Computing Education Research as a Translational Transdiscipline

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ABSTRACT

The field of Computing Education Research (CER) produces important insights into learning and notable interventions, yet due to the *research/practice divide* these do not have the desired impact on learners or practitioners. Even within CER, Computing Education (CE) learning theories have limited influence on learning designs due to the *theory/design divide*, which is unfortunate given that the goal of CER is to impact learners and broaden access to computation.

There is a lack of an overarching model defining CER as a unified field and providing a framework for discussion. While there is discussion around many of the core activities and practices in CER, we have yet to come across a holistic characterisation. We introduce a model of Translational Computing Education Research (TCER) that helps to understand and discuss CER as a field, bridge the divides and provide internal structure, while also making the field more approachable for interdisciplinary and non-academic collaborators. In our TCER model, theory and design are equally important but weighted differently depending on an activity's position along the research/practice continuum.

In addition to the future exploration and exploitation of the presented TCER model, we propose further characterising CER as a field, applying the TCER model to understand past and contemporary CER, applying the model to address current challenges in CER, imagining what the field can become, as well as exploring the potential for translational research programmes to maximise the broader impact of computing education research.

CCS CONCEPTS

• **Social and professional topics → Computing education**.

KEYWORDS

Translational Computing Education Research, Transdisciplinary Research, Translational Research Programmes, TCER Model

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1 INTRODUCTION

Computing Education Research (CER) suffers from two divides that limit our ability to make Computing Education (CE) effective and inclusive. The first divide is a research/practice divide whereby knowledge and artefacts from CER do not translate into practice [5, 21]. The second one is a theory/design divide within CER where advances in theory do not always translate into improved learning designs [10, 21, 25, 30, 47]. We have also experienced this first-hand as computing educators interested in evidence-based practices, yet teaching a learner profile that is overlooked by contemporary CER and in a context where available CER artefacts are difficult to adapt.

These challenges are described in the literature, with a few papers standing out for their actionable suggestions [21, 25, 30, 50]. However, we did not find any article clearly defining both divides or suggesting a relationship between them. While the term "translation" appeared in several papers [4, 21, 48], those focusing on the research/practice divide often use the word "propagation" [4, 15, 17, 19, 48].

In parallel, CER is actively defining itself as a field of study. While CER has a large body of research, it is still developing many of the conventions and features already present in more mature fields. We believe these challenges are easier to address once an overarching theory of CER is established.

None of these challenges are unique to CER. Medicine has a history of leveraging theory into better patient outcomes using a model called Translational Research (TR). Other fields have faced the challenges of self-definition and recognition. To help address both challenges, we propose a unifying theory of CER: Translational Computing Education Research (TCER). After reviewing TR models used in medicine, we developed a model of TCER adapted to the realities and needs of CER and designed to be granular and actionable. We later learned that other fields such as education [4, 28, 38], teacher training [6], reading education [45], STEM education [39], "mind, brain and education" [46], computing [1] and HCI [9] have also explored models of translational research. However, those models were either less developed or not well-suited for CER.

Translational Research is promising for bridging the two divides but there are challenges in its implementation. We looked into criticisms of TR in medicine to better understand the risks involved [2, 3, 24, 34, 56, 58]. A criticism that stood out is that TR can impose a *translational imperative* [24, 58] pressuring researchers to justify all their work with broader impacts (BI) [58]. This is harmful to the long-term health of a field by discouraging exploratory fundamental research which only pays off in the long term. Another criticism is that the term "translational" can appear linear, giving the wrong impression that there is a "pipeline" [2] moving from research (theory) to practice (design). This creates counterproductive expectations since translation is a cyclical, unpredictable and multi-dimensional process [2]. There is also concern that a translational mentality sets false expectations for research programmes that do not align with the history of medicine. Over the last 30 years, translational research in medicine has been wildly inefficient; meanwhile many of the longest-serving interventions in medicine were developed without any underlying theoretical understanding [2].

We are convinced that CER can successfully adopt a TR model in spite of these challenges. Not only can we learn from the past, but CER has a strong tradition of translation, is actively working to improve translation, and there are features of CER and broader computing communities that we believe set the stage for success.

2 CHARACTERISING CER

CER is still engaging in many activities typical of an emerging field, including curating a core literature [33], publishing first text books [14, 41], debating methodology [21, 30, 50], defining domain-specific methodologies [21, 25, 41], building domain-specific theories [25, 47], discussing publication standards[1] [14, 29, 50], characterising its research landscape [10, 12, 32, 47], creating its own educational programmes [23], creating a global community [20] and defining career paths for CER graduate students[2] [27, 55]. These advances are important, but still leave us wondering *"what is CER"*?

In this section we characterise CER by first explaining why we believe it is a *translational transdiscipline*, then describing three key stakeholders in CER and finally listing several defining features of CER that can encourage successful translational research.

2.1 The Nature of CER

While researching and designing our model of CER, we also thought *about* CER as a field. We concluded that CER's main objective is to improve the efficacy and inclusiveness of CE. That much is clear and less controversial, but then things get fuzzier.

2.1.1 CER is Translational. Discussions in existing literature have circled around whether CER is a *research* field generating theories of CE, or a *practice* field creating designs to improve learning [12, 30, 50]. Choosing one or the other does not feel right because both are valuable for impacting CE outcomes. They are even stronger together than alone when practice informs theory and research informs design.

We then learned about the *research/practice continuum* [54] from medical TR and it became clear that translation is more than a useful lens to understand CER; it is also a methodologically inclusive way to characterise CER as a field. Questions about theory versus design can be resolved by imagining a theory/design continuum. Some activities in CER produce theories, others generate promising designs based on theory, and yet others focus on implementing and scaling successful designs.

2.1.2 CER is a Transdiscipline. Next, we asked ourselves whether CER can be considered as a stand-alone discipline. At a basic level this position is simple enough as it has already been defended [43] and it could be argued that contemporary CER meets more recent criteria as well [53].

However, we know from the literature [12] and experience that CER is multi-disciplinary at its core. Computing is infinitely varied and cross-cutting, education is highly contextual and educational research requires diverse collaborations.

It feels too confining to simply call CER "a discipline", in particular considering that CER involves disparate stakeholders and addresses social and systemic challenges facing CE. CER has also been characterised as Discipline-based Education Research [37], but this definition [44] seems too narrowly focused on the research aspects of CER.

We then came across the term "transdisciplinary" [7, 36] which we believe best describes CER:

> *"Transdisciplinary involves scientists from different disciplines as well as non-scientists and other stakeholders and, through role release and role expansion, transcends (hence "trans") the disciplinary boundaries to look at the dynamics of whole systems in a holistic way."*

This term encompasses both the theoretical and design activities within CER, while also including non-academic stakeholders and recognising that true progress in education comes through broad engagement and systemic solutions. Thus, we characterise CER as *"Computing Education Research is a Translational Transdiscipline"*.

2.2 CER Stakeholders

A field as broad as CER has a wide range of stakeholders with varying roles. Inspired by the *immediacy* axis of the Inclusion-Immediacy Criterion (IIC) described by Woodson [58], we first define three broad categories of CER stakeholders:

- *Intrinsic Stakeholders:* Anyone directly contributing to bodies of knowledge in CER.
- *Direct Stakeholders:* Anyone directly benefiting from the outputs of CER.
- *Extrinsic Stakeholders:* Anyone indirectly benefiting from progress in CER.

In the upcoming sections, we discuss three specific *intrinsic* or *direct* stakeholders that are central actors in our TCER model, while *extrinsic* stakeholders are discussed later in Section 4. Note that a single person can fall under more than one category:

2.2.1 Researchers (Intrinsic Stakeholder). We define researchers as anyone who contributes to bodies of knowledge in CER following an appropriate methodology. "Appropriate" can mean different things at different stages along the research/practice continuum. A few examples include methodical theory development, controlled experiments, design methodologies, qualitative research and data analysis.

2.2.2 Educators (Direct Stakeholder). We identify several types of educators with different relationships to CER. The more "stereotypical" practitioner is a teacher simply trying to teach their learners with the best methods available within their means. Their relationship to CER is passive, they consume the products of CER but may not be aware that it exists as a field of study.

There is also the enthusiastic practitioner; an educator who has the opportunity and interest to engage in design and experimentation, alone or in collaboration with researchers. If their work

[1] https://faculty.washington.edu/ajko/cer#experience-reports
[2] https://www.csedgrad.org

follows an appropriate methodology and is added to the body of CER knowledge, they can also be considered a researcher.

2.2.3 Learners (Direct Stakeholder). A learner is anyone interested in learning computing. This includes novices, experienced developers learning a new paradigm, experts in a different domain learning a domain-specific language, conversational programmers [8], digital artists or someone learning for fun.

Self-guided learners are primarily learners; however they are effectively acting as their own teacher and could benefit from many of the guides and resources available to educators.

2.3 Defining Features of CER

We now list some defining features of CE that from our experience lay the foundation for a successful translational practice. Taken together, these considerations outline a field with the potential for successful translational research:

(1) There are no legal or regulatory barriers to most research, only ethical ones.
(2) Health and lives are not at risk. A small unsuccessful experiment is not a risk as long as a better alternative is offered after the experiment concludes.
(3) There is a wide variety of stakeholders who can all benefit from small improvements, and many of these improvements may be low hanging fruits.
(4) Curricula can be updated incrementally. Isolated aspects of a learner's experience can be improved before an entire new solution is ready.
(5) CER is a relatively small field, so one researcher or a small group can have both a broad and deep understanding of CER.
(6) It is common for researchers to also be educators, giving them first-hand insights to CE.
(7) Educators often possess the technical skills necessary to implement their own prototypes.
(8) Prototyping software and learning materials is relatively cheap and it is possible to iterate quickly.
(9) Tight feedback loops between theory and design or research and practice are possible because research often takes place with real learners in an authentic setting.
(10) Many computing communities have a culture of teaching, learning and making.
(11) There is strong public interest in improving and expanding Computing Education.

3 TCER MODEL

The challenge of coordinating theory and practice are not unique to CER. To inspire our model, we reviewed models of translational research in medicine. The primary inspiration for our TCER model illustrated in Figure 1 was a review by Trochim et al. [54] and the more general concept of Translational Science.[3]

We believe our model is relevant no matter what one thinks "computing" means [49]. Our model is focused on the "E" and "R" in "CER"; we are discussing how to generate and exploit the *pedagogical* and *technical* insights to teach whatever computing *content* learners need to know.

[3]https://ncats.nih.gov/translation

We do not propose the TCER model as dogma. All research and intervention efforts should operate within constraints in a way that best benefits their stakeholders and objectives. We also recognise that CER is diverse and some activities may not fit cleanly in our model. We developed our model simply to start the conversation about a shared framework for discussing and understanding CER.

3.1 Judging Our Model

A good model should not only help to understand the world as it is, but also help imagine a different future. We hope to show that discussing CER in terms of the TCER model presented in Figure 1 helps to structure a productive conversation about CER as a field.

We judge our model's success by whether it helps the community to understand, share and discuss CER. We even believe that the TCER model should be measured by similar criteria to a "threshold concept" as described by Flanagan[4], on which we base the following criteria:

- *Transformative:* Once understood, does TCER change the way in which you view CER?
- *Irreversible:* Once you see CER as translational, is it hard for you to go back?
- *Integrative:* Once learned, does TCER bring together different aspects of CER that previously did not appear to be related?
- *Bounded:* Does TCER delineate CER, making it easier for you to understand the field as a unified entity?
- *Discursive:* Does understanding TCER give you a richer vocabulary for discussing CE?
- *Reconstitutive:* Does understanding TCER subjectively change your interactions with CE?
- *Liminal:* Can you imagine learning about TCER being a "right of passage" for newcomers to the field?

Finally, does TCER help us to see how our work and that of our peers are related? Does it help us to better understand CER from the perspective of our peers? Does Silver's [42] characterisation of theory describe how you feel about our theory of TCER?

> *"To understand theory is to travel into someone else's mind and become able to perceive reality as that person does. To understand a theory is to experience a shift in one's own mental structure and discover with startling clarity a different way of thinking. To understand theory is to feel some wonder that one never saw before what now seems to have been obvious all along."*

3.2 Description of the TCER Model

Layers are the highest level of organisation in our model. Each layer spans horizontally through all phases of our model, and each layer below provides a progressively finer-grained description of TCER. In the following, we go through the different layers of our model shown in Figure 1 and explain the reasoning behind each layer.

While the TCER model might seem to be linear with siloed progression from theory to intervention, we foresee strong *feedback loops* between all research activities. This dynamic has also been called the "translational science spectrum".[5]

[4]https://www.ee.ucl.ac.uk/~mflanaga/thresholds.html
[5]https://ncats.nih.gov/translation/spectrum

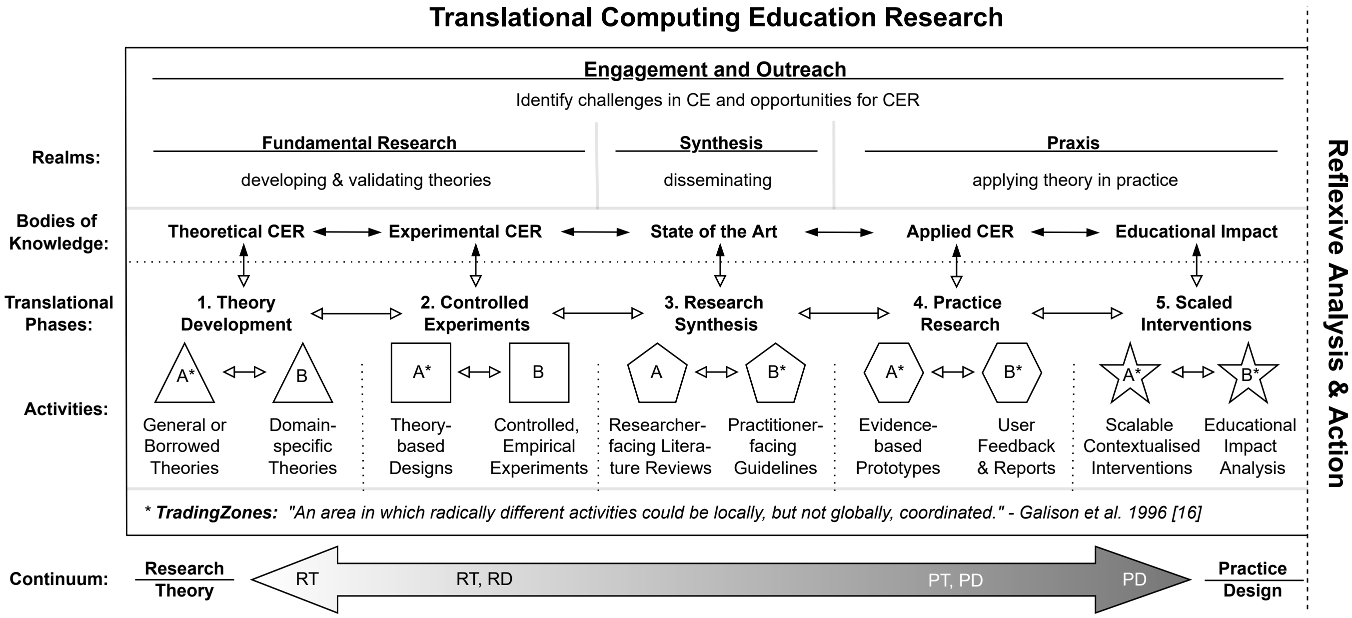

Figure 1: TCER model overview

3.2.1 Theory/Design and Research/Practice Continuum. The foundation of our model is the theory/design and research/practice continuum shown in Figure 2, a two-dimensional continuum classifying contributions to CER based on their evaluation and contribution.

- *Research/Practice:* This axis describes how an artefact is evaluated. Research artefacts are evaluated by their methodology, while practice artefacts are evaluated by their effectiveness.
- *Theory/Design:* This axis describes an artefact's contribution to CER. For example, a lesson plan designed for a controlled experiment might contribute to both theory and design, while a new lesson plan for schools may only contribute to CE design.

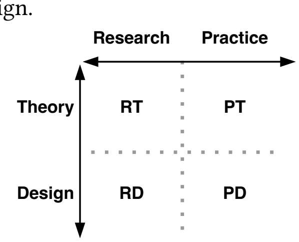

Figure 2: Research/practice and theory/design continuum

Overall, no contribution is more important than another and it is a question of context, with different contributions being more valuable to different activities. Below are the four broad categories of contribution, but keep in mind that in reality this is a sliding scale rather than absolute categories:

- *Research Theories (RT):* Methodologically and empirically validated theories of CE.
- *Research Designs (RD):* Designs created with a strict methodology, often intended as a contribution to the CER literature or used to validate RTs.
- *Practice Theories (PT):* These are useful theories for practitioners that may not be methodologically sound. Some PTs could be called a "heuristic", though PTs may also be more general and less practical than a heuristic.
- *Practice Designs (PD):* A design whose main purpose is to impact CE practice, it can be developed with any methodology and may or may not be evidence-based.

Our continuum is different from Pasteur's Quadrant [26] in that we use differently labelled axes, we do not simply use binary values on both axes, and we draw value from all four quadrants.

3.2.2 Engagement and Outreach. Computing education is everywhere. It is online tutorials, it is meetup groups, it is children, adults and everything in between, it is professional and recreational, it is for novices and experts, it is endless. Fortunately, many computing communities have a culture of learning, teaching and making. Unfortunately, many computing communities do not know CER exists. When it comes to prevalent educational approaches there is still a lot of inertia for non-evidence-based practices, and plenty of "it worked for me".

The CER community has a tradition of outreach and direct engagement with learning communities, and this must be an ongoing effort. If CER is to stay relevant it will need to make a concerted effort to identify new challenges in CE, reach CE communities where they are, and work productively with a variety of stakeholders.

3.2.3 Realms. The next layer of our model breaks CER into three realms without any order or hierarchy:

- **Fundamental Research:** Developing and validating theories for CE.
- **Synthesis:** Consolidating and communicating knowledge from *Fundamental Research* and *Praxis*.
- **Praxis:** Designing evidence-based solutions for CE.

3.2.4 Bodies of Knowledge. Bodies of knowledge are distinct but interrelated groupings of knowledge in CE. Imagine one researcher choosing to specialise in experimental CER across many contexts and another researcher specialising in one CE context and being familiar with relevant knowledge from all bodies.

- **Theoretical CER:** Theoretical understanding of how people teach and learn computing.
- **Experimental CER:** Bodies of empirical evidence used to develop CE theories and inform practise.
- **State of the Art:** Syntheses of all bodies of knowledge, communicated differently depending on the target audience.
- **Applied CER:** Prototypes and heuristics inspired by the state of the art to support specific educational outcomes in specific contexts.
- **Educational Impact:** Practical insights gained from scaling educational interventions and analysing their impact.

3.2.5 Translational Phases. Translational phases are about *what you do*, not just what you know. Compared to bodies of knowledge, translational phases are active and more directional, giving structure to the theory/design and research/practice continuum. Each translational phase is intimately tied to its corresponding body of knowledge, each growing from and building on the other.

1: **Theory Development:** Generating and developing theories of how people learn and teach programming.
2: **Controlled Experiments:** Testing and exploring theories with controlled experiments.
3: **Research Synthesis:** Synthesising results from all phases and communicating the relevant results to each stakeholder.
4: **Practice Research:** Designing and validating prototypes that apply CE theory in diverse educational contexts.
5: **Scaled Interventions:** Exploiting successful designs to have large-scale impact in computing education.

Translational research can only succeed if researchers and practitioners engage in active collaborations and when all stakeholders have reliable channels of communication and shared knowledge. For example, impact reports from phase 5 can help to guide a phase 1 researcher's work, and recent experiments from phase 2 can directly inspire a phase 4 practitioner. To aid in communication, our model has defined a phase of research (phase 3) dedicated to synthesising and disseminating the state of the art to both academic and non-academic audiences.

3.2.6 Activities. Within each of the five phases, we have defined two primary activities. Researchers in each activity ask different questions and answer them with different methods. These ten activities are not isolated or always in order; a single publication may contain a focused literature review (3.A), present a new theory (1.B), design a theory-based intervention (2.A), conduct a controlled experiment (2.B) and conclude with advice for educators (3.B). See Nelson and Ko [30] for a discussion of balancing design, explanation and experiment in one study.

1.A: **General or Borrowed Theories:** Explore and borrow learning theories from other domains.
1.B: **Domain-specific Theories:** Develop domain-specific learning theories for computing education.
2.A: **Theory-based Designs:** Designing small-scale focused interventions to test or develop a specific theory.
2.B: **Controlled Empirical Experiments:** Use controlled experiments to investigate theories from 1.A/B and designs from 2.A. Separating 2.A and 2.B can help in establishing replication standards.
3.A: **Researcher-facing Literature Reviews:** Perform systematic literature reviews of activities in all phases, targeted at an academic audience.
3.B: **Practitioner-facing Guidelines:** Produce evidence-based practical guidelines or suggestions for CE practitioners.
4.A: **Evidence-based Prototypes:** Design evidence-based prototypes for targeted educational outcomes and contexts; share ongoing designs and process.
4.B: **User Feedback & Reports:** Understand what works and what does not work in different settings and share these insights to progress theory and design.
5.A: **Scalable Contextualised Interventions:** Develop and deploy scalable interventions based on promising prototypes.
5.B: **Educational Impact Analysis:** Conduct follow-up studies to analyse an intervention's impact and publish reports to share your findings.

3.2.7 Trading Zones. We have also considered which activities are more "internal" to CER and which activities invite transdisciplinary collaboration. The latter we call trading zones (marked with an asterisk in Figure 1). Galison defined trading zones as *"an arena in which radically different activities could be locally, but not globally, coordinated"* [16], and Draper and Maguire [12] discussed the importance of trading zones in CER. We believe that being explicit about which activities are trading zones can help to foster transdisciplinary collaborations while still maintaining a distinct identity for CER.

3.3 Reflexive Analysis and Action

This final feature of our model is the most important one because even if our model were perfect today, it might become obsolete in the future. A field without the culture and mechanisms to support self-reflection and re-definition cannot stay relevant.

CER currently has this self-reflective culture as evidenced by recent publications about CER [12, 21, 30, 49, 50], a recent special issue on theory in CER [52], conference proceedings[6] and discussions taking place in social media and blogs.[7] If CER is to flourish, this culture needs to be hard-coded into how we define CER, how we collaborate with other fields, interact with non-academic stakeholders and train new members of our field. Each new generation of CE researchers should feel that they can still help to (re)define the field.

4 TRANSLATIONAL RESEARCH PROGRAMMES

One important implication of our TCER model is Translational Research Programmes (TRPs). By coordinating diverse research projects dealing with different aspects of the same problem, TRPs

[6] https://www.ukicer.com/#keynotes
[7] https://twitter.com/NALooker/status/1549780567683653633

can address challenges in CE that are too complex or diffuse for a single researcher or institution. The key features of TRPs could include (in no particular order):

- *Broader Impacts (BIs):* A specific and meaningful impact in CE that the research addresses.
- *A Translational Team:* A team of researchers who together possess the broad range of skills and experience necessary for a TRP to succeed [35].
- *Non-Academic R&D Partners:* Ideally a TRP involves the entities it would like to impact. If not possible, stand-ins with similar constraints are acceptable.
- *Resources:* A TRP will likely be larger and longer than a standard research project. It may be necessary to secure substantial resources.
- *Feasibility:* A TRP should have a reasonable chance of success given its constraints and the challenge it is addressing.

TRPs are iterative and unpredictable projects that require a diverse and flexible "translational science team" [18, 45]. The separation of activities in our TCER model is intended only to help discuss and plan, not to silo. For example, imagine a TRP for which there is enough theory available, but the theories have not been validated for your context—you will need to plan some phase 2 activities. There can be as much "returning to the drawing board" as necessary and as many feedback loops as possible.

TRPs may also stand a higher chance of securing funding [57]. The TCER model can help communicate your research's BIs, your methods and activities, which profiles you will need, and your relationship to non-academic partners.

More insight into what it could mean for CER to adopt translational science can be found in Solari et al. [45] where the same question is discussed in the context of reading education.

4.1 Inclusive and Immediate TRPs

For a TRP to succeed, it will not only need a rigorous approach to research and design (supporting efficacy), but also a rigorous approach to diversity and inclusion. There are already several approaches available to CER including culturally responsive computing education (CRCE) [13, 40], universal or accessible design, engaging openly and frequently with stakeholders, and defining success measures in cooperation with direct and indirect stakeholders.

However, what CER is missing is a way to characterise how a TRP will impact diversity and inclusion in computing. We propose adopting and adapting the Inclusion-Immediacy Criterion (IIC) [58] to qualify BIs in CER. The model has nine categories of BIs defined by a 3x3 grid. The two axes of the grid are *inclusiveness*, defining who will benefit from the impacts, and *immediacy*, expressing how direct the impacts are.

4.2 Quality Assurance

To ensure the quality of a TRP's ongoing activities and subsequent BIs, there must be conventions for evaluating the research process and outcomes. To track the progress of a TRP, Trochim et al.'s *process marker model* (PMM) [54] can be a starting point. The PMM functions in uncertainty by identifying measurable markers that can help understand the health of an ongoing TRP.

The overall success of a TRP should not only take the BIs into account, but the entire process from initial scoping to final delivery. We are not aware of any work providing such a model adapted to CER. However, we think a combination of the Inclusion-Immediacy Criterion, the Translational Science Benefits Model [22], healthy collaboration with practitioner partners [11, 31], and assessments or feedback from stakeholders could serve as a starting point.

5 FUTURE WORK AND CONCLUSION

Our characterisation of CER, the TCER model and TRPs are just a starting point. They open the door to a variety of future research both theoretical and applied, including but not limited to:

- Debating and refining our characterisation of CER.
- Testing and developing the TCER model by using it to describe CER activities and literature.
- Build on existing CER literature classifications [12, 43] using the lens of TCER.
- Using the TCER model to approach existing challenges within CER and imagine possible futures for CER.
- Structuring research/practitioner partnerships with TCER.
- Develop translational research methodologies suited to CER.
- Exploring how TRPs could best operate in CER.
- Identifying suitable challenges for TRPs in CE.
- Exploring the use of TCER and TRPs to secure more substantial funding for CER.[8]

We discussed two important challenges in CER that are limiting our ability to impact CE: the *research/practice* divide and the *theory/design* divide. Before imagining solutions to these challenges, we tried to understand CER holistically and concluded that CER is a *transdiscipline*, and that CER's nature is *translational*. The overarching premise of CER is to work with all stakeholders to translate theoretical and empirical understanding of CE into broader impacts for learners, educators and society.

Our model of Translational Computing Education Research captures CER as a field. Based on the discussed research/practice and theory/design continuum, the presented TCER model recognises the systemic complexities of education, accommodates transdisciplinary collaboration, encourages engagement with broader computing communities, and foresees methodological introspection. We finally explored the use of Translational Research Programmes to address large-scale challenges in CER and discussed different ways to plan for and measure the effects of TRPs on efficacy and inclusiveness in computing education.

Over the last 70 years CER has passed through several periods [51] and the next period might be *translational*—a period where we discover new ways to structure our understanding of Computing Education Research and translate it into a more equitable future.

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