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CURRICULUM DEVELOPMENT AND ASSESSMENT

Physiology Core Concepts

Unpacking and validating the "physiological adaptation" core concept of physiology

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Abstract

A national Task Force of 25 Australian physiology educators used the Delphi protocol to develop seven physiology core concepts that were agreed to nationally. The aim of the current study was to unpack the "physiological adaptation" core concept with the descriptor "organisms adjust and adapt to acute and chronic changes in the internal and external environments across the lifespan." This core concept was unpacked by three Task Force members and a facilitator into four themes and nine subthemes that encompass the role of stressors and disturbed homeostasis in adaptation and the capacity for, and the nature of, the physiological adaptation. Twenty-two Task Force members then provided feedback and rated the themes and subthemes for level of importance and difficulty for students to learn via an online survey using a five-point Likert scale. Seventeen respondents completed all survey questions. For all themes/subthemes, importance was typically rated 1 (Essential) or 2 (Important) ($n = 17$, means ±SD ranged from 1.1 ± 0.3 to 2.2 ± 0.9), and difficulty was typically rated 3 (Moderately Difficult) ($n = 17$, means ranged from 2.9 ± 0.7 to 3.4 ± 0.9). Subtle differences in the proportion of importance scores ($n = 17$, Fisher's exact: $P = 0.004$, ANOVA: $F_{12,220} = 2.630$, $P = 0.003$; $n = 22$, Fisher's exact: $P = 0.002$, ANOVA: $F_{12,281} = 2.743$, $P < 0.001$), but not difficulty scores, were observed between themes/subthemes, and free-text feedback was minor. The results suggest successful unpacking of the physiological adaptation core concept. The themes and subthemes can inform the design of learning outcomes, assessment, and teaching and learning activities that have commonality and consistency across curricula.

NEW & NOTEWORTHY An Australian Task Force of physiology educators identified physiological adaptation as a core concept of physiology. It was subsequently unpacked into four themes and nine subthemes. These were rated, by the Task Force, Essential or Important and Moderately Difficult for students to learn. The themes and subthemes can inform the design of learning outcomes, assessments, and teaching and learning activities that have commonality and consistency across curricula.

core concept; higher education; physiological adaptation; physiology

INTRODUCTION

The ultimate goal of teaching physiology is to support student understanding of physiological processes and the integration and application of knowledge to different situations. Concept-based learning is well suited to physiology learning because it stimulates a higher level of synergistic thinking that allows students to deepen their knowledge beyond memorizing facts (1). This requires a validated list of essential concepts, presented in a logical sequence, that is pertinent to a discipline (2, 3).

In 2009, Michael et al. (4) defined 15 core concepts of physiology that they recommended should be used to teach physiology and aid student learning. In 2020, a group of Australian

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physiology educators mapped the learning objectives of undergraduate physiology curricula at 17 Australian universities with a physiology major/specialization and accessible online information to the 15 core concepts of physiology compiled by Michael et al. (4). The manual mapping and content analysis showed that while some of the curricula's learning objectives were easily mapped to some of these core concepts like "structure and function," others were hardly matched to any (5). Furthermore, the "physiological adaptation" core concept was covered in many of the Australian undergraduate curricula but was overlooked in previous conceptual frameworks (4).

In 2021, a national Task Force of physiology educators was formed via invitation, representing 25 of the 42 Australian universities (36 public, 4 Australian private, and 2 international private). The national Task Force aimed to develop a list of core concepts of physiology using the Delphi protocol to reach Australia-wide consensus. Following this process, "physiological adaptation" with the descriptor "organisms adjust and adapt to acute and chronic changes in the internal and external environments across the lifespan" was endorsed by Australia-wide physiology educators ($n = 151$) as one of seven physiology core concepts (6). Each of the core concepts was then unpacked by teams of the national Task Force.

Given the multidimensional perspectives and constructs embraced within a core concept, like the physiological adaptation core concept, there was a need to unpack the core concept descriptor statement into a logical conceptual framework to facilitate a common understanding of its basic critical constituents (7). Thus the aim of this study was to unpack the physiological adaptation core concept into themes and subthemes and to validate these themes and subthemes. To approach this task, it is important to declare our understanding and definition of a "concept." As described by Erickson et al. (8) a concept is a "mental construct drawn from a topic or a process that transfers to new situations or contexts." Furthermore, Erickson et al. (8) referred to concepts like nesting Russian dolls, where "micro-concepts nest within macro-concepts. The higher you go in the hierarchy the more transferable the concept." Macro-concepts aim to provide "breadth," whereas, micro-concepts provide discipline related conceptual "depth" (9). In fact, these definitions and views informed our approach to unpack the seventh physiological core concept physiological adaptation where we intended to keep the themes clear and broadly applicable and designed the subthemes to embrace a deeper conceptual scope.

To validate the developed conceptual framework of the physiological adaptation core concept, we hypothesized that a group of experienced physiology educators, with diverse discipline expertise and with prior involvement in the Delphi process of the developed core concept, could rate the unpacked themes and subthemes and that they would cover all key aspects of physiological adaptation. The perceived difficulty of each theme and subtheme was also explored to inform future efforts in student learning support and curriculum design in courses featuring physiological adaption.

MATERIALS AND METHODS

This project was approved by the Victoria University Human Research Ethics Committee (HRE20-164) and Task Force members signed an approved consent form.

The method for unpacking the core concept was adapted from that of Michael et al. (10) and followed the creation of seven core concepts by a national Task Force of physiology educators from 25 Australian universities (6). The Task Force came with the following wording for the definition of the physiological adaptation core concept "organisms adjust and adapt to acute and chronic changes in the internal and external environments across the lifespan" and this formed the conceptual basis of the unpacking.

Formation and Composition of the Team

The lead investigator of the national Task Force of physiology educators randomly allocated three Task Force members to each of the seven core concepts for unpacking. All seven core concepts were also allocated the same facilitator, who was a physiology educator with over 25 years of physiology teaching experience. Thus each core concept for unpacking comprised a facilitator and three physiology educators from the Task Force. The three Task Force members that unpacked the physiological adaptation core concept were from separate Australian universities (located over 650 km apart and in different states and territories). The members of the team had expertise in medicine, neuroscience, and exercise and developmental physiology. These members had 7–20 years of experience teaching physiology and 12–80 peer-reviewed publications in physiology journals.

Overall Time Frame

The flow diagram in Fig. 1 outlines the timeline for the unpacking of the physiological adaptation core concept, which occurred in four stages over a 12-month period using a mixture of online communication such as zoom meetings,

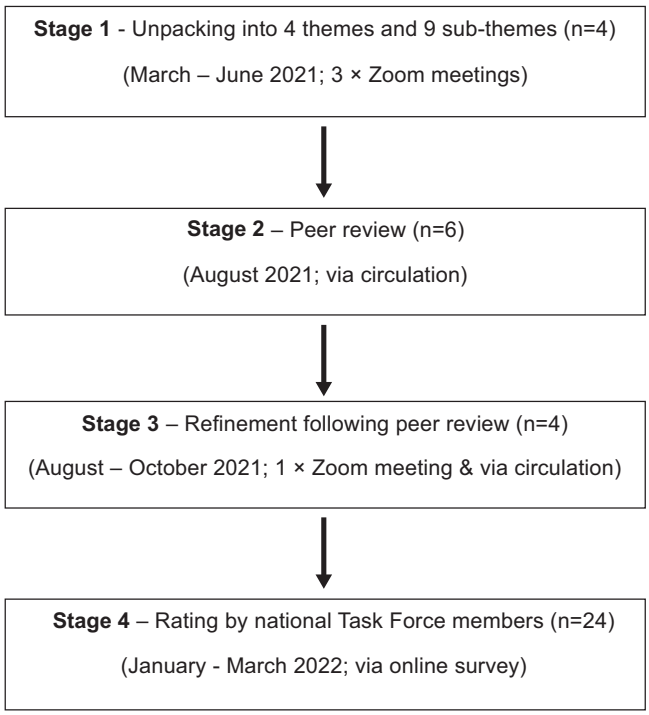

Figure 1. Key stages and timeline for unpacking the physiological adaptation core concept.

editing of documents via email/shared online folders, and online survey.

Stage 1: Unpacking the Physiological Adaptation Core Concept into Its Themes and Subthemes

The group consulted previous literature on unpacking core concepts (11), and then publications from The American Physiological Society and The Physiological Society were examined for common definitions/terminology regarding adaptation, physiological adaptation, adjustment, and stressor. Led by the facilitator, the three physiology educators used a consensus-based approach across three rounds of discussion and editing via Zoom meetings to unpack the physiological adaptation core concept "organisms adjust and adapt to acute and chronic changes in the internal and external environments across the lifespan" into four themes and nine subthemes arranged in a hierarchy, up to two levels deep. The themes encompassed the role of stressors and disturbed homeostasis in adaptation and the capacity for, and the nature of, the physiological adaptation. The unpacking process was informed by the team's intention to keep the conceptual themes clear and broadly applicable without detailing a specific condition or example and for the hierarchical order to aid the progression of student learning.

Stage 2: Peer Review of the Unpacked Physiological Adaptation Core Concept

The unpacked physiological adaptation core concept was then blind reviewed by another core concept unpacking team of three physiology educators from the national Task Force who individually provided critical feedback onto a single shared document.

Stage 3: Refinement and Finalization following Peer Review

The three physiology educators again used a consensus-based approach in a Zoom meeting to review the critical feedback and refine the unpacked physiological adaptation core concept. The four themes and nine subthemes were retained but the wording of definitions across several themes was amended for consistency and clarity. Final edits were then completed by circulation until the team reached an agreement on the final document.

Stage 4: Rating of the Unpacked Physiological Adaptation Core Concept by National Task Force Members

The unpacked themes and subthemes were entered into a Qualtrics survey, adapted from that of Michael et al. (10). A link was sent out to 25 physiology educators who comprised the Task Force that completed the Delphi protocol. Survey respondents were asked to rate the themes and subthemes on a five-point Likert scale for the level of importance for the students to understand (1 = Essential, 2 = Important, 3 = Moderately Important, 4 = Slightly Important, and 5 = Not Important) and level of difficulty for students (1 = Very Difficult, 2= Difficult, 3 = Moderately Difficult, 4 = Slightly Difficult, and 5 = Not Difficult). Respondents were also asked for additional open-ended comments for each of the four themes and also for the core concept overall.

The characteristics of survey respondents were drawn from a separate earlier survey of Task Force members (conducted before the unpacking of the core concepts). The data collected from the earlier survey included the respondents' academic title and qualifications, current role and institution, experience in teaching human physiology, current teaching workload, types of courses/degrees in which they have taught human physiology, the modes of delivery (lectures, workshops, etc.), the undergraduate or postgraduate year level(s) they have taught into, their role(s) in design of curriculum and assessment, and whether the respondent identifies as a physiologist or as an expert in another discipline.

Statistical Analyses

Group data are reported as means ± SD, median, and interquartile range. Group data for ratings of importance and difficulty were analyzed with separate Fisher's exact tests with the Monte Carlo method. When the proportion of importance scores or difficulty scores differed significantly by themes/subthemes, a one-way ANOVA with Dunnett's post hoc comparison was performed (against the most important or difficult theme/subtheme). The relationship between importance and difficulty was explored in the complete data set with polychoric correlation matrix (unified Bayes modal estimation with a weak prior, bootstrap with 95% confidence interval, matrix smoothed if necessary) (12). Statistical analysis was performed in SPSS version 28.0 (SPSS Inc., Chicago, IL). Statistical significance was set at $P < 0.05$.

RESULTS

Unpacked Themes and Subthemes

The physiological adaptation core concept was unpacked into four themes and nine subthemes, and these are presented in Table 1.

Theme and Subtheme Ratings of Importance and Difficulty

Twenty-two of the 25 Task Force members commenced the survey. Four of the 22 Task Force members failed to provide an answer for one or more of the survey questions on importance and difficulty, and an additional Task Force member did not disclose their identity and thus the participant characteristics for this individual are unknown. Thus the sample size for the incomplete data set is $n = 22$, and the sample size for the complete data set is $n = 17$. The participant characteristics for the complete data set ($n = 17$) are presented in Table 2. The complete data set ($n = 17$) consisted of survey respondents from 17 universities (16 public, 1 Australian private), and all of these survey respondents reported currently teaching human physiology in a degree program and having experience in the design of human physiology curriculum and assessment.

Figure 2 shows raw ratings of the importance and difficulty of each core concept and subtheme for the complete data set ($n = 17$). Most survey respondents rated the themes and subthemes as Essential or Important, and the most common rating for level of difficulty for students was Moderately Difficult. Table 3 contains group data for this complete data

Table 1. *"Physiological adaptation" themes and subthemes*

Theme/ Subtheme	Description
1	Changes in the internal or external environment of an organism can disturb homeostasis and disturbed homeostasis can lead to acute and/or chronic adjustments at the molecular, cellular, tissue, organ, organ system, and/or organism level
1.1	Disturbances in homeostasis induce a state of stress and the nature of the stressor(s) (e.g., type, intensity, onset, duration, and frequency of exposure) determines the type and extent of the physiological adjustment
1.2	Several simultaneous stressors may *interact*[a] and influence the overall physiological adjustment
1.3	Adjustments at the molecular, cellular, tissue, organ, organ system, and/or organism level can lead to adaptation that may improve the organisms' suitability to their environment
1.4	Adaptation persists beyond the exposure to the stressor
1.5	Adaptation may or may not be reversible
2	For a given stressor, the capacity for *physiological*[b] adaptation can differ between individuals and across the life span
3	The capacity for *physiological*[b] adaptation is on a continuum and can be trained *through repeated or chronic exposure*[b]
4	Adaptation or failure to adapt can result in a detrimental outcome
4.1	The mechanisms that lead to adaptation may initially be beneficial for a specific body function but may negatively impact other physiological processes/functions
4.2	Failure to initiate *adaptation*[b] or adequately adapt may lead to damage or disease
4.3	The detrimental outcome may or may not be reversible and could result in death
4.4	The repair and/or regeneration capacity of the organism at the molecular, cellular, tissue, organ, and/or organ system level determines the degree of reversibility of detrimental outcomes *arising from failure to adapt*[c]

Italic text identifies revisions made in response to feedback provided by survey respondents. [a]Revised word; [b]added word/s; [c]deleted words.

set ($n = 17$) for ratings of the importance and difficulty of each theme and subtheme. Table 3 suggests that the most important theme/subtheme was deemed to be *theme 1* and the most difficult theme/subthemes were deemed to be *theme 3* and *subthemes 4.1* and *4.4*.

Handling missing categorical data points in a small sample is complicated, and each strategy has its own inherent forms of bias. Thus the statistical analysis was performed on both the complete ($n = 17$) and incomplete ($n = 22$) datasets, and the results of each analysis are reported. The proportion of importance scores differed significantly between themes/subthemes ($n = 17$, Fisher's exact: $P = 0.004$; $n = 22$, Fisher's exact: $P = 0.002$). The difference between themes/subthemes was confirmed with a one-way ANOVA ($n = 17$, $F_{12,220} = 2.630$, $P = 0.003$; $n = 22$, $F_{12,281} = 2.743$, $P < 0.001$). Planned post-hoc comparisons revealed that there was no significant difference between the most important theme/subtheme (*theme 1*) and *theme 4* and *subthemes 1.1*, *1.3*, and *4.2*. However, the most important theme/subtheme (*theme 1*) was deemed to be significantly more important than *themes 2* ($n = 17$, $P = 0.017$; $n = 22$, $P = 0.004$) and *3* ($n = 17$, $P < 0.001$; $n = 22$, $P < 0.001$) and *subthemes 1.2* ($n = 17$, $P = 0.017$; $n = 22$, $P = 0.013$), *1.4* ($n = 17$, $P = 0.008$; $n = 22$, $P = 0.003$), *1.5* ($n = 17$, $P = 0.017$; $n = 22$, $P = 0.016$), *4.1* ($n = 17$, $P = 0.017$; $n = 22$, $P = 0.004$), *4.3* ($n = 17$, $P = 0.004$; $n = 22$, $P = 0.002$), and *4.4* ($n = 17$, $P < 0.001$; $n = 22$, $P < 0.001$). The proportion of difficulty did not significantly differ between the themes/subthemes ($n = 17$, Fisher's exact: $P = 0.999$; $n = 22$, Fisher's exact: $P = 0.970$). There was no correlation between the rating of importance and difficulty in the complete ($n = 17$) data set (polychoric correlation matrix $r = -0.021$).

Survey respondents provided feedback on each theme (and related subthemes) via open-ended responses to the question "Any comments or suggested changes (additions, deletions, corrections)?" The number of survey respondents (out of $n = 22$) who provided comments was 5, 1, 5, and 3 for *themes 1*, *2*, *3*, and *4* (and their related subthemes), respectively. The feedback provided by survey respondents was incorporated into the final version of the themes and subthemes (see Table 1).

DISCUSSION

Physiological adaptation is a higher level physiological concept that requires student understanding and integration of concepts relating to the cell membrane, cell communication, movement of substances, structure and function, homeostasis, and integration (i.e., *core concepts 1–6*). The physiological adaptation core concept encompasses a wide

Table 2. *Characteristics of survey respondents for the complete dataset*

Characteristics	Sample ($n = 17$)
Current position	2 lecturer, 5 senior lecturer, 8 associate professor, 2 professor
Teaching component of current workload	49% (SD 17)
Total human physiology teaching experience	17.1 years (SD 7.5; range: 7–31 years) across 2.4 institutions (SD 1.1; range: 1–5 institutions)
Degree/s taught over last 5 years	Science ($n = 8$), biomedical science ($n = 13$), health sciences ($n = 10$), medical sciences ($n = 7$), medicine ($n = 6$), exercise and sports science ($n = 10$), human movement ($n = 4$), nursing ($n = 7$), paramedics ($n = 5$), others ($n = 11$)*
Year levels taught over last 5 years	First-year undergraduate ($n = 14$), second-year undergraduate ($n = 14$), third-year undergraduate ($n = 13$), professional postgraduate ($n = 4$), postgraduate coursework ($n = 4$)
Modes of delivery over last 5 years	17 lectures, 16 practicals, 13 workshops, 14 tutorials

Teaching component of current workload and total teaching experience are means ± SD. *Other degree/s: occupational therapy, podiatry, optometry, dentistry and oral health, speech pathology, pharmacy, psychology, psychological/behavioral sciences, midwifery, master of exercise physiology, osteopathy, human nutrition, nutritional sciences, medical research, laboratory medicine, biomedical engineering, human biology, forensic science.

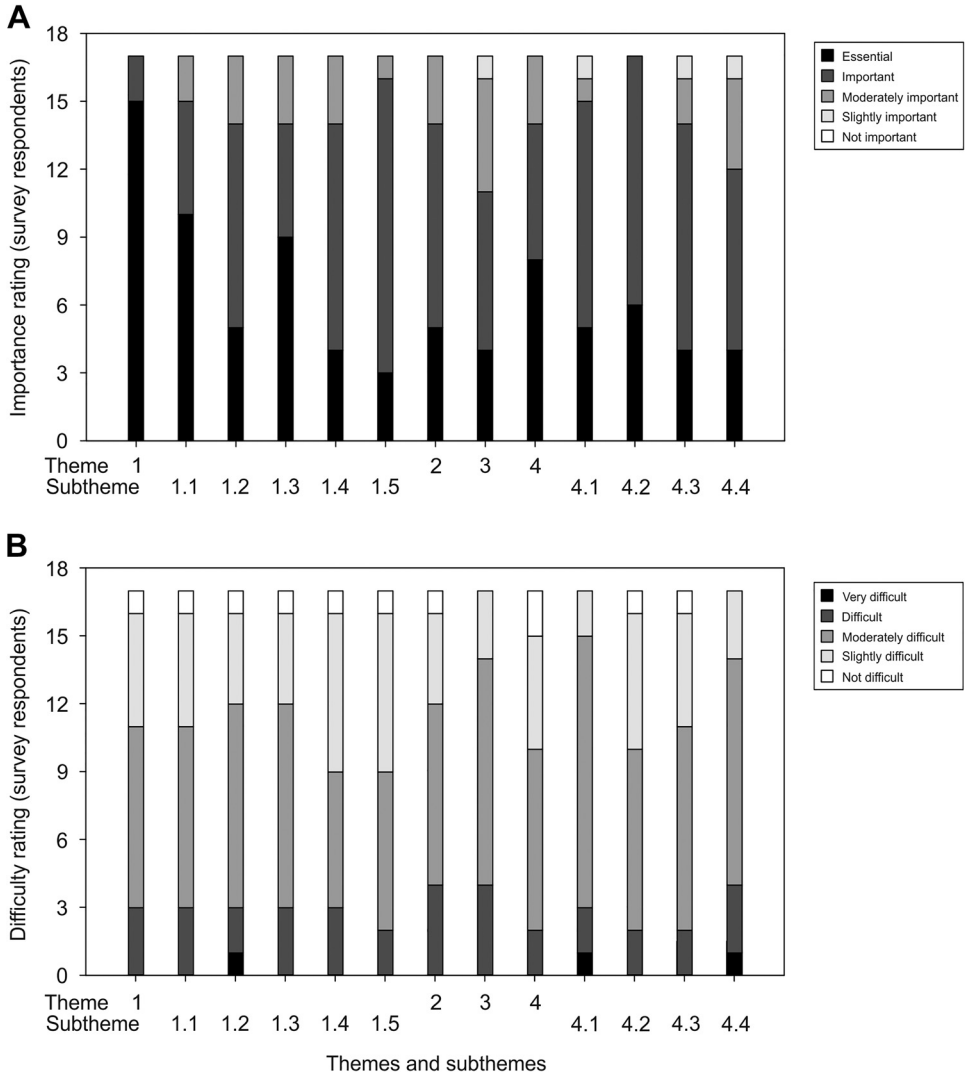

Figure 2. Stacked bar chart showing single subject data for the complete dataset ($n = 17$) for rating of importance and difficultly for each theme and subtheme. The number of survey respondents that provided each rating is shown. *A*: rating of the level of importance for students to understand. *B*: rating of the level of difficultly for students.

range of subject matter, such as exercise training (13) and exposure to environmental stressors [e.g., heat and high altitude (14)]. Physiological adaptation can also contribute to the pathophysiological mechanisms of different pathological conditions [e.g., cardiac hypertrophy in patients with chronic hypertension (15)]. An important defining feature that sets physiological adaptation apart from the other core concepts [such as homeostasis (16)] is the time scale involved. Prolonged exposure, or regular periods of intermittent exposure, to a stressor can result in changes that would not otherwise have happened in the context of acute exposure. For example, while acute cold exposure results in cutaneous vasoconstrictor and shivering thermogenesis responses, prolonged or repeated short exposures result in attenuation of these thermo-effector responses (habituation). Alterations in the vasoconstrictor or shivering response threshold or slope are characteristic indicators of adaptive responses to cold, where hypermetabolic and/or insulative changes are preserved to protect against life-threatening cold stress (17). Furthermore, physiological adaptations remain beyond restored homeostasis and withdrawal of the stressor. A good example is shown through the persistence of the beneficial effects of heat acclimatization, such as reduced cardiovascular strain, and core temperature, in different studies, for different durations, after the last heat exposure (18).

The unpacking of the physiological adaptation core concept (*core concept 7*) was performed under the assumption that students would have already undertaken prior learning in the other concepts. The unpacking of the physiology adaptation core concept led to the creation of four themes and nine subthemes that encompass the role of stressors and disturbed homeostasis in adaptation and the capacity for, and the nature of, the physiological adaptation.

Our team attempted to group and organize the themes in a logical order to provide direction for the courses in which concepts are likely to be taught. The themes and subthemes explained that changes in the internal or external environment of an organism disturb homeostasis and that disturbed homeostasis induces a state of stress that can lead to subsequent acute or chronic adjustments within the body. Several themes and subthemes then focused on the characteristics of the stressor and how these affect the nature of the adaptation. Then, the concept of changes in the capacity of physiological adaptation across the lifespan among individuals and

Table 3. *Group data for the complete dataset for rating of importance and difficultly for each theme and subtheme*

Theme/ Subtheme	Importance				Difficulty			
	Mean	SD	Median	IQR	Mean	SD	Median	IQR
1	1.1	0.3	1	0	3.2	0.8	3	1
1.1	1.5	0.7	1	1	3.2	0.8	3	1
1.2	1.9	0.7	2	1	3.1	0.9	3	1
1.3	1.6	0.8	1	1	3.2	0.8	3	1
1.4	1.9	0.7	2	0.25	3.4	0.9	3	1
1.5	1.9	0.5	2	0	3.4	0.8	3	1
2	1.9	0.7	2	1	3.1	0.9	3	1.25
3	2.2	0.9	2	1.25	2.9	0.7	3	0.25
4	1.7	0.8	2	1	3.4	0.9	3	1
4.1	1.9	0.8	2	1	2.9	0.7	3	0
4.2	1.6	0.5	2	1	3.4	0.8	3	1
4.3	2.0	0.8	2	0.25	3.3	0.8	3	1
4.4	2.1	0.9	2	1.25	2.9	0.8	3	0.25

For the importance domain, the rating of Essential, Important, Moderately Important, Slightly Important, and Not Important were assigned the values of 1, 2, 3, 4, and 5, respectively. For the difficultly domain, the rating of Very Difficult, Difficult, Moderately Difficult, Slightly Difficult, and Not Difficult were assigned the values of 1, 2, 3, 4, and 5, respectively. IQR, interquartile range; $n = 17$.

with training was addressed. Finally, the potential detrimental outcomes of adaptation were outlined. The themes and subthemes then underwent an internal validation process to *1*) determine if the themes and subthemes were appropriate and whether any themes/subthemes were missing, *2*) assess the importance and difficulty of the proposed themes and subthemes, and *3*) seek feedback on the wording and clarity.

The survey results suggest that the themes and subthemes contained all necessary components that represent physiological adaptation. All themes and subthemes were deemed to be Essential or Important and the open-ended questions in the survey did not suggest any major changes to the wording of the themes or subthemes, or the removal or addition of themes or subthemes. There were some statistically significant differences between certain themes and subthemes yet all were within the range of Essential or Important (see Table 3). These outcomes, and our preference for a logical and ordered approach to progression of student learning, led to the existing themes and subthemes, and their order, being retained.

Factors that likely contributed to the successful unpacking were the diverse backgrounds of the three Task Force members. The three Task Force members have expertise in medicine, neuroscience, and exercise and developmental physiology and have several years of experience teaching physiology (7–20 years) and conducting physiological research (12–80 publications). The unpacking process also broadly aligned with methodological approaches previously used in physiology (10) and other disciplines [e.g., pharmacology (19) and nursing (2)]. The themes and subthemes were also internally validated by a larger group of physiology educators with a diverse and extensive range of background discipline expertise and teaching experience.

The perceived difficulty of each theme and subtheme was also explored to inform future efforts in student learning support and curriculum design in courses featuring physiological adaptation. The themes and subthemes were deemed to be Moderately Difficult. Thus the delivery of concurrent student learning support activities and learning scaffolding is recommended. The level of difficulty is not unexpected because understanding physiological adaptation requires prior knowledge, and a higher level of integration, of other core concepts. For example, one needs to first understand how body temperature is regulated and maintained (homeostasis core concept), and the structure, function, and integration of the integumentary system, nervous system, and cardiovascular system (structure and function, and integration core concepts), before exploring the body's response to prolonged exposure to hot or cold environments (physiological adaptation core concept).

The study had three minor limitations. First, the terms Important and Essential were not defined, and we instead relied on the survey respondent's ability to differentiate between these two universal terms. Second, instructions and/or training for rating the themes and subthemes were not provided. Previous studies on unpacking physiology core concepts also did not define these two terms or provide training (10). It is also important to note that this evaluation of concept difficulty represents an educator's point of view and that the student's view on difficulty of the physiology adaptation themes and subthemes is important and warrants exploration (20). Finally, a larger and independent evaluation of the importance, difficulty, order, and grouping of the themes and subthemes is required to confirm validity.

To conclude, the ultimate goal of this study is to provide educators with a list of key themes and subthemes to inform and guide teaching activities relating to physiological adaptation. We have completed the initial steps, but further work is required, particularly regarding external validation by the broader network of physiology educators. It is important to note that the developed conceptual framework should be treated as a guide, rather than a prescription to support teaching and learning of this core concept (10). In addition, because concepts are "universal, timeless, and abstract" (8), we believe that our efforts into unpacking the physiological adaptation core concept, and internally validating its conceptual framework, could provide a guide to support teaching and learning of this core concept they can create commonality and consistency across curricula.

DATA AVAILABILITY

Data will be made available upon reasonable request.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

M.T., A.H., and K.T. conceived and designed research; S.E., G.D.W., G.T., M.T., D.H.H., L.L., A.H., and Task Force performed experiments; S.E., G.D.W., G.T., and A.H. analyzed data; S.E., G.D.W., G.T. and A.H. interpreted results of experiments; S.E., G.D.W., G.T., and A.H. prepared figures; S.E., G.D.W., G.T., D.H.H., L.L., and K.T. drafted manuscript; S.E., G.D.W., G.T., D.H.H., L.L., A.H., and K.T. edited and revised manuscript; K.T. approved final version of manuscript.

REFERENCES

1. **Erickson HL**, **Lanning LA.** *Transitioning to Concept-Based Curriculum and Instruction: How to Bring Content and Process Together*. Thousand Oaks, CA: Corwin Press, 2013.
2. **Giddens JF**, **Brady DP.** Rescuing nursing education from content saturation: the case for a concept-based curriculum. *J Nurs Educ* 46: 65–69, 2007. doi:10.3928/01484834-20070201-05.
3. **Latham L.** Concept-based education. In: *Student-Focused Learning: Higher Education in an Exponential Digital Era*. Lanham, MD: Rowman & Littlefield, 2020, p. 1–18.
4. **Michael J**, **Modell H**, **McFarland J**, **Cliff W.** The "core principles" of physiology: what should students understand? *Adv Physiol Educ* 33: 10–16, 2009. doi:10.1152/advan.90139.2008.
5. **Tangalakis K**, **Julien BL**, **Lexis L**, **Hryciw DH**, **Thomas CJ**, **Husaric M**, **Towstoless M**, **MacKinnon PJ**, **Miao Y**, **Hayes A.** Mapping the core concepts of physiology across Australian university curricula. *Adv Physiol Educ* 47: 411–418, 2023. doi:10.1152/advan.00139.2022.
6. **Tangalakis K**, **Hryciw D**, **Lexis L**, **Towstoless M**, **Bakker T**, **Beckett E**, **Brown D**, **Cameron M**, **Choate J**, **Chopin L**, **Cooke M**, **Douglas T**, **Estephan S**, **Etherington S**, **Gaganis V**, **Moorhouse A**, **Moro C**, **Paravicini T**, **Perry B**, **Phillips R**, **Scott C**, **Todd G**, **Uebergang T**, **Wadley G**, **Watt M**, **Hayes A.** Establishing consensus for the core concepts of physiology in the Australian higher education context using the Delphi method. *Adv Physiol Educ* 47: 419–426, 2023. doi:10.1152/advan.00140.2022.
7. **Michael J**, **Cliff W**, **McFarland J**, **Modell H**, **Wright A.** What does it mean to "unpack" a core concept? In: *The Core Concepts of Physiology: a New Paradigm for Teaching Physiology*. New York: Springer, 2017, p. 37–44,
8. **Erickson HL**, **Lanning LA**, **French R.** *Concept-Based Curriculum and Instruction for the Thinking Classroom*. Thousand Oaks, CA: Corwin Press, 2017.
9. **Marschall C**, **French R.** *Concept-Based Inquiry in Action: Strategies to Promote Transferable Understanding*. Thousand Oaks, CA: Corwin Press: 2018.
10. **Michael J**, **Martinkova P**, **McFarland J**, **Wright A**, **Cliff W**, **Modell H**, **Wenderoth MP.** Validating a conceptual framework for the core concept of "cell-cell communication". *Adv Physiol Educ* 41: 260–265, 2017. doi:10.1152/advan.00100.2016.
11. **Michael J**, **Cliff W**, **McFarland J**, **Modell H**, **Wright A.** What are the core concepts of physiology? In: *The Core Concepts of Physiology*. New York: Springer, 2017, p. 27–36.
12. **Lorenzo-Seva U**, **Ferrando PJ.** POLYMAT-C: a comprehensive SPSS program for computing the polychoric correlation matrix. *Behav Res Methods* 47: 884–889, 2015. doi:10.3758/s13428-014-0511-x.
13. **Hamilton MT**, **Booth FW.** Skeletal muscle adaptation to exercise: a century of progress. *J Appl Physiol (1985)* 88: 327–331, 2000. doi:10.1152/jappl.2000.88.1.327.
14. **Leonard WR.** Physiological adaptations to environmental stressors. In: *Basics in human evolution*, Elsevier, 2015, p. 251–272.
15. **Cooper IG.** Cardiocyte adaptation to chronically altered load. *Annu Rev Physiol* 49: 501–518, 1987. doi:10.1146/annurev.ph.49.030187.002441.
16. **Beckett E**, **Gaganis V**, **Bakker AJ**, **Towstoless M**, **Hayes A**, **Hryciw DH**, **Lexis L**, **Tangalakis K**, **Task Force**. Unpacking the homeostasis core concept in physiology: an Australian perspective. *Adv Physiol Educ* 47: 427–435, 2023. doi:10.1152/advan.00141.2022.
17. **Yurkevicius BR**, **Alba BK**, **Seeley AD**, **Castellani JW.** Human cold habituation: physiology, timeline, and modifiers. *Temperature (Austin)* 9: 122–157, 2022. doi:10.1080/23328940.2021.1903145.
18. **Périard J**, **Racinais S**, **Sawka MN.** Adaptations and mechanisms of human heat acclimation: applications for competitive athletes and sports. *Scand J Med Sci Sports* 25, *Suppl* 1: 20–38, 2015. doi:10.1111/sms.12408.
19. **Santiago M**, **Davis EA**, **Hinton T**, **Angelo TA**, **Shield A**, **Babey AM**, **Kemp-Harper B**, **Maynard G**, **Al-Sallami HS**, **Musgrave IF**, **Fernandes LB**, **Ngo SN**, **Christopoulos A**, **White PJ.** Defining and unpacking the core concepts of pharmacology education. *Pharmacol Res Perspect* 9: e00894, 2021. doi:10.1002/prp2.894.
20. **Colthorpe KL**, **Abe H**, **Ainscough L.** How do students deal with difficult physiological knowledge? *Adv Physiol Educ* 42: 555–564, 2018. doi:10.1152/advan.00102.2018.