me to the world of simulation, my boyfriend, Artur – I honestly do not know what I would have done without you. Thank you for pushing me to try new things, believing in me when I did not believe in myself, and supporting me through it all. Thank you to everyone who contributed and supported this work, I couldn't have done it without you!

TABLE OF CONTENTS

Thesis Examination Information ii

Abstract iii

Authors Declaration iv

Statement of Contributions… v

Acknowledgements vi

Table of Contents vii

List of Tables x

List of Figures. xi

List of Abbreviations and Symbols xii

Chapter 1 General Introduction 1

1.1 Background 1

1.2 References 9

Chapter 2 Theoretical Underpinnings 14

2.1 Simulation Health Professions Education 15

2.1.1 Instructional Design and Simulation Modality. 16

2.1.2 Instructional Method… 17

2.1.3 Presentation 17

2.2 Applied Research Setting. 18

2.2.1 Learner… 18

2.2.2 Skill… 19

2.3 Measuring the Perception of Learning 19

2.4 Research Gap… 20

2.5 Thesis Objectives… 21

2.6. References 21

Chapter 3 General Methods 25

3.1 Guiding Framework. 25

3.2 General Methodology… 26

3.2.1 Design Phase (Study 1) 26
3.2.2 Test and Evaluate Phases (Study 2) 27
3.3 References. 27

Chapter 4 Study 1 - *Defining the Nature of Augmented Feedback for Learning Intraosseous Access Skills in Simulation Based Health Professions Education*....... 30
4.1 Introduction 30
4.2 Materials and Methods. 31
4.2.1 Design-Based Research… 32
4.2.2 DT-Delphi Hybrid 33
4.2.3 Design-Thinking Process 33
4.2.4 Delphi Process 34
4.3 Results… 35
4.3.1 Design-Thinking Session. 35
4.3.2 Delphi Rounds… 37
4.4 Discussion. 45
4.5 Conclusion. 47
4.6 References 47

Chapter 5 Study 2 - *The Perceived Effectiveness of Augmented versus Intrinsic Feedback on the Acquisition of Technical Skills in Simulation-Based Health Professions Education*.......... 50
5.1 Introduction 50
5.2 Materials and Methods. 51
5.2.1 Participants 52
5.2.2 Procedure 52
5.2.3 Variables of Interests and Data Analysis 56
5.3 Results… 56

5.3.1 Relationship between experience and choices of perceived effectiveness of feedback 59
5.3.2 Self-Efficacy of Simulation Environment 59
5.3.3 Perceived Effectiveness of Feedback Data 61
5.3.4 Instructor Perspectives on Learning Experience 64
5.4 Discussion. 65
5.5 Conclusion. 67
6.6 References 67

Chapter 6 Discussion..70
6.1 Summary… 70
6.2 Interpretation and Implication of Results 71
6.3 Limitations and Future Directions..76
6.4 Conclusion..76
6.5 References. 76

LIST OF TABLES

CHAPTER 4

Table 4.1: IO Skills Checklist…..36

Table 4.2: List of IO access steps converted in the form of KP and KR…..........................37

Table 4.3: Results for Delphi round 1…..38

Table 4.4: Comments from Delphi Round 1…...40

Table 4.5: Updated steps based on results of Delphi Round 1…..42

Table 4.6: Results from Delphi round 2…..42

Table 4.7: Comments from Delphi Round 2…...43

Table 4.8: Final list of steps with feedback in forms of KP and KR…..............................45

CHAPTER 5

Table 5.1: Survey for Participants...55

Table 5.2: Survey for Instructors...55

Table 5.3: Significance of correlations of the independent variables with the dependent variables 59

Table 5.4: Self-Efficacy data with outliers as medians... 60

Table 5.5: Most effective versus least effective feedback and Chi-Square analysis.........61

Table 5.6: Themes and supporting quotes...63

LIST OF FIGURES

CHAPTER 1

Figure 1.1: The three stages of learning technical skills; instructions, practice, and feedback… 5

Figure 1.2: Highlight of instructions when learning technical skills. 6

Figure 1.3: Highlight of practice when learning technical skills… 6

Figure 1.4: Highlight of the different types of feedback when learning technical skills… ... 9

CHAPTER 2

Figure 2.1: The Pasteur Quadrant….. 14

Figure 2.2: Framework for developing the instructional design of simulation health professions education……………………………………………………………………..16

CHAPTER 3

Figure 3.1: Design-Based Research Framework..25

CHAPTER 4

Figure 4.1: Situating the Design Thinking and Delphi methods within the Design-Based Research Framework 32

CHAPTER 5

Figure 5.1: Simulation Environment.. 53

Figure 5.2: Years as ACP as indicated by participants 56

Figure 5.3: Summary of the participants' count of estimated total of IOs performed in their career...57

Figure 5.4: Participants' last IO attempt Before Participation in Study............................58

Figure 5.5: The participants' perceived level of confidence in performing IOs 58

LIST OF ABBREVIATIONS AND SYMBOLS

IO	intraosseous
ACPs	advanced care paramedics
HPE	health professions education
KR	knowledge of results
KP	knowledge of performance
SBHPE	simulation-based health professions education
3D	three-dimensional
DBR	Design-Based Research
DT	design-thinking
X^2	Chi- Square
DoF	Degrees of Freedom

Chapter 1. General Introduction

1.1 Background

When paramedics come across a patient in the field that is critically ill or suffering from a cardiac arrest that requires them to perform an intraosseous (IO) infusion, they think back to their past experiences and training in dealing with traumas to know what to do. This recall of information is known as schema theory where a group of memories and concepts (schemas) are stored in our long-term memory and can be brought up when something reminds us of the schema (Schmidt, 1975). However, just as the common saying "use it or lose it" goes, if the schemas are not being actively recalled, the details begin to get a bit fuzzy, and the schema will begin to fade (Schmidt, 1975). While this may not always be a problem for those who perform the skills routinely, for experienced healthcare professionals who do not perform a skill very often, this could be dire as their motor program decays. Therefore, experienced professionals, such as advanced care paramedics (ACPs) need to refresh their psychomotor skills through re-training and practice to maintain and fine-tune their schemas on how to perform IO infusions (Schmidt, 1975).

Therefore, the aim of this work was to assess the perceived effectiveness of different forms of feedback in the context of ACPs practicing their IO infusion skills using a simulator. To understand how experienced paramedics should practice retaining skills related to IO infusions, we need to understand what type of skills IO skills are. This is because learning and maintenance of different types of skills (e.g., cognitive, affective, and psychomotor) requires different educational approaches. For example, Bloom's Taxonomy is an educational hierarchical framework conceived by Benjamin Bloom, an educational psychologist, and his colleagues during the 1950s (Bloom, 1956). This framework proves valuable in connecting the IO-associated abilities with the most effective methods of learning. It comprises three domains of learning, each representing distinct categories of knowledge and skills attainable by individuals (Bloom, 1956). Commonly known as the cognitive, affective, and psychomotor domains, each encompasses a vast array of learning objectives (Bloom, 1956).

Cognitive Domain: The cognitive domain pertains to intellectual capacities and cognitive processes (Athanassiou et al., 2003). It is categorized into six levels of complexity, ranging from the fundamental recall of information to advanced higher-order thinking skills. These levels include:

- Knowledge: The capacity to recall or recognize information
- Comprehension: The grasp and interpretation of concepts.
- Application: The utilization of knowledge in novel situations or problem-solving.
- Analysis: The deconstruction of complex ideas into smaller components and understanding their relationships.
- Synthesis: The integration of diverse elements to generate innovative ideas or products.
- Evaluation: The formation of judgments based on criteria and evidence.

Affective Domain: The affective domain encompasses the emotional, attitudinal, and value-based aspects of learning (Wu et al., 2019). It centers on the cultivation of beliefs, motivations, and emotional responses within an individual (Wu et al., 2019). The levels within this domain follow a hierarchical structure but do not necessarily occur in a sequential order:

- Receiving: Being receptive and open to new information and ideas.
- Responding: Displaying an active willingness to participate and engage in the learning process.
- Valuing: Adopting attitudes or values that align with the newly acquired information or experiences.
- Organization: Integrating these new values or beliefs into one's existing value system.
- Characterization: Internalizing the values to the extent that they become ingrained in one's behavior and identity.

Psychomotor Domain: The psychomotor domain encompasses physical abilities and coordination, emphasizing the development of manual or physical skills, often pertinent to vocational or technical training (Begam & Tholappan, 2018). The levels within this domain progress from fundamental to more intricate skills:

- Perception: Sensory awareness and recognition of stimuli.
- Readiness: Preparing oneself to perform a skill.
- Guided Response: Following instructions or imitating a model to execute a skill.
- Mechanism: Performing a learned skill with improved efficiency and coordination.
- Complex Overt Response: Proficiently executing a skill in a controlled environment.
- Adaptation: Modifying or adjusting a skill to suit different situations.
- Origination: Creating new movements or skills by combining existing ones.

Bloom's Taxonomy has found extensive application in education, aiding the design of instructional objectives, assessments, and curriculum development (Athanassiou et al., 2003). It offers educators a structured framework to plan learning activities that advance from foundational knowledge acquisition to higher order thinking and practical application (Athanassiou et al., 2003; Wu et al., 2019). By incorporating all three domains—cognitive, affective, and psychomotor—educators can ensure a comprehensive approach to learning that encompasses knowledge, skills, attitudes, and values (Wu et al., 2019). It is worth noting that the domains of learning in Bloom's Taxonomy are not mutually exclusive, often intersecting and interacting with one another in various learning scenarios. For instance, resolving a complex problem (cognitive domain) may necessitate collaboration and teamwork (affective domain), as well as the application of physical abilities (psychomotor domain). The taxonomy serves as a guide for educators to promote a well-rounded and balanced approach to learning, fostering the development of individuals with diverse capabilities (Wu et al., 2019). In the context of IO-related skills, which predominantly lie within the psychomotor domain, exploring psychomotor learning literature can inform the design of educational technologies and instructional factors aimed at skill maintenance.

Psychomotor skills are movement tasks that contain both cognitive and motor processes. These processes, in turn, often lead individuals to learn and manipulate the environment around them (Schmidt et al., 2019). In many procedure-oriented professions, such as health care professionals, being able to develop psychomotor skills is the main learning outcome (Changiz et al., 2021). In the context of health professions education (HPE), psychomotor skills are often referred to as technical skills, and they are tasks that are performed by health professionals to the patient (Dubrowski & Backstein, 2004). For the remainder of this thesis, I will refer to these skills as technical skills. HPE is a small sector of the educational system where learning is embedded within the healthcare system, converging the fields of education and healthcare with knowledge and practice (Hays et al., 2020). Unlike knowledge, skills, and attitudes related to cognitive and affective domains of learning (Bloom, 1956), which can be developed through didactic teaching, technical skills require a hands-on component (Dubrowski & Backstein, 2004). Simulation, defined as the imitation of real-world experiences (Banks, 1999), is an effective training modality to develop these skills (Kothari et al., 2017). The general principles of skills acquisition are described in this section, and later on, will focus specifically on the description of simulation-based health professions education.

Applying Schmidt's (2019) definition of psychomotor learning to technical skill learning, it can be defined as, "a set of processes associated with practice or experience leading to relatively permanent changes in the capability for skilled movement" (Schmidt et al., 2019, p. 410). Although technical skills are largely related to movement-oriented activities when teaching these skills there needs to be an integration of the knowledge and values (cognitive) with the physical movement (motor) (Oermann, 1990). The overarching theory which guides this is called Deliberate Practice which explains that learning technical skills goes beyond just practicing a skill but requires elements of instruction and feedback (Chiniara et al., 2013; Dubrowski & Backstein, 2004; Dubrowski et al., 2021; Ericsson, 2004). This is shown in Figure 1.1 below. The instructions and feedback stages help develop the cognitive elements of technical skills while the practice stage allows the learner to develop the motor elements of technical skills.

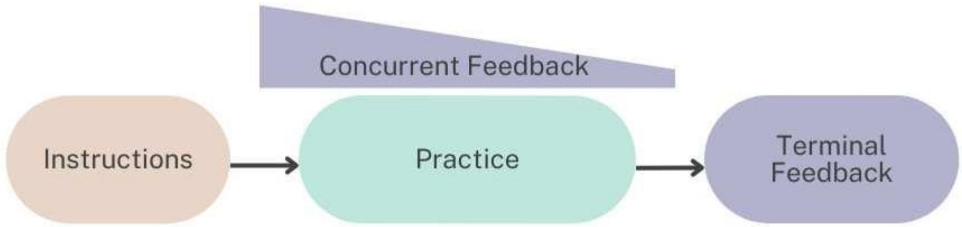

Figure 1.1: The three stages of learning technical skills; instructions, practice, and feedback.

Instructions are the information provided that tells the learners about the skill and what the mechanical principles are that are needed to perform the skill (Schmidt et al., 2019). As a result, instructions shape the cognitive component of technical skills. This information can come from peers, instructors, and instructional materials (i.e., videos, instructional guides, etc.), as indicated in Figure 1.2 (Popp et al., 2020). With instructions, the information is usually presented to the learner verbally, before physically performing the skill (Schmidt et al., 2019). The verbal information will provide learners with details about the skill and the mechanical principles underlying the skill (Schmidt et al., 2019). An effective and commonly used instructional method for technical skill acquisition in HPE is Peyton's Four Step approach (Giacomino et al., 2020; Walker & Peyton, 1998). This approach outlines four steps to providing instructions for procedural skill acquisition in HPE; 1) Demonstration, 2) Deconstruction, 3) Comprehension, and 4) Performance. In the demonstration step, the teacher demonstrates the procedure in real-time. In the deconstruction step, the teacher breaks down the procedure into sub-steps. In the comprehension step, the students take the forefront and talk the teacher through the procedure. In the final performance step, the student carries out the procedure themselves (Giacomino et al., 2020; Walker & Peyton, 1998). Once instructed on the skill, the learners need to practice.

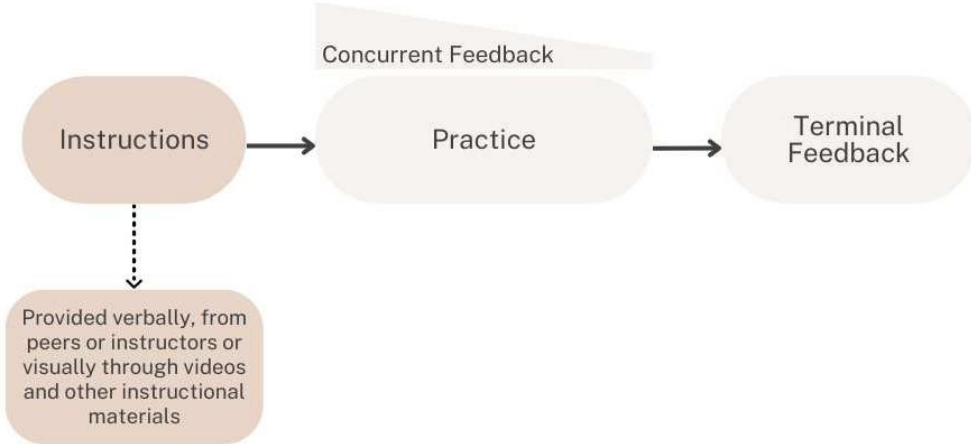

Figure 1.2: Highlight of instructions when learning technical skills

Practice, highlighted in Figure 1.3, is an active process in which an individual is actively attempting to perform a task with the intent of acquiring a new skill so that there is a permanent change in habit (Schmidt et al., 2019). According to Guadagnoli and Lee's (2004) Optimal Challenge Point Framework, there is an optimal practice difficulty where a learner learns optimally. This framework proposes that the relationship between the learner and the learning environment needs to be fluid - as the learner improves, the environment needs to be progressively more challenging (Guadagnoli et al., 2012; Guadagnoli & Lee, 2004). Throughout and after practice, feedback must then be provided.

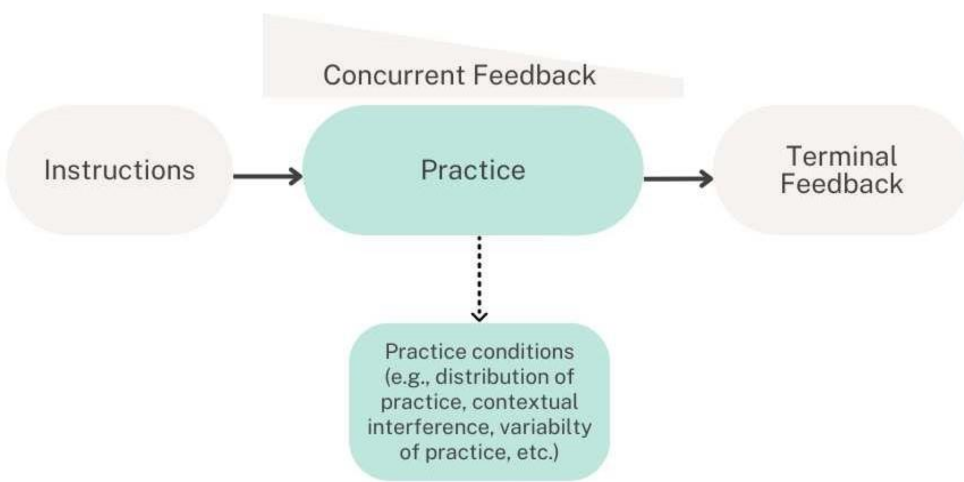

Figure 1.3: Highlight of practice when learning technical skills

Although the nature of both instructions and practice sessions impacts the skills acquisition process, the focus of this thesis is on the nature of feedback that is provided to advanced learners during their maintenance practice sessions. Feedback is defined as information that is given before, during, and after an action has occurred (Schmidt et al., 2019). Feedback given during action is known as concurrent feedback, which is controversial regarding its effectiveness. With novice learners, concurrent feedback may be beneficial if they do not remember certain steps in performing a technical skill (Hadden, 1998). However, providing concurrent feedback can pose a cognitive overload on the learner where too much information is presented to them at one moment resulting in sub-optimal learning (Walsh et al., 2009; Li et al., 2011). An alternative to concurrent feedback is terminal feedback, which is provided to learners after the action has occurred and has been shown to be more effective in learning technical skills (Salmoni et al., 1984; Schmidt et al., 2019).

In addition to the temporal classification of feedback (i.e., when it is obtained by the learner), feedback can also be classified in terms of how it is obtained; 1) inherent feedback and 2) augmented feedback. Inherent feedback is defined as the information that is naturally understood and gathered through our senses (Schmidt et al., 2019). For example, when a basketball player makes a free throw, they will be able to immediately see whether they got the ball in or not, and therefore know whether they were successful in performing the task or not. While this is an example of how errors in performance are very clearly detected inherently by the learner, the reasoning for the error is not as easy to understand. This is because inherent feedback depends on the learner's reference to correctness, which is learned over time (Schmidt et al., 2019). Augmented feedback, on the other hand, refers to additional information or cues provided to learners about their performance during or after movement execution (Schmidt et al., 2019). It is also known as extrinsic feedback because it comes from an external source, such as a coach, instructor, educator, or technology, rather than from the individual's senses. Augmented feedback serves several purposes in motor learning. First, it provides learners with information about the quality, accuracy, or effectiveness of their performance. This feedback helps them understand how well they are executing a particular skill or movement. It also highlights errors or deviations from the desired performance. By identifying mistakes, learners can focus on specific areas for improvement and make necessary adjustments. Furthermore, it provides positive reinforcement to correct or successful performance, providing motivation and encouragement to learners. It can boost confidence and reinforce desirable movement patterns. It can guide learners by providing information about the specific aspects of their performance that need attention. Finally, it can direct their focus to critical elements or cues related to the skill.

Additionally, augmented feedback can be further subdivided into two main dimensions: knowledge of results (KR) and knowledge of performance (KP). KR informs learners about the outcome or consequences of their performance. It includes objective measures such as time, distance, or score, helping learners evaluate their progress and set goals. For example, the basketball player's coach may provide feedback on where the ball hit the backboard to provide an explanation as to why the ball did or did not go into the net. When KR was provided to participants involved in an arm-positioning task, they performed better than the group who did not receive KR, therefore proving that KR helps the learning process (Bilodeau et al., 1959). On the contrary, KP provides information about the technique, form, or execution of the movement itself. It helps learners understand how they performed the skill and provides guidance on adjustments or refinements (Schmidt et al., 2019). This is where the basketball coach would provide feedback regarding the basketball player's form while making the free throw. In a study by Sharma et al. (2016), when comparing KP and KR in a motor skill learning task, both KP and KR being provided led to improvements, however, there was a significant improvement for the group that received KP. These different types of feedback are highlighted in Figure 1.4, and the different types of terminal feedback are going to be the focus of this thesis.

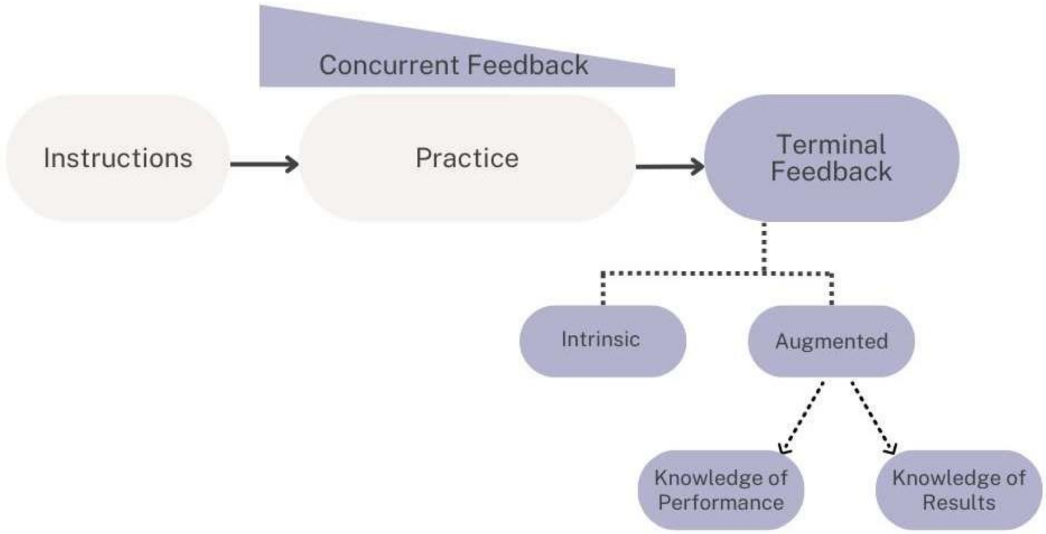

Figure 1.4: Highlight of the different types of feedback when learning technical skills

In summary, augmented feedback can be delivered in various ways, including verbal cues, visual displays, video analysis, or haptic feedback. It can be provided immediately after each trial (concurrent feedback) or after a series of trials (terminal feedback). The timing and frequency of augmented feedback depend on the learner's stage of skill acquisition, task complexity, and individual needs. Finally, and what is most important to this thesis, the nature of the augmented feedback (KR vs. KP) may impact skills acquisition and maintenance. Furthermore, to the best of my knowledge, the role of intrinsic feedback versus the two types of augmented feedback (i.e., KP and KR) has not been addressed in the design of maintenance protocols for advanced learners, such as APCs, practicing and reinforcing complex psychomotor skills such as IO insertion. Therefore, this gap was addressed by the work described in this thesis.

1.2 References

Athanassiou, N., McNett, J. M., & Harvey, C. (2003). Critical Thinking in the Management Classroom: Bloom’s Taxonomy as a Learning Tool. *Journal of Management Education*, *27*(5), 533–555. https://doi.org/10.1177/1052562903252515

Banks, J. (1999, December). Introduction to simulation. In *Proceedings of the 31st conference on Winter simulation: Simulation---a bridge to the future-Volume 1* (pp. 7-13).

Begam, A. A. A., & Tholappan, A. (2018). Psychomotor domain of Bloom's taxonomy in teacher education. *Shanlax International Journal of Education*, *6*(3), 11-14. https://doi.org/10.5281/zenodo.1299766

Bilodeau, E. A., Bilodeau, I. M., & Schumsky, D. A. (1959). Some effects of introducing and withdrawing knowledge of results early and late in practice. *Journal of experimental psychology*, *58*(2), 142. https://doi.org/10.1037/h0040262

Bloom, B. (1956). *Bloom's taxonomy.*

Brydges, R., Carnahan, H., Backstein, D., & Dubrowski, A. (2007). Application of motor learning principles to complex surgical tasks: searching for the optimal practice schedule. *Journal of motor behavior, 39*(1), 40–48. https://doi.org/10.3200/JMBR.39.1.40-48

Changiz, T., Amouzeshi, Z., Najimi, A., & Adibi, P. (2021). A narrative review of psychomotor abilities in medical sciences: Definition, categorization, tests, and training. *Journal of research in medical sciences : the official journal of Isfahan University of Medical Sciences*, *26*, 69. https://doi.org/10.4103/jrms.JRMS_965_19

Chiniara, G., Cole, G., Brisbin, K., Huffman, D., Cragg, B., Lamacchia, M., Norman, D., & Canadian Network For Simulation In Healthcare, Guidelines Working Group (2013). Simulation in healthcare: a taxonomy and a conceptual framework for instructional design and media selection. *Medical teacher*, *35*(8), e1380–e1395. https://doi.org/10.3109/0142159X.2012.733451

Dubrowski, A., Kapralos, B., Peisachovich, E., Da Silva, C., & Torres, A. (2021). A Model for an Online Learning Management System for Simulation-Based Acquisition of Psychomotor Skills in Health Professions Education. *Cureus, 13*(3), e14055. https://doi.org/10.7759/cureus.14055

Dubrowski, A., & Backstein, D. (2004). The contributions of kinesiology to surgical education. The Journal of bone and joint surgery. *American volume*, *86*(12), 2778–2781. https://doi.org/10.2106/00004623-200412000-00029

Ericsson, K. A. (2004). Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Academic medicine, 79*(10), S70 S81.

Giacomino, K., Caliesch, R., & Sattelmayer, K. M. (2020). The effectiveness of the Peyton's 4-step teaching approach on skill acquisition of procedures in health professions education: A systematic review and meta-analysis with integrated meta-regression. *PeerJ,* 8, e10129. https://doi.org/10.7717/peerj.10129

Guadagnoli, M., Morin, M. P., & Dubrowski, A. (2012). The application of the challenge point framework in medical education. *Medical education, 46*(5), 447-453. https://doi.org/10.1111/j.1365-2923.2011.04210.x

Guadagnoli, M. A., & Lee, T. D. (2004). Challenge point: a framework for conceptualizing the effects of various practice conditions in motor learning. *Journal of motor behavior, 36*(2), 212-224. https://doi.org/10.3200/JMBR.36.2.212-224

Hadden, C.M. (1998). Concurrent vs. Terminal Augmented Feedback in the Learning of a Discrete Bimanual Coordination Task. *LSU Historical Dissertations and Theses, 6735*. doi:10.31390/gradschool_disstheses.6735

Hays, R. B., Ramani, S., & Hassell, A. (2020). Healthcare systems and the sciences of health professional education. *Advances in health sciences education : theory and practice, 25*(5), 1149–1162. https://doi.org/10.1007/s10459-020-10010-1

Johnson, G. G. R. J., Park, J., Vergis, A., Gillman, L. M., & Rivard, J. D. (2022). Contextual interference for skills development and transfer in laparoscopic surgery: a randomized controlled trial. *Surgical endoscopy, 36*(9), 6377–6386. https://doi.org/10.1007/s00464-021-08946-5

Kothari, L. G., Shah, K., & Barach, P. (2017). Simulation based medical education in graduate medical education training and assessment programs. *Progress in Pediatric Cardiology, 44*, 33-42. https://doi.org/10.1016/j.ppedcard.2017.02.001

Li, Q., Ma, E. L., Liu, J., Fang, L. Q., & Xia, T. (2011). Pre-training evaluation and feedback improve medical students' skills in basic life support. *Medical teacher, 33*(10), e549-e555. https://doi.org/10.3109/0142159X.2011.600360

Oermann, M. H. (1990). Psychomotor skill development. *The Journal of Continuing Education in Nursing*, *21*(5), 202-204. https://doi.org/10.3928/0022-0124 19900901-05

Ruch, T. C. (1928). Factors influencing the relative economy of massed and distributed practice in learning. *Psychological Review*, 35(1), 19.

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin*, *95*(3), 355 386. https://doi.org/10.1037/0033-2909.95.3.355

Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological review*, *82*(4), 225.

Sharma, D. A., Chevidikunnan, M. F., Khan, F. R., & Gaowgzeh, R. A. (2016). Effectiveness of knowledge of result and knowledge of performance in the learning of a skilled motor activity by healthy young adults. Journal of physical therapy science, 28(5), 1482–1486. https://doi-org.uproxy.library.dc uoit.ca/10.1589/jpts.28.1482

Shea, J. B., & Morgan, R. L. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory*, *5*(2), 179–187. https://doi.org/10.1037/0278 7393.5.2.179

Shea, C. H., & Kohl, R. M. (1990). Specificity and variability of practice. *Research quarterly for exercise and sport*, *61*(2), 169-177. https://doi.org/10.1080/02701367.1990.10608671

Smith, S. M., & Rothkopf, E. Z. (1984). Contextual enrichment and distribution of practice in the classroom. *Cognition and Instruction*, *1*(3), 341-358.

Walker, M., & Peyton, J. W. R. (1998). Teaching in theatre. Teaching and learning in medical practice. *Rickmansworth, UK: Manticore Europe Limited*, 171-180

Walsh, C. M., Ling, S. C., Wang, C. S., & Carnahan, H. (2009). Concurrent versus terminal feedback: it may be better to wait. *Academic Medicine*, *84*(10), S54-S57. doi: 10.1097/ACM.0b013e3181b38daf

Wu, W. H., Kao, H. Y., Wu, S. H., & Wei, C. W. (2019). Development and evaluation of affective domain using student's feedback in entrepreneurial Massive Open

Online Courses. *Frontiers in psychology, 1109*.
https://doi.org/10.3389/fpsyg.2019.01109

Chapter 2. Theoretical Underpinnings

In 1997, Donald Stokes, a political scientist, in his book "Pasteur's Quadrant: Basic Science and Technological Innovation" challenged the traditional linear model that separates basic research and applied research (Stokes, 1997). According to Stokes, the Pasteur Quadrant (shown in Figure 2.1) is a conceptual framework that classifies scientific research based on its potential for both fundamental understanding and practical application (Stokes, 1997). The quadrant is named after Louis Pasteur, a renowned scientist who made significant contributions to both fundamental scientific knowledge and practical applications (Stokes, 1997).

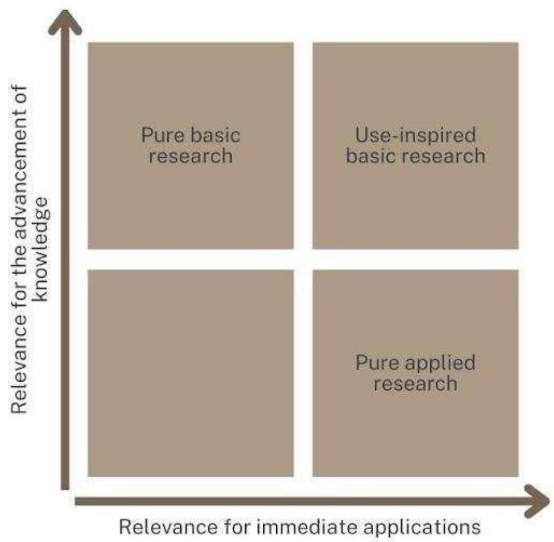

Figure 2.1: The Pasteur Quadrant

The Pasteur Quadrant consists of four quadrants, each representing a different combination of basic and applied research. The first quadrant is called “Pure Basic Research” and represents research driven primarily by curiosity and the pursuit of fundamental understanding without any immediate practical application in mind (Stokes, 1997). The aim is to expand scientific knowledge and explore new concepts or phenomena. Examples include theoretical physics, basic biological studies, and fundamental mathematical research. Next, the “Use-Inspired Basic Research” is a quadrant that combines a focus on fundamental understanding to address specific practical problems or needs (Stokes, 1997). Researchers in this quadrant seek to gain new insights and knowledge that can be applied to real-world challenges. This type of research is driven by a balance between curiosity-driven inquiry and a desire to solve practical problems (Stokes, 1997). Examples include research on new materials for energy applications or studying basic biological processes to develop medical treatments. “Pure Applied Research” is a quadrant where the primary objective is to develop practical solutions to specific problems or meet particular needs (Stokes, 1997). Researchers focus on finding immediate applications without necessarily seeking a deeper understanding of underlying principles. This type of research is often conducted by engineers, inventors, or industry scientists aiming to create new products or technologies (Stokes, 1997). Examples include developing new pharmaceutical drugs, designing innovative engineering systems, or improving manufacturing processes.

My work is situated in the “Use-Inspired Basic Research” quadrant as it seeks to test the application of feedback theory to design the most optimal simulated practice environment for advanced care paramedics to refresh and maintain skills related to performing an IO skill. Therefore, the anticipated contributions of this research are pragmatic in the sense that it will provide guidance on how to structure feedback when advanced care paramedics are practicing IO skills. However, it may also inform our fundamental understanding of the role of different forms of feedback when experienced and highly motivated learners practice complex skills in general. In the subsequent sections, I describe and operationally define key concepts and theories necessary related to this thesis.

2.1 Simulation-Based Health Professions Education

Simulation-based health professions education (SBHPE) uses simulation experiences to allow healthcare professionals to practice clinical skills without causing unnecessary patient harm (Kothari et al., 2017). In this context, simulation can employ models, actors, animal parts, digital technologies, as well as supplementary materials and scripts to create an immersive, replicable, and standardized learning environment (Kothari et al., 2017), known as simulation modalities. Therefore, using SBHPE to amplify HPE can be a very effective tool that can target instructions, practice, and feedback - the three elements of learning technical skills. Chiniara et al. (2013) have devised a framework to support the instructional design of SBHPE that consists of four levels; 1) instructional medium, 2) simulation modality, 3) instructional method, and 4) presentation, where each level progressively builds on the level prior. Figure 2.2 depicts this framework, and each of the levels will be explained in the following subsections.

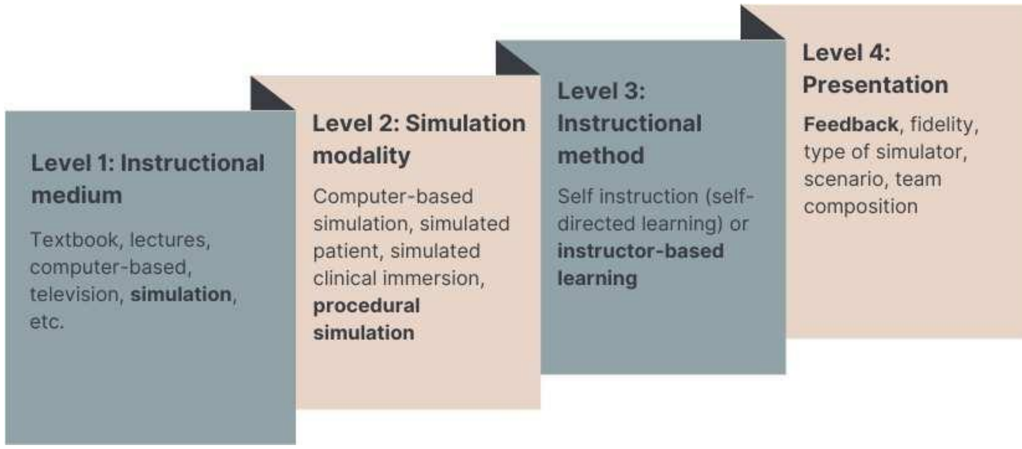

Figure 2.2: Framework for developing the instructional design of simulation health professions education.

2.1.1 Instructional Design and Simulation Modality

At the first level, the mode of delivery is determined, and for SBHPE that would be simulation in general. Next is to select the simulation modality. In the framework proposed by Chiniara et al. (2013), the various simulation modalities that can be used are computer-based simulation, simulated patient, simulated clinical immersion, procedural simulation, and a hybrid of each modality (Chiniara et al., 2013). Computer-based simulations provide a simulation experience through a computer, for example, virtual reality (Chiniara et al., 2013). Simulated patients utilize actors to replicate an encounter with an actual patient, while simulated clinical immersion exposes learners to a specific patient problem within the clinical/work environment (Chiniara et al., 2013). There are procedural simulations that focus on acquiring or improving technical skills by practicing the procedure on a simulation model (Chiniara et al., 2013). In this thesis, the use of procedural simulations is being used. Then, there can be a combination of any (or all) of these modalities to create a hybrid simulation. For example, augmented reality, which is the layering of the virtual world onto the real world, can be used alongside a simulation model to create a unique simulation experience through the combination of computer-based (augmented reality) and procedural (simulation model) simulation modalities.

2.1.2 Instructional Method

Simulations alone do not provide an effective means for training technical skills. They need to be accompanied by guidance and feedback from an expert to ensure the correct habits are formed. In line with level three of the SBHPE instructional design framework by Chiniara et al. (2013), there are two main instructional methods; 1) self-directed learning and 2) instructor-based learning. Self-directed learning gives learners the freedom to move through the instructional materials at their own pace and to set their own goals (Brydges et al., 2009; Chiniara et al., 2013). In a study by Brydges et al. (2009) which assessed the effectiveness of self-directed learning in learning technical skills, it was found that the learners that used self-guided learning showed greater technical skill retention compared to the control group. However, this benefit was only seen when the learners also set process goals in comparison to outcome goals (Brydges et al., 2009). This type of instructional method fits best with computer-based and procedural simulations (Chiniara et al., 2013). Alternatively, there is instructor-based learning which is the more dominant method of instruction for SBHPE and is also the instructional method that will be utilized in this thesis (Chiniara et al., 2013). As the name suggests, instructor-based learning utilizes the expertise of an instructor to supervise the learner while using the simulation (Chiniara et al., 2013).

2.1.3 Presentation

In level 4 of the SBHPE instructional design framework by Chiniara et al. (2013), presentation involves the characteristics that define how the SBHPE experience will be shaped and designed. These characteristics include simulator type and how that can alter the simulation experience. There is an importance placed on repetitive practice to effectively learn the motor element associated with technical skills (Chiniara et al., 2013; Micallef et al., 2020). Therefore, procedural simulators are ideal for practicing technical skills as learners can use the simulations as much as they need to get that hands-on practice without causing harm to an actual patient. In the past, there have been issues with simulators not being easily accessible due to the high expenses associated with attaining these simulators. However, using additive manufacturing (AM) techniques, such as three-dimensional (3D) printing, and silicone work, to create healthcare simulators provide a cost-effective solution for students to practice psychomotor skills (Barth et al., 2022; Micallef et al., 2022a; Micallef et al., 2022b; Micallef et al., 2021; Micallef et al., 2020; Sivanathan et al., 2022a; Sivanathan et al., 2022b). In this thesis, an IO access procedural simulator that was previously developed by Sivanathan et al. (2022b) was used.

In addition to the simulator type, another characteristic in line with Level 4 of Chiniara et al.'s (2013) framework is feedback. Feedback is one of the most important characteristics of SBHPE as it has a direct impact on learning (Chiniara et al., 2013; Schmidt et al., 2019). In SBHPE, feedback allows learners to reflect and set goals which enhance learning and allow for better skill acquisition (Chiniara et al., 2013). There are a few different ways that feedback can be provided in SBHPE. It can be provided to learners by their peers, an expert instructor, or a combination of the two (Dubrowski et al., 2021). Additionally, feedback can be provided in the form of checklists such as Global Rating Scales, as well as provided verbally in a free-form type of format (Pelletier et al., 2023). Despite feedback being one of the most important aspects of learning technical skills, it is unknown whether KP or KR is most effective within the context of SBHPE (Schmidt et al., 2019). Therefore, this work aims to assess the perceived effectiveness of KP, KR, and intrinsic feedback in learning technical skills related to technical clinical skills, specifically IO access performed by ACPs.

2.2 Applied Research Setting

2.2.1 Learner

ACPs are highly trained healthcare professionals who provide advanced medical care in emergency situations. Therefore, they undergo extensive training and education beyond the basic level of paramedic training to acquire advanced knowledge and skills to assess, diagnose, and treat a wide range of medical emergencies. Their advanced training enables them to handle complex medical conditions and make critical decisions to stabilize patients and optimize their chances of survival. As a result, ACPs are considered advanced learners as they have training and experience in critical technical skills, such as IO access skills, in comparison to novice learners who do not have the knowledge or experience in such technical skills. However, even advanced learners need to continuously learn or retrain their skills in order to maintain their schemas.

2.2.2 Skill

IO access is a procedure performed by ACPs that involves drilling a hollow bore needle into the medullary space of a bone to administer medicine (Jousi et al., 2019; Strandberg et al., 2019). IO access is typically performed when intravenous access is not available (Jousi et al., 2019). While the IO route is twice as successful compared to the IV route for critical patients, studies show that it is underutilized as many HPEs do not feel confident enough with IO access or are not familiar enough with the skill (Cheung et al., 2014; Ngo et al., 2009). Therefore, there is a need to familiarize HPEs with this potentially lifesaving technique, and SBPHE can be an excellent way to provide IO access education to SBHPE.

2.3 Measuring the Perception of Learning

Learning of technical skills can be measured directly through transfer or retention tests. These tests involve a period of time after the skill has been practiced where they do not perform the skill, then come back and based on memory, perform the same skill (retention) or the skill with some variability (transfer) (Schmidt et al., 2019). However, when this is impossible, learning can also be measured in terms of perceptions. Measuring the perception of learning involves assessing individuals' subjective beliefs, attitudes, and perceptions regarding their own learning experiences and outcomes. It focuses on understanding how learners perceive their own knowledge acquisition, skill development, and overall progress (Wilkinson & Cadogan, 2023). Several methods can be employed to measure the perception of learning, including self-reports and surveys, interviews, focus groups, and journals and reflections (Choi & Wong, 2019). In this thesis, I have used self-report surveys to assess the differences in perceived learning due to receiving different types of feedback. These surveys typically include Likert scale items or open-ended questions to assess learners' beliefs, attitudes, confidence levels, satisfaction, and perceived gains in knowledge or skills. Self-report surveys provide direct insight into learners' subjective experiences and can be administered before, during, or after a learning activity or course. I have selected this approach because of pragmatic reasons. First, because the participants are advanced learners and their availability in terms of numbers is small, each participant experienced each type of feedback during the practice. Therefore, they were asked to make perceptual relative comparisons. Second, these participants are busy practitioners who are not willing to sit through lengthy observational assessments, such as the Objective Structured Assessments of Technical Skills (Reznick et al., 1997). Such observational assessments are typically carried out by instructors or trained observers who can provide insights into learners' behaviors, engagement, and expressions during the learning process.

2.4 Research Gap

Research on augmented feedback in learning technical skills largely focuses on KR and not KP (Schmidt et al., 2019). This is because it is easier to measure the results of an action, compared to the performance itself, which usually requires a recording device to capture the movement (Schmidt et al., 2019). While it is assumed that these sources of feedback are equally effective for the learner, the comparison of KR and KP is also under-researched to make that definitive conclusion within the context of SBHPE (Schmidt et al., 2019). Additionally, these types of augmented feedback have not been compared with intrinsic feedback, and research in this field has only been conducted with novice learners, so there is a need to examine learning conditions and technical skill acquisition from the perspective of advanced learners (Oppici et al., 2021). This gap was filled in my work by testing the perceived effectiveness of KP, KR, and intrinsic feedback in training technical skills in a SBHPE environment. This research followed a design-based research approach to create a SBHPE environment consisting of an IO access simulator and feedback provided by instructors. Each of the participants (ACPs) received all three forms of feedback and then ranked which feedback they felt was most effective for them when training this skill using the IO access simulator. This gap is important to be filled as it informs the field of SBHPE about what type of augmented feedback is most effective in learning technical skills. This work also adds to the applied and fundamental field of psychomotor learning by providing more evidence about the effects of augmented feedback on learning technical skills in a SBHPE context, as this is still largely unknown. Additionally, research done regarding KP and KR only focuses on novice learners, therefore, this thesis provides a unique perspective from advanced learners which helps advance the field of how KP and KR affect the learning process.

2.5 Thesis Objectives

This thesis aims to discover what the perceived effectiveness of KP, KR, and intrinsic feedback are in training ACPs using an IO access simulator. Therefore, the research question addressed by this work is: *What type of feedback (i.e., KP, KR, or intrinsic) is perceived to be most effective when acquiring complex technical skills by advanced learners in the context of simulation-based training of IO skills by ACPs?* To address this overarching aim, two research sub-questions were developed, each of which was addressed by separate studies:

1) *Study 1: Can expert educators and paramedics agree on the definitions of two types of augmented feedback (KP and KR) in this context?* This was achieved by using a consensus-building approach with an expert panel through a hybrid of design thinking and Delphi methods to determine and reach a consensus on the steps involved in performing an IO access with the procedural simulator, and then determining how those steps can be said in the form of KP and KR.
2) *Study 2: Do the learners perceive one of these sources of augmented feedback to be more effective, when compared to intrinsic feedback?* This was accomplished by having ACPs use the procedural IO access simulator and receiving each of the types of feedback so they can compare which one they felt was most effective.

2.6. References

Barth, B., Arutiunian, A., Micallef, J., Sivanathan, M., Wang, Z., Chorney, D., Salmers, E., McCabe, J., & Dubrowski, A. (2022). From Centralized to Decentralized Model of Simulation-Based Education: Curricular Integration of Take-Home Simulators in Nursing Education. *Cureus, 14*(6): e26373. doi:10.7759/cureus.26373

Brydges, R., Carnahan, H., Safir, O., & Dubrowski, A. (2009). How effective is self guided learning of clinical technical skills? It's all about process. *Medical education, 43*(6), 507–515. https://doi.org/10.1111/j.1365-2923.2009.03329.x

Cheung, J. W., Rosenberg, H., & Vaillancourt, C. (2014). Barriers and facilitators to intraosseous access in adult resuscitations when peripheral intravenous access is not achievable. *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine, 21*(3), 250–256. https://doi.org/10.1111/acem.12329

Chiniara, G., Cole, G., Brisbin, K., Huffman, D., Cragg, B., Lamacchia, M., Norman, D., & Canadian Network For Simulation In Healthcare, Guidelines Working Group (2013). Simulation in healthcare: a taxonomy and a conceptual framework for instructional design and media selection. *Medical teacher, 35*(8), e1380–e1395. https://doi.org/10.3109/0142159X.2012.733451

Choi, Y. F., & Wong, T. W. (2019). High-fidelity simulation training programme for final-year medical students: implications from the perceived learning outcomes. *Hong Kong Medical Journal*, *25*(5), 392. https://doi.org/10.12809/hkmj197898

Dubrowski, A., & Backstein, D. (2004). The contributions of kinesiology to surgical education. *The Journal of bone and joint surgery. American volume*, *86*(12), 2778–2781.https://doi.org/10.2106/00004623-200412000-00029

Dubrowski, A., Kapralos, B., Peisachovich, E., Da Silva, C., & Torres, A. (2021). A model for an online learning management system for simulation-based acquisition of psychomotor skills in health professions education. *Cureus, 13*(3). doi:10.7759/cureus.14055

Faulkner, H., Regehr, G., Martin, J., & Reznick, R. (1996). Validation of an objective structured assessment of technical skill for surgical residents. *Academic medicine: journal of the Association of American Medical Colleges, 71*(12), 1363–1365. https://doi.org/10.1097/00001888-199612000-00023

Jousi, M., Björkman, J., & Nurmi, J. (2019). Point-of-care analyses of blood samples from intraosseous access in pre-hospital critical care. *Acta anaesthesiologica Scandinavica*, *63*(10), 1419–1425. https://doi.org/10.1111/aas.13443

Kothari, L. G., Shah, K., & Barach, P. (2017). Simulation based medical education in graduate medical education training and assessment programs. *Progress in Pediatric Cardiology*, *44*, 33-42. https://doi.org/10.1016/j.ppedcard.2017.02.001

Micallef, J., Sivanathan, M., Clarke, K. M., Habti, M., Bénard, F., Meloche-Dumas, L., Patocskai, E., & Dubrowski, A. (2022a). Development and Initial Assessment of a Novel and Customized Bile Duct Simulator for Handsewn Anastomosis Training. *Cureus*, *14*(11). doi:10.7759/cureus.31749

Micallef, J., Broekhuyse, A., Vuyyuru, S., Wax, R., Sridhar, K., Heath, J., Clarke, S., & Dubrowski, A. (2022b). Application of 3D Printing in Training Health Care Providers; The Development of Diverse Facial Overlays for Simulation-Based Medical Training. *Cureus*, *14*(7): e26637. doi:10.7759/cureus.26637

Micallef, J., Arutiunian, A., Hiley, J., Benson, A., & Dubrowski, A. (2021). The Development of a Cost-Effective Infant Intraosseous Infusion Simulator for Neonatal Resuscitation Program Training. *Cureus*, *13*(10): e18824. doi:10.7759/cureus.18824

Micallef, J., Arutiunian, A., & Dubrowski, A. (2020). The Development of an Intramuscular Injection Simulation for Nursing Students. *Cureus*, *12*(12), e12366. https://doi.org/10.7759/cureus.12366

Ngo, A. S., Oh, J. J., Chen, Y., Yong, D., & Ong, M. E. (2009). Intraosseous vascular access in adults using the EZ-IO in an emergency department. *International journal of emergency medicine*, *2*(3), 155–160. https://doi.org/10.1007/s12245 009-0116-9

Oppici, L., Dix, A., & Narciss, S. (2021). When is knowledge of performance (KP) superior to knowledge of results (KR) in promoting motor skill learning? A systematic review. *International Review of Sport and Exercise Psychology*, 1-25. https://doi.org/10.1080/1750984X.2021.1986849

Pelletier, F., Torres, A., Meloche-Dumas, L., Guérard-Poirier, N., Kaviani, A., Kapralos, B., Mercier, F., Dubrowski, A., & Patocskai, E. (2023). The Role of Collaborative Observational Practice and Feedback-Discourse to Promote Remote Acquisition of Technical Surgical Skills. *The Journal of surgical research, 288,* 372–382. https://doi.org/10.1016/j.jss.2023.02.006

Popp, N. J., Yokoi, A., Gribble, P. L., & Diedrichsen, J. (2020). The effect of instruction on motor skill learning. *Journal of Neurophysiology, 124*(5), 1449-1457. https://doi.org/10.1152/jn.00271.2020

Reznick, R., Regehr, G., MacRae, H., Martin, J., & McCulloch, W. (1997). Testing technical skill via an innovative "bench station" examination. *American journal of surgery*, *173*(3), 226–230. https://doi.org/10.1016/s0002-9610(97)89597-9

Schmidt, R. A., Zelaznik, H. N., Wulf, G., Winstein, C. J., & Lee, T. D. (2019). *Chapter 11: Augmented Feedback*. In Motor control and learning: A behavioral emphasis (6th ed.). Human Kinetics.

Sivanathan, M., Micallef, J., Clarke, K. M., Habti, M., Bénard, F., Meloche-Dumas, L., Patocskai, E., & Dubrowski, A. (2022a). Development and Initial Assessment of a Novel Customized Deep Laceration Simulator for Suturing Training. *Cureus, 14*(12). doi:10.7759/cureus.32213

Sivanathan, M., Micallef, J., Clarke, K. M., Gino, B., Joshi, S., Abdo, S., Buttu, D., Mnaymneh, M., Siraj, S., Torres, A., Brock, G., Pereira, C., & Dubrowski, A. (2022b). The Development and Initial End-Point User Feedback of a 3D-Printed Adult Proximal Tibia IO Simulator. *Cureus, 14*(5), e25481. doi:10.7759/cureus.25481

Stokes, D. E. (1997). *Pasteur's quadrant: Basic science and technological innovation.* Washington, DC: Brookings Institution Press.

Strandberg, G., Larsson, A., Lipcsey, M., & Eriksson, M. (2019). Comparison of Intraosseous, Arterial, and Venous Blood Sampling for Laboratory Analysis in Hemorrhagic Shock. *Clinical laboratory*, *65*(7). https://doi.org/10.7754/Clin.Lab.2019.181214

Wilkinson, E., & Cadogan, E. (2023). Radiographers' perceptions of first year diagnostic radiography students' performance following implementation of a simulation based education model. *Radiography, 29*(4), 721-728. https://doi.org/10.1016/j.radi.2023.05.002

Chapter 3. General Methods

3.1 Guiding Framework

This thesis work followed the Design-Based Research (DBR) framework (Figure 3.1) (Brown, 1992). DBR is an educational framework that explains an iterative process, focusing on the collaboration of researchers, stakeholders, and end-point users, to generate solutions (i.e., resources) that can be applied to specific learning contexts (Fahd et al., 2021; Wang & Hannafin, 2005). DBR contains four iterative phases; 1) Design, 2) Test, 3) Evaluate, and 4) Reflect (Scott et al., 2021). The design phase involves developing a solution that addresses both the theoretical and practical concerns of the problem (Edelson, 2002; Wang & Hannafin, 2005). The test phase involves implementing the solution in a real-world setting (Hoadley, 2004). The evaluation phase evaluates the effectiveness of the solution using evidence from endpoint users' learning (Barab & Squire, 2004; Anderson & Shattuck, 2012). Finally, the reflect phase involves a retrospective analysis of the DBR methodology and methods used in the prior phases (Cobb et al., 2003; Barab & Squire, 2004). To address the first research question, study 1 focused on the design phase. The methods used to accomplish this phase were a combination of Design-Thinking and Delphi. To address the second research question, study 2 focused on the testing and evaluation phases of the DBR.

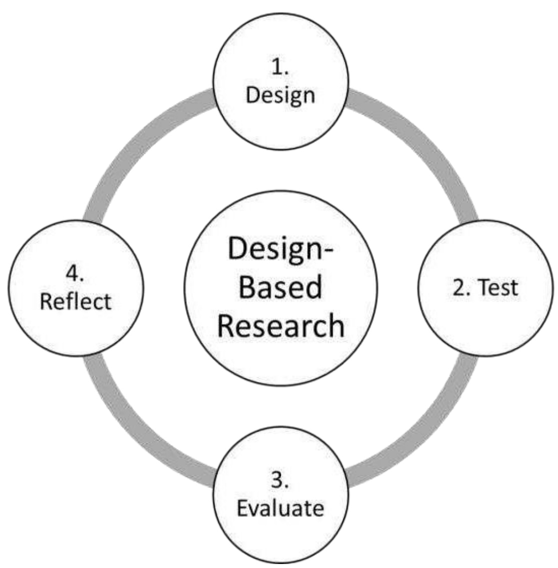

Figure 3.1: Design-Based Research Framework

3.2 General Methodology

3.2.1 Design Phase (Study 1)

Design-thinking (DT) is a flexible and collaborative problem-solving process consisting of five stages; 1) empathize, 2) define, 3) ideate, 4) prototype, and 5) test (McLaughlin et al., 2019). The main goal of the empathize stage is for the researchers to get an understanding of who the stakeholders and end-point users are (McLaughlin et al., 2019). The define stage aims to pinpoint the needs and problems of the stakeholders and end-point users (McLaughlin et al., 2019). The ideate phase involves brainstorming possible solutions to the problem, which are then created in the prototyping phase (McLaughlin et al., 2019). The final test phase involves testing the proposed solutions to see if they meet the needs of the endpoint users and stakeholders (McLaughlin et al., 2019). In this thesis, the empathize and define stages of DT were utilized to generate an initial list of feedback in the form of KP and KR based on an IO access skills checklist. Building on Sivanathan et al. (2022), who argued that medical educators and simulation researchers prefer quantitative data to ensure content validity, I have used a quantitative methodology to build consensus on the prototype of the feedback content.

The Delphi process is a structured group communication process that seeks to gather information and achieve consensus from a panel of experts using iterative survey questionnaires (Haji et al., 2015). In general, the Delphi method process starts with the selection of a group of experts based on the topic being examined - referred to as the Delphi panel. Once all panelists are identified and confirmed, each is sent a survey with instructions to comment on each topic based on their personal opinion, experience, or previous research. They are then asked to return the surveys to the researcher who groups the comments and prepares copies of the information. An agreement between the panelists is determined a-priori and the researcher determines if the agreement has been reached, or if the content needs to be modified and re-sent for further deliberation by the panel. This is known as a Delphi round, and these rounds are repeated as many times as necessary to achieve a general sense of consensus (Haji et al., 2015). In this thesis, the initial list of feedback generated from the DT then underwent Delphi rounds where experts rated the importance of each of the steps on a Likert scale of 1 (not important) to

5 (very important) to be included in the study. To summarize, during the DT session, the define stage was conducted to determine what the objectives of learning IO access are, and the ideate stage is where we outlined what augmented feedback, in the form of KP and KR, can be provided to learners when using the IO access simulator. The feedback determined from the ideate stage of the DT session was then put through Delphi rounds in order to gain a consensus on what KP and KR can be provided to ACPs when learning IO access using the IO access simulator.

3.2.2 Test and Evaluate Phases (Study 2)

The test phase of this thesis involved having ACPs use an IO access simulator and perform the skill a minimum of three times, where in between each attempt, a different form of feedback (KP, KR, and intrinsic) was provided by an ACP instructor based on the feedback generated from the design phase of this work. In the evaluation phase, each of the participants then completed a survey that consisted of four parts; 1) demographic information, 2) self-efficacy data, 3) ranking the most and least effective feedback, and 4) an open-ended question to provide a rationale for their selections. The demographic data were collected to assess what everyone's base levels and comfort levels were with performing IO access skills. The self-efficacy component was based on the Michigan Standard Simulation Experience Scale (Seagull & Rooney, 2014) to assess whether participants found the learning experience (using the IO access simulator while receiving feedback) helped improve their knowledge, confidence, and ability in performing the IO access procedure. Participants had to rank each question on a 5-point Likert scale with 1 being strongly disagree and 5 being strongly agree. The final two components of the survey required participants to select which feedback was most effective and which was least effective, then explain their selections in an open-ended question format. In addition to this, the instructors also completed a survey to gather their perspectives on the experience using the IO access simulator and providing feedback to the participants.

3.3 References

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research?. *Educational researcher*, *41*(1), 16-25. \ https://doi.org/10.3102/0013189X11428813

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The journal of the learning sciences*, *13*(1), 1-14. https://doi.org/10.1207/s15327809jls1301_1

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The journal of the learning sciences*, *2*(2), 141-178. https://doi.org/10.1207/s15327809jls0202_2

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher*, *32*(1), 9-13. https://doi.org/10.3102/0013189X032001009

Edelson, D. C. (2002). Design research: What we learn when we engage in design. *The Journal of the Learning sciences*, *11*(1), 105-121. https://doi.org/10.1207/S15327809JLS1101_4

Fahd, K., Miah, S. J., Ahmed, K., Venkatraman, S., & Miao, Y. (2021). Integrating design science research and design based research frameworks for developing education support systems. *Education and Information Technologies*, *26*, 4027 4048. https://doi.org/10.1007/s10639-021-10442-1

Haji, F. A., Khan, R., Regehr, G., Ng, G., de Ribaupierre, S., & Dubrowski, A. (2015). Operationalising elaboration theory for simulation instruction design: a Delphi study. *Medical education*, 49(6), 576-588. https://doi.org/10.1111/medu.12726

Hoadley, C. M. (2004). Methodological alignment in design-based research. *Educational psychologist*, *39*(4), 203-212. https://doi.org/10.1207/s15326985ep3904_2

McLaughlin, J. E., Wolcott, M. D., Hubbard, D., Umstead, K., & Rider, T. R. (2019). A qualitative review of the design thinking framework in health professions education. *BMC medical education*, 19(1), 1-8. https://doi.org/10.1186/s12909 019-1528-8

Scott, E. E., Wenderoth, M. P., & Doherty, J. H. (2020). Design-based research: a methodology to extend and enrich biology education research. *CBE—Life Sciences Education*, *19*(2), es11. https://doi.org/10.1187/cbe.19-11-0245

Seagull, F. J., & Rooney, D. M. (2014). Filling a void: developing a standard subjective assessment tool for surgical simulation through focused review of current practices. *Surgery*, *156*(3), 718-722. https://doi.org/10.1016/j.surg.2014.04.048

Sivanathan, M., Micallef, J., Clarke, K. M., Gino, B., Joshi, S., Abdo, S., Buttu, D., Mnaymneh, M., Siraj, S., Torres, A., Brock, G., Pereira, C., & Dubrowski, A. (2022). The Development and Initial End-Point User Feedback of a 3D-Printed Adult Proximal Tibia IO Simulator. *Cureus, 14*(5), e25481. doi:10.7759/cureus.25481

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational technology research and development, 53*(4), 5-23. https://doi.org/10.1007/BF02504682

Chapter 4. Study 1 - Defining the Nature of Augmented Feedback for Learning Intraosseous Access Skills in Simulation Based Health Professions Education

[As published in Cureus]

4.1 Introduction

Psychomotor skills are movement tasks that contain both cognitive and motor processes. These processes, in turn, often lead individuals to learn and manipulate the environment around them (Schmidt et al., 2019). In the context of health professions education (HPE), psychomotor skills are often referred to as technical skills, being tasks that are performed by health professionals to the patient (Dubrowski & Backstein, 2004). In HPE, learning technical skills involves three stages that ensure that both the cognitive and motor elements are understood: 1) instructions, 2) practice, and 3) feedback (Chiniara et al., 2004; Dubrowski et al., 2021; Dubrowski & Backstein, 2004). Instructions comprise the information provided to the learners about the skills and the mechanical principles that are needed to perform the task (Schmidt et al., 2019). Practice is an active process in which an individual is attempting to perform a task with the intent of acquiring a new skill so that there is a permanent change in habit (Schmidt et al., 2019). Finally, feedback can be defined as information that is given before, during, and after an action has occurred (Schmidt et al., 2019). Feedback is typically divided into two categories: 1) intrinsic feedback and 2) augmented feedback. Intrinsic feedback is defined as the information that is naturally understood and gathered through our senses (Schmidt et al., 2019). For example, a basketball player could see if they made their shot or can feel if their throw was off. Augmented feedback supplements intrinsic feedback by providing information about the movement sequence or outcome from an external point of view (Schmidt et al., 2019). Augmented feedback can be further subdivided into two main dimensions: knowledge of results (KR) and knowledge of performance (KP). KR is the feedback that is given regarding the outcome of the overall goal of the action. Using the same basketball example, the player's coach may provide feedback on the parabola of the ball after it was shot, or where the ball hit the backboard to provide an explanation as to why the ball did or did not go into the net. KP is the feedback provided regarding the action movement that leads to the outcome (Schmidt et al., 2019), this is where the basketball coach would provide feedback regarding the form of the player while they were making the shot.

Simulation-based health professions education (SBHPE) uses simulators to allow individuals in health care professions to practice clinical procedures in a safe and controlled environment (Kothari et al., 2017). In this context, simulation can employ models, actors, animal parts, digital technologies, as well as supplementary materials and scripts to create an immersive, replicable, and standardized learning environment (Kothari et al., 2017). Therefore, using SBHPE to amplify HPE can be an effective tool encompassing all three stages of learning technical skills.

Concerning feedback, it is unknown which type is most effective, especially within the context of SBHPE with advanced learners (Schmidt et al., 2019). Therefore, the overarching aim of this work was to assess the perceived effectiveness of KP, KR, and intrinsic feedback in learning technical skills with advanced care paramedics (ACPs). We have selected intraosseous (IO) vascular access because it is a commonly utilized skill by ACPs, it has clear procedural steps, and we had access to a previously developed IO access simulator (Sivanathan et al., 2022a; Sivanathan et al., 2022b). Before the perceived effectiveness could be investigated, we first had to determine what KP and KR can be provided specifically for learning IO access using the developed IO access simulator. Therefore, the objective of this article is to share the methods utilized and the results of determining what KP and KR can be provided in the context of learning IO access by ACPs.

4.2 Materials and Methods

The development of an advanced IO access simulator using 3D printing and silicone work was described in a previous report (Sivanathan et al., 2022a; Sivanathan et al., 2022b). It is this IO access simulator that will be used, alongside feedback from a Quality and Development Facilitator with an ACP Certification, to assess the perceived effectiveness of KP, KR, and intrinsic feedback by ACPs from the Region of Durham Paramedic Services (Whitby, Ontario). However, before the perceived effectiveness can be investigated, we had to determine what KP and KR can be provided in the context of learning IO access using the advanced IO access simulator. The ethics for this project was exempted by the Ontario Tech University Research Ethics Board as per TCPS2 Article 6.1 issue number 16892 as a protocol development study.

This work will be accomplished following the Design-Based Research (DBR) framework, specifically within phase 1, which is the design phase. This phase will be accomplished using a hybrid of Design Thinking and Delphi methodology. Shown in Figure 4.1 below is how the methods will be situated within the DBR framework, with the phases in the green boxes being the phases utilized in this work.

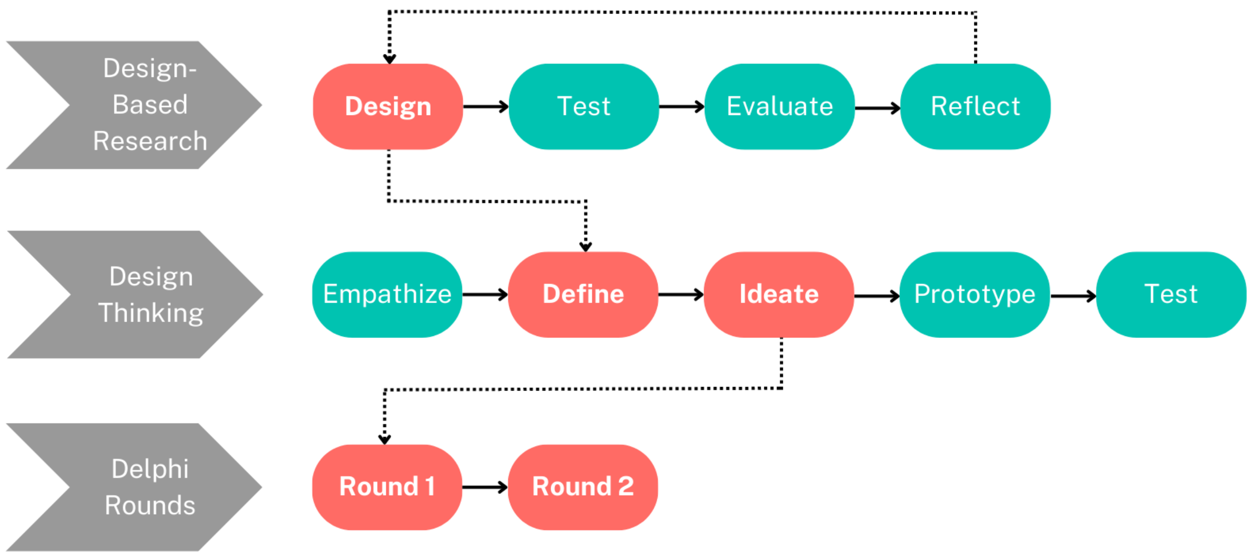

Figure 4.1: Situating the Design Thinking and Delphi methods within the Design-Based Research Framework.

4.2.1 Design-Based Research

In order to determine what KP and KR can be provided to ACPs when learning IO access using our previously developed IO access simulator, we followed the DBR framework. DBR is an educational framework that explains an iterative process, focusing on the collaboration of researchers, stakeholders, and end-point users, to generate solutions (i.e., resources) that can be applied to specific learning contexts (Fahd et al., 2021; Wang & Hannafin, 2005). DBR contains four iterative phases: 1) Design, 2) Test,

3) Evaluate, and 4) Reflect (Scott et al., 2020). The design phase involves developing a solution that addresses both the theoretical and practical concerns of the problem (Edelson, 2002; Wang & Hannafin, 2005). The test phase involves implementing the solution in a real-world setting (Hoadley, 2004). The evaluate phase evaluates the effectiveness of the solution using evidence from endpoint users' learning (Anderson & Shattuck, 2012; Barab & Squire, 2004). Finally, the reflect phase involves a retrospective analysis of the DBR methodology and methods used in the prior phases (Barab & Squire, 2004; Cobb et al., 2003). To achieve the desired outcomes, this work focuses on the design phase. The methods used to accomplish this phase are a hybrid of Design-Thinking (DT) and Delphi.

4.2.2 DT-Delphi Hybrid

The combination of DT and Delphi used to achieve the objective of this work is pictured in Figure 1. During the DT session, the define stage was conducted to determine what the objectives of learning IO access are, and the ideate stage is where we outlined what augmented feedback, in the form of KP and KR, can be provided to learners when using the IO access simulator. The feedback determined from the ideate stage of the DT session was then put through Delphi rounds in order to gain a consensus on what KP and KR can be provided to ACPs when learning IO access using the IO access simulator.

4.2.3 Design-Thinking Process

DT is a flexible and collaborative problem-solving process consisting of five stages; 1) empathize, 2) define, 3) ideate, 4) prototype, and 5) test (McLaughlin et al., 2019). The main goal of the empathize stage is for the researchers to get an understanding of who the stakeholders and end-point users are (McLaughlin et al., 2019). The define stage aims to pinpoint the needs and problems of the stakeholders and end-point users (McLaughlin et al., 2019). The ideate phase involves brainstorming possible solutions to the problem, which are then created in the prototyping phase (McLaughlin et al., 2019). The final test phase involves testing the proposed solutions to see if they meet the needs of the endpoint users and stakeholders (McLaughlin et al., 2019). To fit in with the scope of this work, we will just be focusing on the defining and ideating stages of DT. The DT session was held in person at the Region of Durham Paramedic Services building

(Whitby, Ontario) with two members of the research team (JM and AD), a total of four participants (n=4); one ACP instructor (n=1), one ACP student (n=1), and two working ACPs (n=2). These participants were recruited via emails from the research team asking for participation. The inclusion criteria were that the participants had to be either a working ACP or ACP student and had to be familiar with the IO access procedure. The 1-hour session was conducted in the format of a focus group interview, facilitated by one of the researchers (JM), and guided using a PowerPoint presentation. The outputs from these phases then feed into the Delphi process.

4.2.4 Delphi Process

The Delphi process is a structured group communication process that seeks to gather information and achieve consensus from a panel of experts using iterative survey questionnaires (Haji et al., 2015). In general, the Delphi method process starts with the selection of a group of experts based on the topic being examined - referred to as the Delphi panel. Once all panelists are identified and confirmed, each is sent a survey with instructions to comment on each topic based on their opinion, experience, or previous research. They are then asked to return the surveys to the researcher who groups the comments and prepares copies of the information. An agreement between the panelists is determined a-priori and the researcher determines if the agreement has been reached, or if the content needs to be modified and re-sent for further deliberation by the panel. This is known as a Delphi round, and these rounds are repeated as many times as necessary to achieve a general sense of consensus (Haji et al., 2015). For this work, we used an electronic survey (google forms) which was emailed to 9 participants (n=9) consisting of ACPs from the Region of Durham Paramedic Services (n=6), paramedic educators (n=2), and a medical doctor (n=1). These participants were recruited via emails from the research team asking for participation. The inclusion criteria were that the participants had to be familiar with the IO access procedure. The survey was formatted so that each participant had to rate on a 5-point Likert scale, the level of importance of the steps in the form of KP and KR indicated from the DT session. In addition to participants ranking on a 5-point Likert scale, there were also sections in the survey where they could provide comments. The cutoff criteria for the Delphi methods were set a priori, where a median above 3 and a standard deviation below 1 would be considered a consensus among the participants to keep the particular item on the list. Items with a median lower than 3, and a standard deviation lower than 1 would be rejected, and items with a median lower than 3 but a standard deviation higher than 1 would be revised based on comments and included in subsequent rounds, with one week to complete each round. There were no limits to the number of rounds, and the end of the consensus-building exercise was reached when all items scored a median over 3 and showed a standard deviation lower than 1. For this work, only two rounds were needed.

4.3 Results

4.3.1 Design-Thinking Session

The define stage of the DT session was guided by asking the participants what the objectives for learning IO access are. This resulted in five main objectives:

1. To identify indications
2. To use the appropriate tools
3. To landmark correctly
4. To ensure the IO needle is secured
5. To confirm the success of the IO access

Next, during the ideate stage, the participants decided that the best course of action would be to use a previously developed skills checklist by one of the team members (DB), shown in Table 4.1, on how to perform an IO access and reword the steps so that they can be forms of augmented feedback (KP and KR). We condensed the 28 steps outlined in the skills checklist into 7 steps that had a version of KP and KR for each step to ensure the feedback in each form was given in equal quantities. The results of the DT are shown in Table 4.2 below.

Completion Requirements	Met or not met?
Ensures that adequate basic life support is performed	met/not met
Appropriate consent	met/not met
Appropriate infection control precautions	met/not met
Assembles and prepares necessary equipment	met/not met
Selects appropriate solution	met/not met
Checks solution for expiry, clarity, particulate, leaks	met/not met
Selects and flushes appropriate solution admin set	met/not met
Selects site based on patient presentation/clinical need	met/not met
Places patient on resilient surface	met/not met
Leg externally rotated to display medial aspect	met/not met
Landmarks 1-2 cm distal to tibial tuberosity on flat portion of bone	met/not met
Cleans intended site with alcohol/betadine	met/not met
Swabs in circular motion out from injection site	met/not met
Inserts needle at approximately 90 degrees angled slightly away from joint	met/not met
Uses firm twisting motion until “pop” is felt	met/not met
Unscrews cap and removes stylet directly into sharps container	met/not met
Attaches syringe with saline and aspirates for blood and particles of marrow	met/not met
Slowly injects saline, observing for signs of infiltration	met/not met
Connects solution set and adjusts flow rate as necessary	met/not met
Disposes of sharps directly into sharps container	met/not met
Attaches solution set and establishes patency of IV access	met/not met

Table 4.1: IO Skills Checklist

Step	KP Version	KR Version
1	The learner landmarks IO model 1-2 cm distal to tibial tuberosity on flat portion of bone	The learner landmarked
2	The learner cleans the intended injection site in a circular motion out from the injection site using an alcohol wipe	The learner disinfected the intended injection site
3	The learner inserts the needle at approximately 90 degrees from the joint and stops when the bone is reached	The learner inserted the needle
4	The learner drills into bone until "pop" is felt	The learner drilled into bone
5	The learner secures the needle with stabilizer so that there is no movement	The learner stabilized the needle
6	The learner attaches a 10 ml syringe filled with saline to the needle and aspirates for blood and particles of marrow	The learner aspirated
7	The learner slowly injects saline and monitors drip	Learner injected saline, so that a steady drip flowed from the end of the IO model, showing indication of correct injection site

Table 4.2: List of IO access steps converted in the form of KP and KR.

4.3.2 Delphi Rounds

The seven steps identified in the DT were then subjected to consensus-building exercises following the Delphi methodology (Haji et al., 2015). The results of this first Delphi round are shown in Table 4.3 below, where the frequencies, median, and standard deviation are noted.

Step	*KP / KR*	*Likert Scale Frequencies*					*Median*	*SD*
		1	***2***	***3***	***4***	***5***		
1	**KP**	0	0	0	1	8	5	0.33
	KR	0	0	1	1	7	5	0.71
2	**KP**	0	0	1	2	6	5	0.73
	KR	0	0	2	0	7	5	0.88
3	**KP**	0	0	0	1	8	5	0.33
	KR	0	0	3	0	6	5	1
4	**KP**	0	0	0	2	7	5	0.44
	KR	0	0	3	0	6	5	1
5	**KP**	0	0	0	1	8	5	0.33
	KR	0	1	1	1	6	5	1
6	**KP**	0	1	2	0	6	5	1.2
	KR	1	1	3	1	3	3	1.42
7	**KP**	0	1	1	2	5	5	1.09
	KR	0	0	1	2	6	5	0.73

Table 4.3: Results for Delphi round 1

Based on the data from the first Delphi round, step 6 for both the KP and KR versions, did not reach a consensus (standard deviations were both above 1) and had to be fixed, as well as the KP version of step 7 since it did not meet the consensus criteria of having a standard deviation below 1. Comments from the participants are shown in Table 4.4. They indicated that aspirating for blood (step 6) is no longer used in practice so that step should be removed. They also noted that KP for step 7 was not worded properly and should be re-written. Additionally, many participants noted that adding a step of preparing the patient as well as confirming the success of the procedure should be included as feedback as well.

Step	*Comments*
1	KR Step 1 - I believe it should say "successfully landmarked" as it is possible to landmark incorrectly.
2	Circular motion is best practice but may not represent exactly what is occurring in the field.
3	Again, I believe WHERE the learner inserted the needle is a key component of the KR
	Not a fan of the wording of the KP statement. Should read: "The learner inserts the needle through the skin at a 90 degree angle to the bone and stops when the bone is contacted."
	KR could be done incorrectly.
4	KR - Drilled into the bone in the correct area, ending in the osseous space without going through the bone.,
	The KP and the KR statement is more than just drilling into the bone. The result should be the needle is drilled into the bone with consistent pressure and released when the pop is felt.
	KR may not have reached the correct location.
	The pop may not always be felt. Resistance is the key - resistance will lighten once in.
5	There really should be a step between 4 and 5 where the stylet is removed from the needle in the bone.
	Possibly the same result if the appropriate stabilizer device is used.
6	aspirating for blood is no longer in our step by step process for confirmation, although it does confirm placement
	Depending on where you read, this step may not be necessary. Recent procedures have steered away from this, as sometimes the bone marrow can block the IO needle.

	FYI, if a 10 ml syringe is filled with saline, there is no room to aspirate any material as the syringe is already full. The syringe could actually be empty for the purpose of aspiration.
	Doesn't always yield a positive result when done.
	Although this is important, your initial flushed is used to confirm patency and placement by determining if you DON'T feel infiltration into the surrounding tissues. This might be hard in a simulated environment. You may be able to do this by creating a reservoir where saline can collect if placement is not correct.
	The "flush" should be relatively quick to create the open space that allows the IV to drip afterwards.
	This is correct but can be worded that a saline flush is administered to ensure patency which is evidenced by the flow of liquid from the IO trainer.
7	not sure i understand this fully, but sounds as though this is to confirm site, so it would be more important for the result then the actual skill of slowly infusing saline which is not part of IO insertion in practice
	I think this is a minimal difference between the KP and the KR for a skill like this.
	Consider adding a final step speaking to confirm the IO procedure by ensuring the IV runs well, no signs of infiltration, no bruising or swelling of the leg etc.
	maybe something related to prepping the patient (e.g., positioning)
	these all seem appropriate, would suggest technique and result are ideal for most of these steps for learning
OVERALL	You could have put something about indicating this procedure.

Table 4.4: Comments from Delphi Round 1

These results were then incorporated into the new steps listed in Table 4.5 below. In this new list of steps, step 6 was removed, two new steps were added, and the KP version of step 7 was fixed, resulting in eight steps in the form of KP and KR. Only the new steps (steps 1, 7, and 8 in Table 3) went through another Delphi round with the same participants from round 1 and were given one week to complete. The results from the second Delphi round are shown in Table 4.6.

Step	KP Version	KR Version
1	The learner places IO model on sturdy surface and positions IO model so it is externally rotated to display medial aspect	The learner correctly placed and positioned IO model
2	The learner landmarks IO model 1-2 cm distal to tibial tuberosity on flat portion of bone	The learner successfully landmarked.
3	The learner cleans the intended injection site in a circular motion out from the injection site using an alcohol wipe	The learner disinfected the intended injection site
4	The learner inserts the needle through the skin at a 90 degree angle to the bone, 1 cm to 2 cm inferior and medial to the tibial tuberosity in the flat portion of the tibia, and stops when the bone is contacted	The learner inserted the needle correctly, in the proximal tibia location
5	The learner drills into bone in the proximal tibia location until resistance is lightened	The learner drilled into bone in proximal tibia location, ending in the osseous space, without going through the bone.
6	The learner secures the needle with stabilizer so that there is no movement	The learner stabilized the needle

7	The learner administers saline flush to ensure space for IV drip	Learner administered saline flush, which is evidenced by the flow of liquid from the IO trainer
8	The learner attaches solution set to IO model and establishes patency of IV access by monitoring IV drip	The learner established patency of IV access indicated by steady IV drip into IO model

Table 4.5: Updated steps based on results of Delphi Round 1

Step	*KP / KR*	*Likert Scale Frequencies*					*Median*	*SD*
		1	***2***	***3***	***4***	***5***		
1	**KP**	0	2	0	2	4	5	1.11
	KR	0	2	1	3	2	4	1.07
7	**KP**	0	0	0	3	5	5	0.49
8	**KP**	0	0	1	2	4	5	0.79
	KP	0	0	1	2	4	5	0.79

Table 4.6: Results from Delphi round 2

The new step 1 did not reach a consensus for either the KP or KR version, due to the standard deviation being above 1. The comments are shown in Table 4.7 below, and they indicated that the step is important to indicate that the IO access simulator is positioned properly, however, indicating placement is not important as the simulator will already be on a steady surface, therefore, the step was reworded for KP and KR to satisfy the comments. The remainder of the steps met a consensus.

Step	*Comments*
1	I think the placement/display of the IO model on a sturdy surface may potentially impact the success of the remainder of the skill, however seeing as this "perfect" scenario never exists in the field, I don't think it's a valuable measure. Perhaps a more realistic scenario would be beneficial.

	It is important to comment on the external rotation as it will be difficult to perform the skill if the model isn't in the right position
	The student must place the IO model on a hard surface so that he can train efficiently and safely.
	I agree with your statement and understanding that saline access is used as placement confirmation. While other factors like feeling the "pop" or resistance met are confirmation methods directly related to the skill of IO insertion, I think this would be an important factor for an expert to evaluate overall success of the skill performed. My other comparison would be the skill of intubation, and attaching equipment to see if lungs inflate - not directly related to the skill itself, but an important factor to evaluate.
	I agree with the comments stating the flush is required to ensure patency and avoid infiltration into the surrounding tissues.
	The KP doesn't sound right to me, I believe it should state: The learner administers a saline flush and assesses for infiltration into the surrounding tissues. In real life we can't see the fluid flow from the end of the model and therefore the KR would confirm you do not have infiltration (fluid in the surrounding tissues and not in the osseous space)
7	It is important for the student to understand that this step (injecting saline and monitoring the drip) is important as it is part of successfully performing the procedure.
	Typically the fluid would be placed under pressure
	This is a good additional step - as it is a key component of initiating the IO.
	Step 8, we are actually looking at flow rate and it would be more important to look at the rate of flow because you may need to make a decision to use a pressure infuser to actually get a steady flow rate.
8	It is important for the student to understand that this step (injecting saline and monitoring the drip) is important as it is part of successfully performing the procedure.

Table 4.7: Comments from Delphi Round 2

The resulting steps from the Delphi rounds are shown in Table 4.8. It is these steps that will be used by instructors to provide learners with KP and KR in the next study of this research in assessing the perceived effectiveness of KP and KR on learning IO access using an IO access simulator.

Step	KP Version	KR Version
1	The learner positions the IO model so it is externally rotated to display medial aspects	The learner correctly positioned the IO model
2	The learner landmarks IO model 1-2 cm distal to tibial tuberosity on the flat portion of bone	The learner successfully landmarked
3	The learner cleans the intended injection site in a circular motion out from the injection site using an alcohol wipe	The learner disinfected the intended injection site
4	The learner inserts the needle through the skin at a 90 degree angle to the bone, 1 cm to 2 cm inferior and medial to the tibial tuberosity in the flat portion of the tibia, and stops when the bone is contacted	The learner inserted the needle correctly, in the proximal tibia location
5	The learner drills into bone in the proximal tibia location until resistance is lightened	The learner drilled into bone in proximal tibia location, ending in the osseous space, without going through the bone
6	The learner secures the needle with stabilizer so that there is no movement	The learner stabilized the needle
7	The learner administers a saline flush and assesses for infiltration into the surrounding tissues	Learner administered saline flush

8	The learner attaches a solution set to the IO model, applies pressure, and establishes patency of IV access by monitoring IV drip	The learner established patency of IV access indicated by steady IV drip into IO model.

Table 4.8: Final list of steps with feedback in forms of KP and KR.

4.4 Discussion

This discussion is organized around two main contributions: 1) pragmatic and 2) methodological. First, the purpose of this study was to determine what KP and KR can be provided to ACPs when learning IO access using an IO access simulator. To accomplish this, we followed the initial phase of a DBR approach, specifically within the design phase, using a hybrid of DT and Delphi methods. The main purpose of the design phase of DBR is to generate solutions that can address the theoretical and practical implications of a specific learning problem (Edelson, 2002; Wang & Hannafin, 2005). The theoretical concern we are addressing in this work is the matter of what type of feedback is perceived to be most effective by ACPs when learning IO access using an IO access simulator. When learning technical skills, such as IO access, feedback is the most important feature, however, it is still not known whether KP or KR is more effective (Schmidt et al., 2019; Sharma et al., 2016). Practically, we needed to determine what KP and KR can be given to learners, specifically in the context of learning IO access in a SBHPE environment. The DT session cultivated an initial list of steps, with each step being feedback that can be provided in the form of KP as well as KR. The Delphi rounds refined the list to result in 8 steps, each written in the form of KP and KR so that it can be used as a guide for paramedic instructors to provide augmented feedback to ACPs learning IO access using an IO access simulator. In summary, the result was a set of steps when feedback needs to be provided. For each step, the experts and the learners provided input on how to operationalize the feedback to be either KR or KP in nature. This list will be used in subsequent research that will focus on testing and evaluating the perceived effectiveness of these types of feedback in training.

Second, the methodological contributions of this paper are centered around the use of the DBR approach in the construction of instructional (i.e., feedback) materials in

SBHPE. Specifically, DBR was introduced to the educational field in the early 1990s by Ann Brown with the purpose of creating interventions in a collaborative manner (between the researcher and practitioner) that can be used in educational settings (Anderson & Shattuck, 2012). While this methodology has been predominantly used for traditional learning settings, with the increase in SBHPE, DBR can be applied to experiential learning as well. In an article by Schmitz et al. (2015), a mobile simulation game was successfully designed and implemented following a DBR approach. Additionally, DBR has been used to create educational models for simulation facilitators (Koivisto et al., 2018). There are no requirements for the methods used in each of the phases of DBR (Scott et al., 2020). Therefore, using a combination of DT and Delphi methods to accomplish the design phase of DBR is unique to this research. However, it is not unique to SBHPE as a study by Sivanathan et al. (2022c) has used a combination of DT and Delphi to help guide the design of a virtual reality simulation to help with moral distress experienced by healthcare professionals. As DBR necessitates the cooperation of researchers, designers, educators, and learners, employing a blend of DT and Delphi methods offers a chance to fulfill the requirements of all involved parties. For example, designers, educators, and learners prefer utilizing DT, a creative design process that facilitates idea generation and problem-solving. Conversely, the use of the Delphi method satisfies the rigorous demands of researchers seeking approaches that ensure content validity. Therefore, using a combination of the two approaches allows for the creative generation of solutions that can be validated through consensus-building (Sivanathan et al., 2022b; Sivanathan et al., 2022c).

There are a few limitations and strengths to this study. First, while DT and Delphi methods are validated methodological approaches, using them in combination with each being modified has not been validated as an approach. Despite this combination being used successfully in the past (Sivanathan et al., 2022b; Sivanathan et al., 2022c) for SBHPE scenarios, the approach itself has not been tested and validated. On the other hand, this methodological combination is unique to DBR and can be an advancement to the field. One of the strengths of this work is that we were able to get the perspectives and feedback of stakeholders (paramedic instructors) as well as the end-point users (ACPs and ACP students). However, our small sample size for the Delphi rounds was a limitation, as a sample of 15-30 is more adequate (Haji et al., 2015).

4.5 Conclusion

In this article, the utilization of the DBR framework integrating the DT and Delphi methods was described. The primary objective of this study was to determine what KP and KR can be provided by paramedic instructors to ACPs in the context of learning IO access skills using a previously developed IO access simulator. Through the systematic application of the DT method, an initial list of feedback in the form of KP and KR was developed based on an IO access skills checklist. The Delphi method provided a consensus on the identified KP and KR for instructing ACPs in IO access skills. This resulted in an 8-step list of feedback in the form of KP and KR which will be used in the next phase of this research project which assesses the perceived effectiveness of feedback in training ACPs IO access skills in a SBHPE environment.

4.6 References

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research?. *Educational researcher, 41*(1), 16-25. \ https://doi.org/10.3102/0013189X11428813

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The journal of the learning sciences, 13*(1), 1-14. https://doi.org/10.1207/s15327809jls1301_1

Chiniara, G., Cole, G., Brisbin, K., Huffman, D., Cragg, B., Lamacchia, M., Norman, D., & Canadian Network For Simulation In Healthcare, Guidelines Working Group (2013). Simulation in healthcare: a taxonomy and a conceptual framework for instructional design and media selection. *Medical teacher, 35*(8), e1380–e1395. https://doi.org/10.3109/0142159X.2012.733451

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher, 32*(1), 9-13. https://doi.org/10.3102/0013189X032001009

Dubrowski, A., Kapralos, B., Peisachovich, E., Da Silva, C., & Torres, A. (2021). A Model for an Online Learning Management System for Simulation-Based

Acquisition of Psychomotor Skills in Health Professions Education. *Cureus, 13*(3), e14055. https://doi.org/10.7759/cureus.14055

Dubrowski, A., & Backstein, D. (2004). The contributions of kinesiology to surgical education. The Journal of bone and joint surgery. *American volume*, *86*(12), 2778–2781. https://doi.org/10.2106/00004623-200412000-00029

Edelson, D. C. (2002). Design research: What we learn when we engage in design. *The Journal of the Learning sciences*, *11*(1), 105-121. https://doi.org/10.1207/S15327809JLS1101_4

Fahd, K., Miah, S. J., Ahmed, K., Venkatraman, S., & Miao, Y. (2021). Integrating design science research and design based research frameworks for developing education support systems. *Education and Information Technologies*, *26*, 4027 4048. https://doi.org/10.1007/s10639-021-10442-1

Haji, F. A., Khan, R., Regehr, G., Ng, G., de Ribaupierre, S., & Dubrowski, A. (2015). Operationalising elaboration theory for simulation instruction design: a Delphi study. *Medical education,* 49(6), 576-588. https://doi.org/10.1111/medu.12726

Hoadley, C. M. (2004). Methodological alignment in design-based research. *Educational psychologist*, *39*(4), 203-212. https://doi.org/10.1207/s15326985ep3904_2

Koivisto, J. M., Hannula, L., Bøje, R. B., Prescott, S., Bland, A., Rekola, L., & Haho, P. (2018). Design-based research in designing the model for educating simulation facilitators. *Nurse Education in Practice*, *29*, 206-211. https://doi.org/10.1016/j.nepr.2018.02.002

Kothari, L. G., Shah, K., & Barach, P. (2017). Simulation based medical education in graduate medical education training and assessment programs. *Progress in Pediatric Cardiology*, *44*, 33-42. https://doi.org/10.1016/j.ppedcard.2017.02.001

McLaughlin, J. E., Wolcott, M. D., Hubbard, D., Umstead, K., & Rider, T. R. (2019). A qualitative review of the design thinking framework in health professions education. *BMC medical education,* 19(1), 1-8. https://doi.org/10.1186/s12909 019-1528-8

Schmidt, R. A., Zelaznik, H. N., Wulf, G., Winstein, C. J., & Lee, T. D. (2019). *Chapter 11: Augmented Feedback.* In Motor control and learning: A behavioral emphasis (6th ed.). Human Kinetics.

Schmitz, B., Klemke, R., Walhout, J., & Specht, M. (2015). Attuning a mobile simulation game for school children using a design-based research approach. *Computers & Education,* 81, 35-48. https://doi.org/10.1016/j.compedu.2014.09.001

Scott, E. E., Wenderoth, M. P., & Doherty, J. H. (2020). Design-based research: a methodology to extend and enrich biology education research. *CBE—Life Sciences Education, 19*(2), es11. https://doi.org/10.1187/cbe.19-11-0245

Sharma, D. A., Chevidikunnan, M. F., Khan, F. R., & Gaowgzeh, R. A. (2016). Effectiveness of knowledge of result and knowledge of performance in the learning of a skilled motor activity by healthy young adults. *Journal of physical therapy science, 28*(5), 1482–1486. https://doi-org.uproxy.library.dc uoit.ca/10.1589/jpts.28.1482

Sivanathan, M., Micallef, J., Clarke, K. M., Gino, B., Joshi, S., Abdo, S., Buttu, D., Mnaymneh, M., Siraj, S., Torres, A., Brock, G., Pereira, C., & Dubrowski, A. (2022a). The Development and Initial End-Point User Feedback of a 3D-Printed Adult Proximal Tibia IO Simulator. *Cureus, 14*(5), e25481. doi:10.7759/cureus.25481

Sivanathan, M., Franco, L. Y., Joshi, S., Micallef, J., Button, D., & Dubrowski, A. (2022b). Development of Simple and Advanced Adult Proximal Tibia Simulators for a Decentralized Simulation-Based Education Model to Teach Paramedics-in Training the Intraosseous Infusion Procedure. *Cureus, 14*(10). doi:10.7759/cureus.30929

Sivanathan, M., Espinola, C. W., Uribe Quevedo, A., Kapralos, B., Krishnan, S., Bhat, V., & Dubrowski, A. (2022c). Development of Content for a Virtual Reality Simulation to Understand and Mitigate Moral Distress in Healthcare Workers. *Cureus, 14*(11), e31240. https://doi.org/10.7759/cureus.31240

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational technology research and development, 53*(4), 5-23. https://doi.org/10.1007/BF02504682

Chapter 5. Study 2 - The Perceived Effectiveness of Various Forms of Feedback on the Acquisition of Technical Skills by Advanced Learners in Simulation-Based Health Professions Education

[As accepted in Cureus]

5.1 Introduction

Simulation-based health professions education (SBHPE) employs simulation experiences to enable healthcare professionals to practice technical skills without risking harm to patients (Kothari et al., 2017). In health professions education (HPE), technical skills, also known as psychomotor skills, encompass the tasks performed by healthcare providers for patients (Dubrowski & Backstein, 2004). SBHPE facilitates the acquisition of these technical skills through a three-stage process that ensures a comprehensive understanding of both cognitive and motor aspects: 1) instruction, 2) practice and guidance, and 3) feedback. The instruction and feedback stages contribute to the development of cognitive elements, while the practice stage allows learners to refine their motor skills (Sherwood & Lee, 2003). This study specifically focuses on the feedback stage.

In this context, there are two distinct categories of feedback: 1) intrinsic feedback and 2) augmented feedback. Intrinsic feedback refers to the sensory information an individual receives during the performance of a psychomotor skill. It includes proprioceptive, visual, and auditory cues that provide real-time information about the execution of the skill. This internal feedback allows individuals to adjust and refine their movements, leading to skill improvement (Schmidt et al., 2019). Augmented feedback, on the other hand, complements intrinsic feedback by offering additional insights into the movement sequence or outcome from a different perspective (Schmidt et al., 2019). It is also known as extrinsic feedback because it comes from an external source, such as a coach, instructor, educator, or technology, rather than from the individual's senses (Schmidt et al., 2019). Augmented feedback can be further classified into two primary dimensions: knowledge of results (KR) and knowledge of performance (KP). KR informs learners about the outcome or consequences of their performance, while KP provides information about the technique, form, or execution of the movement itself

(Moinuddin et al., 2021; Schmidt et al., 2019).

The role of feedback in technical skills acquisition is crucial, however, no prior research has explored what type of feedback is most suitable in the context of advanced learners, learning and/or maintaining complex technical skills in SBHPE. In this exploratory study, we focused on the acquisition and maintenance of intraosseous (IO) access skills by advanced care paramedics (ACPs) using an IO access simulator. However, to date, the nature of KR and KP as they relate to IO access skills has not been well defined. Thus, before assessing the perceived effectiveness of each of these types of feedback, a prior study was conducted to establish consensus among expert paramedic educators regarding the definitions of two types of augmented feedback (KP and KR) in this specific context. This process, described in the companion paper (Micallef et al., 2023) yielded an 8-point feedback list, comprising both KP and KR, which served as a guideline for paramedic facilitators when offering feedback to ACPs using the IO access simulator. The KP feedback was highly specific, focusing on the correct execution of each step, while KR feedback merely indicated whether the outcome of the step was accurate or not. Subsequently, the objective of this study was to assess which feedback type (KP, KR, or intrinsic) was deemed most effective by ACPs when acquiring IO access skills using an IO access simulator.

5.2 Methods

Design-Based Research (DBR) is an educational framework that explains an iterative process focusing on the collaboration of researchers, stakeholders, and end-point users, to generate solutions that can be applied to specific learning contexts (Fahd et al., 2021; Wang & Hannafin, 2005; Momand et al., 2022). DBR contains four iterative phases; 1) design, 2) test, 3) evaluate, and 4) reflect (Scott et al., 2021). The design phase involves developing a solution that addresses both the theoretical and practical concerns of a problem (Edelson, 2002; Wang & Hannafin, 2005). The test phase involves implementing the solution in a real-world setting (Hoadley, 2004). The evaluation phase evaluates the effectiveness of the solution using evidence from endpoint users' learning (Anderson & Shattuck, 2012; Barab & Squire, 2004). Finally, the reflect phase involves a retrospective analysis of the DBR methodology and methods used in the prior phases

(Barab & Squire, 2004; Cobb et al., 2003).

In the first phase of this work, the design phase utilized Design Thinking and Delphi methods to determine what KP and KR can be provided to ACPs concerning the IO access simulator, as described in a previous report (Micallef et al., 2023). The second phase, and the focus of this article, was situated within the test and evaluation phases of DBR. The test phase consisted of ACPs receiving feedback in the form of KP and KR, and then comparing them to their intrinsic feedback, when using the IO access simulator. The evaluation phase consisted of ACPs completing a survey to gather demographic data, evaluate the learning experience (using the IO simulator with each type of feedback), as well as ranking their perceived effectiveness of each type of feedback.

5.2.1 Participants

Ethics was obtained for this work by the Durham College Research Ethics Board file number 241-2122 and approved by the Region of Durham Paramedic Services ethics board. Quality and Development Facilitators (n=2) with an ACP Certification from the Region of Durham Paramedic Services who are members of the research team (CM and LK) were asked to act as the instructors to provide feedback to the participants. The ACPs (n=23) were recruited from those attending the Region of Durham Paramedic Services' continuing education sessions which occur biannually to introduce and review patient care standards, equipment, and changes to policies and procedures within the organization. Participation in this study was voluntary and each participant was compensated with a $5 Starbucks gift card. The only inclusion criterion was that the paramedics had to be either an ACP student or an ACP as paramedics at this level already know the steps involved in performing an IO access.

5.2.2 Procedure

The simulation environment was set up at the Region of Durham Paramedic Services and included; 1) a poster explaining the three types of feedback (KP, KR, and intrinsic), 2) a poster outlining the study procedure, 3) an IO access simulator with all of the necessary equipment, and 4) a laptop for the survey (Figure 5.1). In addition, one instructor and an additional member of the research team were present to provide feedback and observe, respectively.

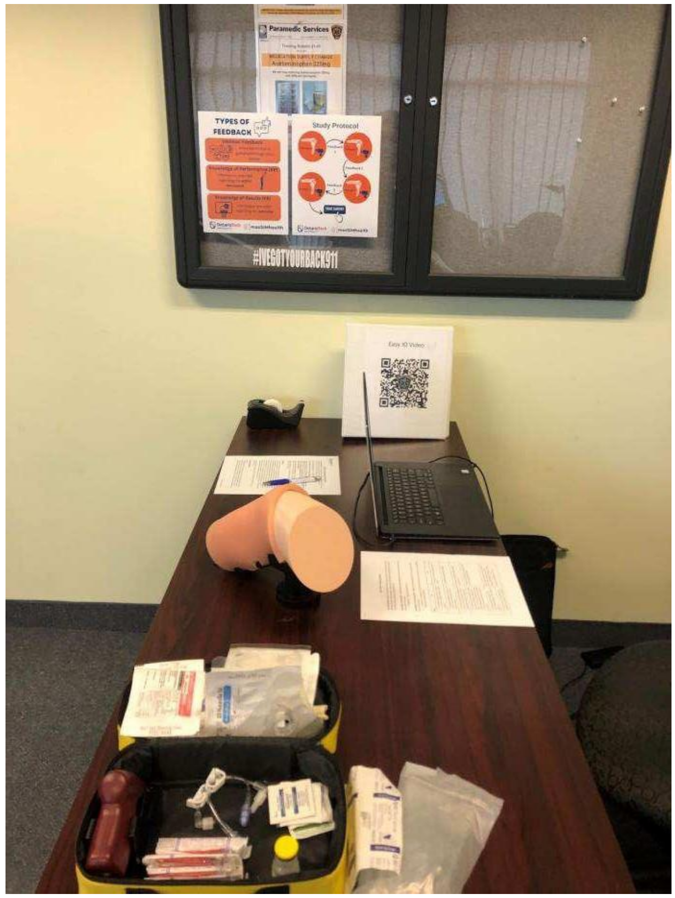

Figure 5.1: Simulation Environment

Participants completed the study one at a time. The study lasted a total of approximately 15 minutes, including being briefed by a member of the research team (JM) regarding the different types of feedback they would receive and the study protocol. Each participant provided written consent prior to participation. The protocol required each participant to perform three IO access attempts on the IO access simulator (Sivanathan et al., 2022) with an instructor providing one of the three types of feedback in between each attempt, following a guiding script for each type of augmented feedback. The order in which the type of feedback was provided after each attempt was rotated using a Latin square design. The participants were informed by the instructors of what feedback type they would be receiving prior to each attempt, and again right before providing it after each attempt, but they were not aware of the order in which they would receive the feedback at the start of the study. At the end of the practice session, the participants were then asked to complete an online survey (Table 5.1) to assess the perceived relative effectiveness of each type of feedback. There were three components to the survey; 1) demographic data, 2) self-efficacy data regarding the learning experience, and 3) indicating which feedback was most effective and why. The demographic data collected aimed to gather information on how experienced the ACP was in performing an IO access. The self-efficacy component was based on the Michigan Standard Simulation Experience Scale (Seagull & Rooney, 2014), which is used to gather perspectives on SBHPE environments, to assess whether participants found the learning experience (using the IO access simulator while receiving feedback) helped improve their knowledge, confidence, and ability in performing the IO access procedure. Participants had to rank each question on a 5-point Likert scale with 1 being strongly disagree and 5 being strongly agree. The final component of the survey required participants to select which feedback was most effective and which was least effective, then explain their selections in an open-ended question format.

Question #	*Question*
	DEMOGRAPHIC QUESTIONS
1	How many years have you been in practice as an ACP? Please indicate full time or part time.
2	How many IOs have you done in your career?
3	I attempted an IO in the last...
4	What is your perceived ability to perform IOs?
	SELF-EFFICACY QUESTIONS
5	This learning experience helped improve my KNOWLEDGE on the procedure in scope.
6	This learning experience helped improve my CONFIDENCE in performing the procedure in scope.
7	This learning experience helped improve my ABILITY in performing the procedure in scope.

	FEEDBACK QUESTIONS
8	Which type of feedback was the MOST effective for you?
9	Which type of feedback was the LEAST effective for you?
10	Please explain your reasoning for your response to questions 8 and 9.

Table 5.1: Survey for Participants

In addition, after the data was collected for each of the ACPs, an online survey was given to the two instructors to assess their perspective of the experience by ranking on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree), to determine which feedback was easiest for them to provide to learners, and to express which feedback they believed was most effective for the learners. The questions are shown in Table 5.2 below.

Question #	*Question*
1	It was easy to follow the script developed from the Design Thinking and Delphi rounds.
2	The learning experience (using the IO simulator with your feedback) was a beneficial training experience for you.
3	Was it easier to provide participants with KP (knowledge of performance) or KR (knowledge of results)?
4	Which feedback do YOU think the participants liked the most?
5	Please explain your answers for the questions above, and provide any additional comments you would like to add regarding this experience.

Table 5.2: Survey for Instructors

5.2.3 Variables of Interests and Data Analysis

A linear regression analysis was conducted for the demographic data using SPSS Version 28 (IBM® Corp., 2021) to determine if there were any correlations between the prior experience of the ACP with which feedback they chose to be most and least effective. The self-efficacy data was considered ordinal, therefore, the median and standard deviations for each question were calculated. The feedback ranking data was separated into quantitative and qualitative data. The quantitative data from the surveys were analyzed using a Chi-square analysis and the qualitative data were thematically analyzed. The instructor data were not analyzed using inferential statistics, as there were only two individuals enrolled in the study. However, the results were utilized to provide some insight into the different perspectives of the learning experience.

5.3 Results

The descriptive statistics are illustrated in Figures 5.2-5.5. Figure 5.2 shows a plot indicating how many years the participants have been an ACP ranging from 0 years (an ACP student) to 24 years. There was an even spread of participants' years as ACPs within the range, with no particular groupings at a specific year.

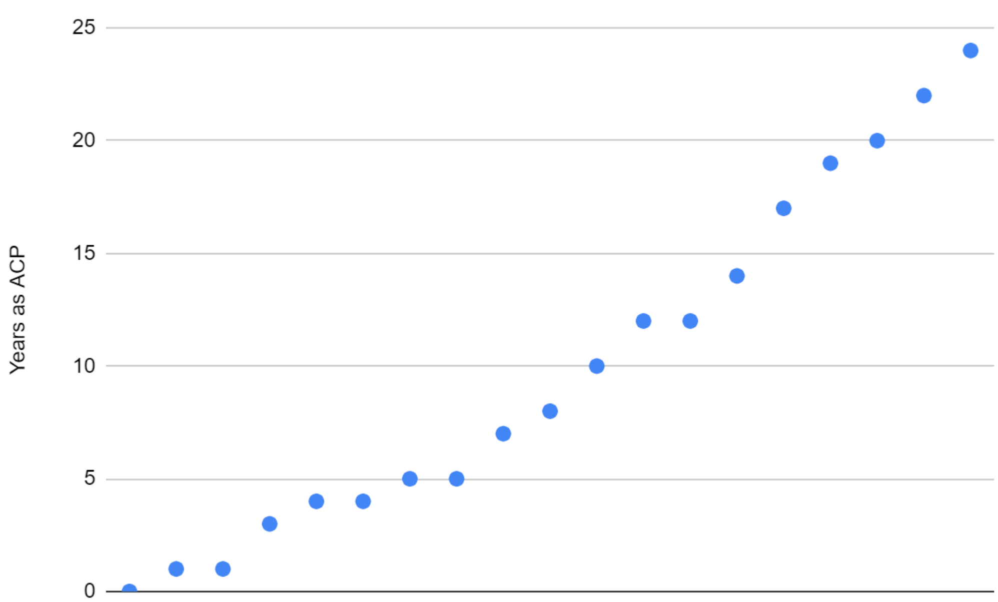

Figure 5.2: Years as ACP as indicated by participants.

Figure 5.3 shows how many estimated IOs have been performed by the participants throughout their careers. The most prominent range of total IOs performed was 10-15 with 5 participants, next was 5-10, 25-50, and 50, each with 4 participants. This was followed by 20-25 IOs total performed in their career as indicated by 3 participants, and finally, one participant indicated they have performed 1-5 IOs total in their career so far.

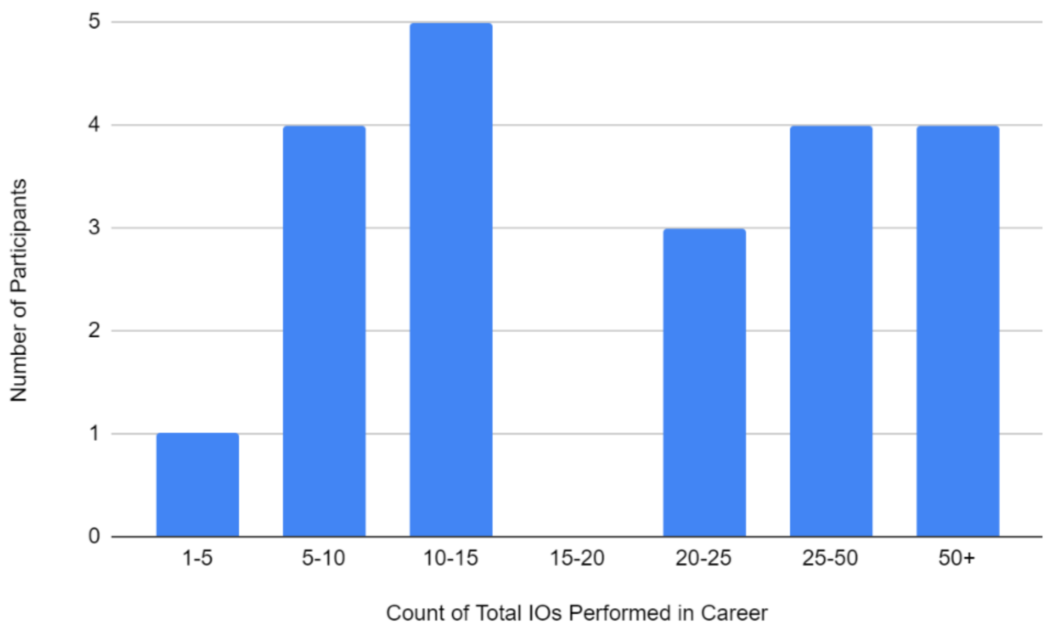

Figure 5.3: Summary of the participants' count of estimated total of IOs performed in their career

Figure 5.4 shows when the participants last attempted an IO in practice before participating in the study. Twelve participants selected that they had performed an IO within the last month prior to participation in this study, followed by 6 participants who performed an IO within the last year, and 3 participants indicated that they had performed an IO within the last week prior to completing the study.

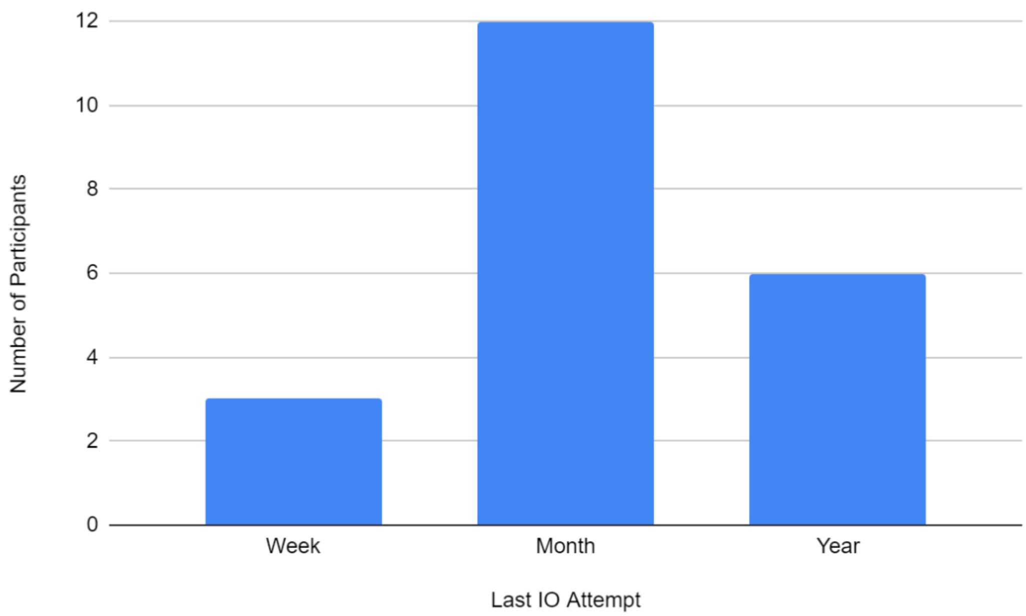

Figure 5.4: Participants' last IO attempt Before Participation in Study

Figure 5.5 shows the participants perceived confidence in performing IOs. As seen in the figure, eighteen participants indicated that they were either confident (n=9) or very confident (n=9) in performing IO access skills. 2 participants said they were neutral, with one participant indicating that they were not confident in performing IOs.

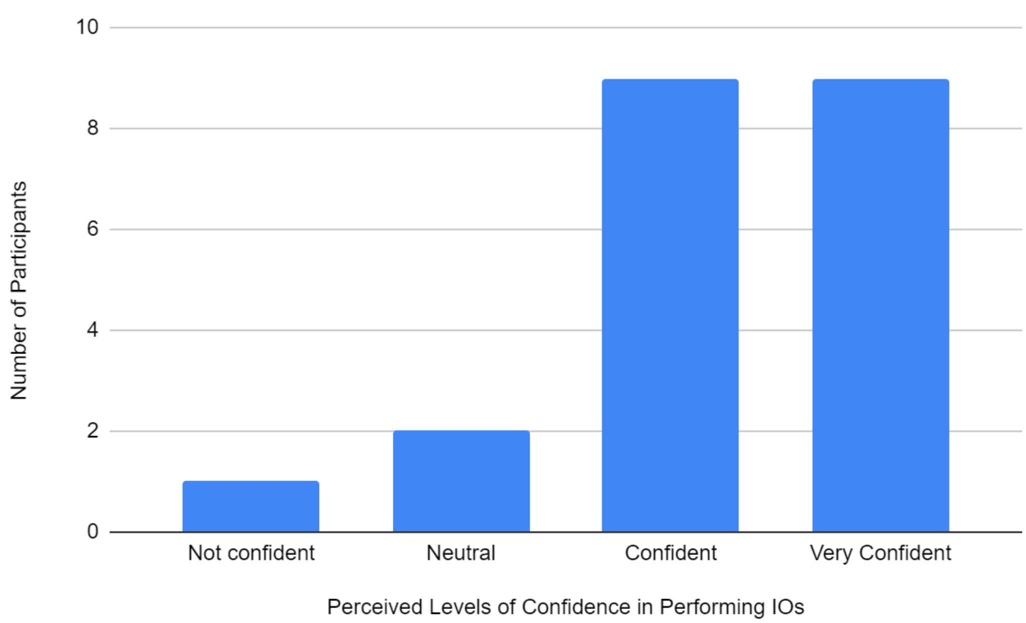

Figure 5.5: The participants' perceived level of confidence in performing IOs

5.3.1 Relationship between experience and choices of perceived effectiveness of feedback

The results of the linear regression analysis are shown below in Table 5.3. In addition to the independent variables indicated in the above figures (years as ACP, estimated total of IOs performed in career, the last time attempting an IO prior to participation in the study, and the perceived confidence in performing IOs), the instructor the participants had for the study was also investigated to see if who the instructor was affected the participants choice of perceived effectiveness of feedback. Based on these results, the only significant correlation was between the last time the participants attempted an IO in practice and what they perceived as the least effective feedback ($p = 0.01$). However, the R squared value was only 0.241, indicating that there was only a 24% chance of that variability being predicted.

Independent Variables	**Significance of Correlations with Dependant Variables**	
	Most Effective Feedback	*Least Effective Feedback*
Years as ACP	0.45	0.36
Total IOs in Career	0.48	0.29
Last Time Attempting IO	0.10	0.01
Perceived Ability	0.46	0.39
Instructor	0.20	0.31

Table 5.3: Significance of correlations of the independent variables with the dependent variables

5.3.2 Self-Efficacy of Simulation Environment

The data are presented in Table 5.4 as frequencies, medians, and standard deviations. Overall, the participants thought that the learning experience (using the IO access simulator with feedback from an instructor) helped improve their knowledge (median = 4, SD = 0.470), confidence (median = 4, SD = 0.600), and ability in performing the procedure (median = 4, SD = 0.733). Therefore, indicating that the SBHPE environment was beneficial to improving their self-efficacy in performing this procedure.

	This learning experience helped improve my KNOWLEDGE on the procedure in scope	*This learning experience helped improve my CONFIDENCE in performing the procedure in scope*	*This learning experience helped improve my ABILITY in performing the procedure in scope*
Strongly Disagree (1)	0	0	0
Disagree (2)	0	0	1
Neutral (3)	0	2	4
Agree (4)	16	14	14
Strongly Agree (5)	7	7	4
Data Analysis			
Median	4.000	4.000	4.000
Standard Deviation	0.470	0.600	0.733

Table 5.4: Self-Efficacy data with outliers as medians

5.3.3 Perceived Effectiveness of Feedback Data

Quantitative analyses: The quantitative results shown in Table 5.5 indicate that KP was significantly perceived as the most effective feedback and KR was significantly perceived as the least effective feedback (p = 0.0003).

Type of Feedback	*Most Effective*	*Least Effective*
KP	15	3
KR	2	13
Intrinsic	6	7
Data Analysis		
X^2	16.1436	
DoF	2	
p	0.0003	

Table 5.5: Most effective versus least effective feedback and Chi-Square analysis

Qualitative analyses: Three main themes emerged from the qualitative analysis which revolve around the types of feedback received (KP, KR, intrinsic), their perceived value or effectiveness, and the role of feedback in learning, adjustment, and improvement. The three themes are; 1) the value of KP; 2) the limitations of KR or intrinsic feedback; and 3) the importance of feedback for learning and improvement. These themes with supporting quotes are shown in Table 5.6 below. For the first theme (value of KP), several comments were highlighting the importance and effectiveness of receiving specific and detailed feedback on the procedure, technique, and steps involved in performing a skill. Participants appreciated the ability to adjust, improve, and learn from their mistakes based on this type of feedback. The second theme, limitations of KR or intrinsic feedback, some comments were expressing less value or effectiveness attributed to KR or intrinsic feedback. KR, which provides information on whether the skill was performed correctly or incorrectly, is seen as less informative and lacking in instructional guidance. Intrinsic feedback, based on personal assessment or feeling, is considered subjective and may not necessarily lead to recognizing inefficiencies or areas for improvement. Finally, the third theme, the importance of feedback for learning and improvement was highlighted by many participants emphasizing the significance of feedback in the learning process and improving skills. Feedback, particularly KP, is viewed as valuable for adjusting and refining techniques, understanding specific steps, and enhancing overall performance. The ability to learn from feedback and make corrections for future attempts is seen as crucial for skill development.

Themes	**Supporting Quotes**
Value of KP	"Knowledge of Performance was most effective because it outlined the specifics that needed to be changed or repeated to correctly perform the given skill" (participant #2) "[Knowledge of] Performance was more valuable as I was able to correct my initial attempt and remark my needle positioning" (participant #11) "Knowledge of Performance gave me information on the actual procedure and where I went right/wrong" (participant #4) "The most effective feedback for me was knowledge of performance. I enjoyed having the very specific guidelines given to me so that I could assess how I was doing directly after performing the skill. I was able to create a checklist in my head of what was good and what needed improvement" (participant #21)
Limitations of KR or Intrinsic Feedback	"I believe that the knowledge of results was least informative as it just tells me whether I did it right or wrong" (participant #4)

	"The least effective was the knowledge of results as it seemed very "cold" and "clinical" and lacked humanity" (participant #17) "Intrinsic feedback was least valuable because the skill may have been performed incorrectly even if based off of my assessment it appeared to be done right" (participant #2) "Intrinsic feedback didn't provide the reassurance and confirmation that would increase my confidence in a skill." (participant #23)
Importance of Feedback for Learning and Improvement	"I appreciate hearing feedback. you can learn from feedback, improve on mistakes" (participant #20) "Knowing why a skill was done right or wrong helps to better correct wrong steps" (participant #18) "With Knowledge of Performance, you can learn from your feedback and improve on skills in the future" (participant #12) "I found that the location [of IO needle insertion] was much better positioned when I did in fact listen to the feedback about needing more external rotation" (participant #14)

Table 5.6: Themes and supporting quotes

Apart from these main themes, some nuanced and interesting topics emerged from the open-ended question. First is that there are individual learning preferences that affect which feedback is most effective for the participants. Several participants mentioned their preference for detailed feedback and a step-by-step breakdown of the skill, as indicated by the first theme in Table 5. On the other hand, some participants valued a more general overview and reinforcement of their existing knowledge, with one participant noting that, “knowledge of results helped to reinforce my existing knowledge without overwhelming with other information and details” (participant #22). Another topic that arose with some of the more experienced learners (17+ years of experience) was that they provided some insight into why intrinsic feedback may be favorably compared to augmented feedback. One participant indicated, “I think my intrinsic feedback was more valuable than KR due to the fact I have done it multiple times so using a training adjunct I can feel to landmark, feel the pop of the IO gives me more value than just being told I did it correctly” (participant #1). Similarly, another participant noted, “I think KP is very important for a new learner but for someone who does IO regularly or an experienced provider they might be comfortable with the steps but need that feedback of the results” (participant #10). Finally, an interesting point emerged with how the feedback received when using the IO access simulator would differ when performing this skill on an actual patient. The participant first explained that KP was more effective for them when using the IO access simulator, then went on to say that, “...although I am very intrinsic in terms of how my practice is, and on real patients, it is easier to tell what is working and what is not working, however on the training tool there was little ability to see if the line flushed well, or medication was able to be administered” (participant #21).

5.3.4 Instructor Perspectives on Learning Experience

The responses from both instructors were identical to each other in that they both strongly agreed that it was easy to follow the feedback script provided to them and that the learning experience was a beneficial training experience. Additionally, both instructors found that it was easier to provide KP in comparison to KR and that they believed that KP was liked by participants the most in comparison to KR and intrinsic feedback. When providing reasoning for this, one instructor indicated, “I truly think students want detailed feedback, especially this generation. But having that intrinsic feedback where they get to see their “poor placement” is beneficial to their learning and practice” (instructor X). On a similar note, the other instructor commented, “I suspect most participants would prefer KP or intrinsic feedback. KP would likely be most beneficial for the new learner, with intrinsic feedback being appreciated by the experienced learner” (instructor Y). When discussing the overall experience, it was suggested, “to provide a bit more 'training', just to ensure more consistency between myself and the other administrators of the feedback” (instructor Y).

5.4 Discussion

The overarching aim of this work was to answer the question of what type of feedback (KR, KP, intrinsic) is perceived to be most effective when acquiring complex technical skills by advanced learners in the context of SBHPE of learning IO access skills by ACPs. To accomplish this, we first had to operationally define two types of augmented feedback (KP and KR) in this context. This was described in the companion paper and resulted in the generation of an 8-point list of feedback in the form of KP and the form of KR based on an IO skills checklist (Micallef et al., 2023). Next, we asked ACPS to practice the skill three times, and after each attempt, they received one of the three types of feedback to investigate if they perceived one of these sources of feedback to be more effective when compared to intrinsic feedback. Twenty-three ACPs from the Region of Durham Paramedic Services used a previously developed IO access simulator and received all three forms of feedback (KP, KR, and intrinsic) from paramedic educators. The participants then had to rank which feedback they perceived to be more effective and explain their reasoning. The results from this study indicated that KP was perceived to be the most effective, then intrinsic, and then KR as the least effective.

There are methodological, practical, and theoretical contributions of this work: *Methodological contributions*: Methodologically, using the DBR approach to study the development, testing, and implementation of educational innovation in a simulation setting is emerging (Momand et al., 2022). Using this approach in the context of simulation education allows for the collaboration of designers, stakeholders (facilitators), and end-point users (learners) to develop an educational intervention, which can result in an increase in ease in practically using the intervention (Sivanathan et al., 2022). *Practical contributions*: This leads to the practical implications of how paramedic educators can create an SBHPE environment for advanced learners. Understanding that despite the learners being more experienced, they still require feedback to be able to recall specific steps and understand how to correctly perform them. As well, it is also important to note that since the learners are more experienced, intrinsic feedback can be of value to them to help solidify their learning. Based on the perspectives of the instructors in this study, ensuring proper training in the different types of feedback should be considered to ensure that the instructors are comfortable and consistent with the different forms of feedback. This is in line with most deterministic implementation science frameworks, such as CFIR (Damschroder et al., 2022) that speculate that educational materials are one of the critical constructs that facilitate the successful implementation of innovation in the practice setting. *Theoretical contributions*: To the best of our knowledge, no research assesses the perceived preferences of the two types of augmented feedback (KP and KR) in comparison to intrinsic feedback for advanced learners in a SBHPE environment, therefore this work provides e insights on how feedback can be utilized in simulation. In a systematic review by Oppici et al. (2021), the authors examine the effectiveness of two types of augmented feedback in promoting motor skill learning. The results from this review indicate that for skills that require technique and precision, KP tends to be more effective than KR. This is in line with our findings in this article, as IO access skills require technique and precision to perform successfully. However, the systematic review indicates that these findings can only be generalized to novice learners, highlighting the gap that this work begins to fill by getting the perceptions on feedback from advanced learners. Additionally, none of the articles in the systematic review assess the feedback in a SBHPE environment. Additionally, an interesting finding from this work is that intrinsic feedback was ranked higher than KR for perceived effectiveness.

Study limitations: We were unable to assess if actual learning was affected based on the different forms of feedback due to time constraints with the participants. Our future work will employ an experimental design that would allow us to assess this. Another potential limitation is that we had to rely on the participants' understanding of the different types of feedback. For many, this study was the first time they heard of these types of feedback. To mitigate this, we provided an oral overview of the feedback types with a visual poster to reference throughout the study, as well as a cheat sheet with the definitions and the feedback given to them while filling out the survey.

5.5 Conclusion

This study aimed to assess the perceived effectiveness of different types of feedback (intrinsic, KP, and KR) for ACPs acquiring IO access skills using an IO access simulator. The study followed the test and evaluation phases of the DBR framework where instructors provided augmented feedback to the participants while they used the IO access simulator and compared it to their intrinsic feedback. The participants then completed an online survey to evaluate their perception of the relative effectiveness of each type of feedback, resulting in KP being perceived as the most effective, then intrinsic feedback, and KR as the least effective.

Overall, this study contributes to the existing knowledge in the field of feedback by exploring the perceived effectiveness of both augmented and intrinsic feedback in a SBHPE context. The findings have the potential to inform educators and practitioners in healthcare professions about the most effective feedback strategies for advanced learners acquiring complex technical skills. Further research to compare the actual learning effects of these types of feedback will provide a comprehensive understanding of which feedback type for advanced learners in SBHPE is best, ultimately enhancing the training and development of healthcare professionals.

5.6 References

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research?. *Educational researcher, 41*(1), 16-25. https://doi.org/10.3102/0013189X11428813

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The journal of the learning sciences, 13*(1), 1-14. https://doi.org/10.1207/s15327809jls1301_1

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher, 32*(1), 9-13. https://doi.org/10.3102/0013189X032001009

Damschroder, L. J., Reardon, C. M., Widerquist, M. A. O., & Lowery, J. (2022). The updated Consolidated Framework for Implementation Research based on user feedback. *Implementation science*, *17*(1), 1-16. https://doi.org/10.1186/s13012 022-01245-0

Dubrowski, A., & Backstein, D. (2004). The contributions of kinesiology to surgical education. The Journal of bone and joint surgery. *American volume*, *86*(12), 2778–2781. https://doi.org/10.2106/00004623-200412000-00029

Edelson, D. C. (2002). Design research: What we learn when we engage in design. *The Journal of the Learning sciences*, *11*(1), 105-121. https://doi.org/10.1207/S15327809JLS1101_4

Fahd, K., Miah, S. J., Ahmed, K., Venkatraman, S., & Miao, Y. (2021). Integrating design science research and design based research frameworks for developing education support systems. *Education and Information Technologies*, 26, 4027 4048. https://doi.org/10.1007/s10639-021-10442-1

Hoadley, C. M. (2004). Methodological alignment in design-based research. *Educational psychologist*, 39(4), 203-212. https://doi.org/10.1207/s15326985ep3904_2

Kothari, L. G., Shah, K., & Barach, P. (2017). Simulation based medical education in graduate medical education training and assessment programs. *Progress in Pediatric Cardiology*, *44*, 33-42. https://doi.org/10.1016/j.ppedcard.2017.02.001

Micallef, J., Button, D., Uribe Quevedo, A., McClatchey, C., King, L., & Dubrowski, A. [in press: accepted] Defining the Nature of Augmented Feedback for Learning Intraosseous Access Skills in Simulation-Based Health Professions Education. *Cureus*, (): e. doi:10.7759/cureus.

Moinuddin, A., Goel, A., & Sethi, Y. (2021). The Role of Augmented Feedback on Motor Learning: A Systematic Review. *Cureus*, *13*(11), e19695. https://doi.org/10.7759/cureus.19695

Oppici, L., Dix, A., & Narciss, S. (2021). When is knowledge of performance (KP) superior to knowledge of results (KR) in promoting motor skill learning? A systematic review. *International Review of Sport and Exercise Psychology*, 1-25. https://doi.org/10.1080/1750984X.2021.1986849

Schmidt, R. A., Zelaznik, H. N., Wulf, G., Winstein, C. J., & Lee, T. D. (2019). *Chapter 11: Augmented Feedback.* In Motor control and learning: A behavioral emphasis (6th ed.). Human Kinetics.

Scott, E. E., Wenderoth, M. P., & Doherty, J. H. (2020). Design-based research: a methodology to extend and enrich biology education research. *CBE—Life Sciences Education*, *19*(2), es11. https://doi.org/10.1187/cbe.19-11-0245

Seagull, F. J., & Rooney, D. M. (2014). Filling a void: developing a standard subjective assessment tool for surgical simulation through focused review of current practices. *Surgery, 156*(3), 718-722. https://doi.org/10.1016/j.surg.2014.04.048

Sherwood, D. E., & Lee, T. D. (2003). Schema theory: critical review and implications for the role of cognition in a new theory of motor learning. *Research quarterly for exercise and sport*, *74*(4), 376-382. https://doi.org/10.1080/02701367.2003.10609107

Sivanathan, M., Micallef, J., Clarke, K. M., Gino, B., Joshi, S., Abdo, S., Buttu, D., Mnaymneh, M., Siraj, S., Torres, A., Brock, G., Pereira, C., & Dubrowski, A. (2022). The Development and Initial End-Point User Feedback of a 3D-Printed Adult Proximal Tibia IO Simulator. *Cureus, 14*(5), e25481. doi:10.7759/cureus.25481

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational technology research and development, 53*(4), 5-23. https://doi.org/10.1007/BF02504682

Chapter 6. Discussion

6.1 Summary

The overarching aim of this work was to determine *what type of feedback (KP, KR, or intrinsic) is perceived to be most effective when acquiring complex technical skills by advanced learners in the context of SBHPE when learning IO access skills by ACPs?* To answer this question, two sub-questions were developed to guide this work:

1. *Can expert educators and paramedics agree on the definitions of two types of augmented feedback (KP and KR) in this context? (study 1)*
2. *Do learners perceive one of these sources of augmented feedback (KP or KR) to be more effective when compared to intrinsic feedback in this context? (study 2)*

This thesis work was guided by the DBR framework (Brown, 1992), with an emphasis on the design, test, and evaluation phases. Study 1 was rooted in the design phase of DBR where a solution had to be developed which solved the theoretical and practical problems. For this work, that meant I had to determine what KP and KR can be provided to ACPs when learning IO access skills using the previously developed simulator to determine which is perceived to be most effective. This was achieved by using a hybrid ideation and consensus-building approach with an expert panel method to determine and reach a consensus on the steps involved in performing an IO access with the procedural simulator (Sivanathan et al., 2022a; Sivanathan et al., 2022b). Next, the experts were asked to determine how those steps can be used to structure augmented feedback in the form of KP and KR. This resulted in the generation of an 8-point list of feedback in the form of KP and the form of KR based on an IO skills checklist that was used by the paramedic instructors as a guide when providing feedback to the ACPs in the second part of my thesis. Study 2 of this work was rooted in the test and evaluate stages of DBR where the intervention developed is tested and formally evaluated. This was accomplished by asking the ACPs to use the procedural IO access simulator. During practice, they received each of the types of feedback from the instructors, and they were tasked with comparing the perceived effectiveness of each type, as well as intrinsic feedback (i.e., no feedback from instructors). The results from this study indicated that

KP was significantly perceived to be the most effective, then intrinsic, and then KR was perceived to be the least effective.

6.2 Interpretation and Implication of Results

The results of this thesis are interpreted and provide implications methodologically, theoretically, and practically. The methodological contributions of this thesis work revolve around utilizing the DBR approach to develop feedback in SBHPE. DBR was originally introduced by Ann Brown in the early 1990s as a collaborative method for creating interventions in educational settings (Anderson & Shattuck, 2012). While traditionally used in conventional learning environments (such as in classrooms to develop curricula), DBR can also be applied to experiential learning, just as it was in this thesis for a SBHPE context. Similarly, Schmitz et al. (2015) investigated a mobile game that was successfully designed using DBR. The researchers here used DBR to develop and implement a cardiopulmonary resuscitation training approach, called HeartRun, for school children. They underwent a total of three cycles (three studies) of DBR where participants - medical experts (study 1), students aged 10 to 16 (study 2), and students aged 14 to 18 with learning disabilities (study 3) - assessed the design and useability of the game using a questionnaire following the System Usability Scale (SUS) where they had to rank certain criteria of the game on a Likert scale of 1 to 5 (Brooke, 1996). In studies 2 and 3, the participants also provided self-assessed learning outcomes while using the training tool through questionnaires that had participants rank on a scale of 1 to 5 whether they had learned the specific learning outcomes, as well as interviews to allow for further elaboration. Similar to Schmitz et al. (2015), this thesis work also used DBR to both develop a new training approach (feedback to suit the specific SBHPE context of ACPs learning IO access skills using a procedural simulator) and assess the perceived learning using the said approach. While Schmitz and colleagues collected their quantitative data via self-assessed learning outcome questionnaires and qualitative data via interviews, my thesis work collected both qualitative and quantitative data in the form of a survey that had both rankings on a 5-point Likert scale and open-ended questions. An interesting difference between this study and my thesis is the methods used to gather consensus on the design of the learning tool. Schmitz et al. (2015) utilized the SUS which is a commonly used questionnaire-based method utilized to evaluate the usability of a system or product. It involves participants rating 10 statements on a 5-point Likert scale, yielding a numeric indicator of the system's perceived user-friendliness and satisfaction (Brooke, 1986).

The flexibility of the methods employed in each phase of DBR allows for customization to specific research contexts (Scott et al., 2020). Therefore, the unique aspect of this research lies in the combination of DT and Delphi methods during the design phase of DBR. Two studies by Sivanathan et al. (2022a and 2022b) used a similar combination of DT and Delphi to guide the design of a virtual reality simulation addressing moral distress in healthcare professionals, as well as to develop the IO access simulator that was used in this thesis. While Sivanathan and colleagues utilized these methods to build a game and a simulator, in this thesis, it was used to build a feedback system for a SBHPE context. The work by Sivanathan et al. (2022a and 2022b) had to address constraints with the technology to develop the virtual reality and IO access simulators, respectively, can and cannot do, and then use focus groups to bring things together. However, in my thesis, the constraint that I had to address was to provide education about feedback types to everyone involved. This was necessary as the experts were clinical experts and not education experts, and they went into the DT and Delphi rounds with no idea about what KP, KR, and intrinsic feedback are. Because of the collaborative nature of DBR, my thesis work highlights the importance of the need to ensure that DBR involves a process that; a) checks for knowledge, and b) provides education for stakeholders to bring them to a minimum competency that is needed for them to provide researchers and designers with their opinions.

Theoretically, my thesis work advances the field of SBHPE and feedback, by providing early evidence about what type of feedback to use when teaching advanced learners technical skills in a SBHPE environment. A key finding from this research was that intrinsic feedback was not perceived to be the least effective, but rather it was perceived to be less effective than KP (perceived to be most effective), but more effective than KR (perceived to be least effective). Intrinsic feedback does not involve formal evaluation but requires the learner to be able to identify their errors and learn from them

(Schmidt et al., 2019). In this thesis, participants were allowed to take apart the IO access simulator and get a better look at their landmarking to be able to identify where they went wrong. One possible explanation for this finding is that the ACPs may have the experience and advanced knowledge to know what they did wrong between attempts and can correct themselves. There are two bodies of evidence that can help with the interpretation of these results: KP vs KR, and self-regulation in SBHPE. When comparing KP and KR, previous research shows that for skills that require technique and precision, KP tends to be more effective than KR (Oppici et al., 2021). This is in line with the findings of this research concerning KP being ranked as most effective and KR being ranked as least effective because IO access skills require technique and precision to perform successfully (Oppici et al., 2021). However, the systematic review by Oppici et al. (2021) indicates that these findings can only be generalized to novice learners. As well, the findings concerning studies that assess these types of feedback in learning athletic and exercise tasks, as with the majority of the research done in this field. Therefore, the results of my work support and extend these effects to highly skilled learners in a SBHPE environment, who undergo maintenance training on complex psychomotor tasks.

Self-regulation and intrinsic feedback play crucial roles in the acquisition and refinement of psychomotor skills, and the interplay of these two can provide some insight as to why intrinsic feedback was perceived to be more effective than KR. Self-regulation refers to an individual's ability to monitor, control, and adjust their behavior, thoughts, and emotions during the learning process (Brydges et al., 2012; Panadero, 2017). In the context of psychomotor skills acquisition, self-regulation involves the ability to regulate one's movements, actions, and strategies to improve performance (Wang et al., 2020). It includes processes such as setting goals, planning, monitoring progress, and making adjustments based on feedback (Chiniara et al., 2013). Intrinsic feedback is the sensory information received by an individual's senses during the performance of a psychomotor skill (Schmidt et al., 2019), which is why we allowed participants to not only reflect on how the procedure felt but let them fully examine the IO access simulator to see where they potentially went wrong or to confirm they did it right. Intrinsic feedback provides real-time information about the quality, accuracy, and effectiveness of the skill execution

(Schmidt et al., 2019). For example, in sports, intrinsic feedback can come from the feel of the movement, the sound of a ball being struck, or the visual cues of body positioning.

Research has highlighted the following key points regarding self-regulation and intrinsic feedback in technical skills acquisition. First is that self-regulation involves setting specific, challenging, and realistic goals related to the acquisition of technical skills (Chiniara et al., 2013). Clear goals provide direction and motivation, and learners can use intrinsic feedback to monitor their progress toward these goals. Next is that self-regulated learners actively monitor their performance by using their intrinsic feedback (Wang et al., 2020). They evaluate their movements, compare them to desired outcomes or standards, and make adjustments accordingly. This self-monitoring process helps in error detection and correction (Schmidt et al., 2019). Third is that intrinsic feedback enables learners to identify errors or discrepancies between their intended actions and actual performance which allows them to make appropriate adjustments, refine their movements, and develop more accurate motor patterns over time (Schmidt et al., 2019). Additionally, self-regulated learners use intrinsic feedback to adapt their movements and strategies (Brydges et al., 2012). They experiment with different approaches, analyze the effects, and select the most effective techniques. This iterative process of exploration and adjustment facilitates skill refinement and optimization (Schmidt et al., 2019). Finally, while intrinsic feedback is crucial, external feedback from coaches, instructors, or peers also plays a role in self-regulation by providing additional information, guidance, and perspectives that complement intrinsic feedback (Schmidt et al., 2019). As seen in the results of this work, despite the participants all being considered advanced learners that can effectively utilize their intrinsic feedback and self-regulate their errors based on their experiences, the feedback perceived to be most effective as a type of augmented feedback (KP, specifically) provided by the instructors. Effective self-regulation involves integrating external feedback with intrinsic feedback for comprehensive skill development. Within the field of SBHPE, providing feedback to learners is a crucial aspect of simulation education, as it generates enduring learning outcomes and enables students to gain an understanding of their performance, and helps mitigate the decline in knowledge retention over time (Burns, 2015; Issenberg et al., 2005). Feedback in simulation usually comes in the form of checklists such as Global Rating Scales as well as provided verbally free form (Burns, 2015; Pelletier et al., 2023). However, no research looks into how KP, KR, and intrinsic feedback can be utilized in SBHPE environments. Therefore, this is a significant gap that this thesis begins to close through the comparison of augmented forms of feedback (KP and KR) with intrinsic feedback.

Practically, this work highlights the importance of the need to provide training regarding educational concepts, such as KP, KR, and intrinsic feedback for this to be implemented in the curriculum and increase the uptake of educators. Within this thesis, it was noted in the instructor survey that despite us providing some base knowledge on these feedback types, more training was needed for how to provide the feedback. This is in line with the Consolidated Framework for Implementation Research, an implementation framework, which has the domain of providing access to knowledge and information through training so that the innovation can be properly implemented and delivered (Damschroder et al., 2022). Through doing this, educational materials can be created for educators that can highlight the main concepts of how to teach. Another practical implication of this work is how simulations can be developed to inform learners about outcomes and be able to use their existing knowledge of intrinsic feedback to self-regulate. Having the IO access simulator developed in a manner that allowed the participants the freedom to take it apart and be able to reflect and adjust their performance was shown to be a helpful component to the learning process as indicated by the participants. Finally, while advanced learners can use their experiences to reflect and adjust their performance using intrinsic feedback, as per the results of this work, receiving augmented feedback in the form of KP is still important, even for advanced learners. While many of the participants, as well as the instructors, indicated that the more experienced ACPs would appreciate relying on their intrinsic feedback as this is what they utilize in the field, using a simulator is different from performing this skill on a patient and involves a learning curve for even the most experienced participants. Therefore, the augmented feedback helped with this learning curve and possibly provides some rationale as to why KP in a SBHPE environment was still the most preferred compared to intrinsic feedback.

6.3 Limitations and Future Directions

The main limitation of this work is that only the perceived effectiveness of the different forms of feedback was assessed without assessing actual effects on learning - which is usually done through retention or transfer tests. This thesis work was tailored to the availability of the participants, and since they were all ACPs and working in the field, we could only use 15 minutes of their time. As a result, there was no room for retention or transfer tests, so we used perceptions instead of real learning. This limitation informs the next steps of this work which would be to do a proper randomized control trial assessing the potential learning differences between KP, KR, and intrinsic feedback. Additionally, the reflect phase of DBR was not utilized in this work and is often neglected or not touched on in other studies which use DBR (McKenney & Reeves, 2018). Therefore, in future work using DBR as a framework, I plan on better utilizing the reflecting phase.

6.4 Conclusion

Through my thesis work, I was able to utilize the DBR framework and apply it to developing a SBHPE environment with advanced learners and a procedural simulator to assess the perceived effectiveness of augmented feedback (KP and KR) in comparison to intrinsic feedback when learning IO access skills. This was completed in two studies where I first used DT and Delphi methods to get a consensus on an 8-item list of feedback in the form of both KP and KR that can be provided to ACPs when using the IO access simulator. The second part of this thesis work tested and evaluated augmented feedback in comparison with intrinsic feedback. The results indicated that KP was perceived to be most effective, and KR was least effective, with intrinsic feedback being in the middle. There were theoretical contributions to the field of feedback and SBHPE, as well as methodological contributions concerning using DBR in this context. This work is just the beginning of furthering our understanding of feedback for advanced learners in a SBHPE environment.

6.5 References

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research?. *Educational researcher, 41*(1), 16-25.

https://doi.org/10.3102/0013189X11428813

Brooke, J. (1996). SUS: a ‘quick and dirty’ usability scale. *Usability evaluation in industry*, *189*(3), 189-194.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The journal of the learning sciences*, *2*(2), 141-178. https://doi.org/10.1207/s15327809jls0202_2

Brydges, R., Nair, P., Ma, I., Shanks, D., & Hatala, R. (2012). Directed self-regulated learning versus instructor-regulated learning in simulation training. *Medical education*, *46*(7), 648-656. https://doi-org.uproxy.library.dc uoit.ca/10.1111/j.1365-2923.2012.04268.x

Burns C. L. (2015). Using debriefing and feedback in simulation to improve participant performance: an educator's perspective. *International journal of medical education*, *6*, 118–120. https://doi.org/10.5116/ijme.55fb.3d3a

Chiniara, G., Cole, G., Brisbin, K., Huffman, D., Cragg, B., Lamacchia, M., Norman, D., & Canadian Network For Simulation In Healthcare, Guidelines Working Group (2013). Simulation in healthcare: a taxonomy and a conceptual framework for instructional design and media selection. *Medical teacher*, *35*(8), e1380–e1395. https://doi.org/10.3109/0142159X.2012.733451

Damschroder, L. J., Reardon, C. M., Widerquist, M. A. O., & Lowery, J. (2022). The updated Consolidated Framework for Implementation Research based on user feedback. *Implementation science*, *17*(1), 1-16. https://doi.org/10.1186/s13012 022-01245-0

Issenberg, S. B., McGaghie, W. C., Petrusa, E. R., Lee Gordon, D., & Scalese, R. J. (2005). Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. *Medical teacher*, *27*(1), 10–28. https://doi.org/10.1080/01421590500046924

McKenney, S., & Reeves, T. C. (2018). *Conducting educational design research.* Routledge.

Oppici, L., Dix, A., & Narciss, S. (2021). When is knowledge of performance (KP) superior to knowledge of results (KR) in promoting motor skill learning? A systematic review. *International Review of Sport and Exercise Psychology,* 1-25. https://doi.org/10.1080/1750984X.2021.1986849

Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. *Frontiers in psychology*, *8*, 422. https://doi.org/10.3389/fpsyg.2017.00422

Pelletier, F., Torres, A., Meloche-Dumas, L., Guérard-Poirier, N., Kaviani, A., Kapralos, B., Mercier, F., Dubrowski, A., & Patocskai, E. (2023). The Role of Collaborative Observational Practice and Feedback-Discourse to Promote Remote Acquisition of Technical Surgical Skills. *The Journal of surgical research*, *288*, 372–382. https://doi.org/10.1016/j.jss.2023.02.006

Schmidt, R. A., Zelaznik, H. N., Wulf, G., Winstein, C. J., & Lee, T. D. (2019). *Chapter 11: Augmented Feedback*. In Motor control and learning: A behavioral emphasis (6th ed.). Human Kinetics.

Schmitz, B., Klemke, R., Walhout, J., & Specht, M. (2015). Attuning a mobile simulation game for school children using a design-based research approach. *Computers & Education*, *81*, 35-48. https://doi.org/10.1016/j.compedu.2014.09.001

Scott, E. E., Wenderoth, M. P., & Doherty, J. H. (2020). Design-based research: a methodology to extend and enrich biology education research. *CBE—Life Sciences Education*, *19*(2), es11. https://doi.org/10.1187/cbe.19-11-0245

Sivanathan, M., Espinola, C. W., Uribe Quevedo, A., Kapralos, B., Krishnan, S., Bhat, V., & Dubrowski, A. (2022a). Development of Content for a Virtual Reality Simulation to Understand and Mitigate Moral Distress in Healthcare Workers. *Cureus*, *14*(11), e31240. https://doi.org/10.7759/cureus.31240

Sivanathan, M., Franco, L. Y., Joshi, S., Micallef, J., Button, D., & Dubrowski, A. (2022b). Development of Simple and Advanced Adult Proximal Tibia Simulators for a Decentralized Simulation-Based Education Model to Teach Paramedics-in\ Training the Intraosseous Infusion Procedure. *Cureus, 14*(10). doi:10.7759/cureus.30929

Wang, P. Z. T., Xie, W. Y., Nair, S., Dave, S., Shatzer, J., & Chahine, S. (2020). A comparison of guided video reflection versus self-regulated learning to teach knot tying to medical students: a pilot randomized controlled trial. *Journal of Surgical Education*, *77*(4), 805-816. https://doi.org/10.1016/j.jsurg.2020.02.014