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Theoretical physicist identity development: A critical account of factors influencing progression from novice to expert

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Abstract

In a context of rapid change in higher education and work, lecturers are still expected to provide meaningful learning experiences that enculturate students to disciplinary knowledge, values, and practices. Within the STEM disciplines, this process of enculturation is premised on the existence of an underpinning 'culture of science' defined by long-established discipline-specific discourses that include values, models of thinking, patterns of behaviour and even language conventions. In this reflective autoethnographic study, we apply Carlone and Johnson's 'science identity' framework to analyse the reflections of a theoretical physics lecturer on the journey to becoming a theoretical physicist. The analysis reveals the factors (implicit and explicit) that may enhance or constrain academic progression. These factors are discussed in relation to implications for students from diverse backgrounds, and the critical role played by lecturers in revealing the 'rules of the game'.

Keywords: science identity, theoretical physics, disciplinary knowledge, hidden curriculum

Introduction

The universities of today are vastly different from universities a century ago. Yet, in this age of massification and commodification of higher education, lecturers are still expected to provide learning experiences that facilitate epistemological access (Morrow, 2009) and enable the development disciplinary identities by enculturating students to disciplinary norms and practices (Prior & Bilbro, 2012). Within science in particular, this process of academic enculturation is, in turn, premised on the existence of a society and underpinning culture of science defined by disciplinary values, models of thinking, patterns of behaviour, language style and an appreciation for a particular 'science lifestyle' (Wang, 2018). Learning, in turn, is viewed as the process of developing a science 'identity' within this community:

> Learning is, in this purview, more basically, a process of coming to be, of forging identities in activity in the world. In short, learners are never only that, but are becoming certain sorts of subjects with certain ways of participating in the world… Subjects occupy different locations, and have different interests, reasons and understandings of who they are and what they are up to. (Lave, 1992: 3)

In this respect, one is reminded of Bourdieu's conception of 'habitus' (Bourdieu, 1985). Habitus is a concept used to describe the ways in which norms (in this case disciplinary knowledge, practices, beliefs, and behaviours) become internalised in the form of lasting dispositions, or trained capacities and structured ways of thinking, feeling, and acting, which then guides action and agency in particular ways. In a similar vein, Middendorf and Pace (2004) highlight the critical role played by lecturers (as disciplinary experts), inducting students (novices) into new disciplinary cultures. Maton (2014) extends this notion, referring to the development of particular orientations to knowing and being as a specific type of 'gaze' unique to different disciplines. It is the relative ease or difficulty with which students are able to recognise and internalise academic and discipline specific cultural norms and values (set by the research scientists in the context of theoretical physics (Brickhouse et al., 2000)), that enables genuine participation in the discipline. It may also be one of the factors contributing to the relatively high attrition rate of students in undergraduate physics programmes and the reason for the 'pipeline metaphor' which 'models physics retention as a stream of students flowing through a physics pipeline until they "leak" out (leaving physics), or arrive at a fixed endpoint where they have developed the identity of full-fledged physicists' (Quan, 2017: 16).

In this paper, we contribute to ongoing attempts to demystify the shift from novice to expert in theoretical physics. Our intention is to make the often-tacit (implicit) 'rules of the game' more explicit by drawing on the personal experiences and insights of one of the authors, a lecturer in this discipline, to highlight the iterative cycles of epistemological and ontological shifts that occur in the process of theoretical physicist identity development. In the process, we reveal what is valued in the discipline at different stages of undergraduate and postgraduate education, specifically from the lecturer/ postgraduate supervisor perspective, highlighting how these values influence and shape student identity formation. In doing so, we expose the organising principles that shape the disciplinary education of theoretical physicists. We conclude with a reflection on the consequences of the 'hidden curriculum' (Cornbleth, 1984) on students' theoretical physicist identity development and science identity development more broadly. We also highlight the importance of engaging in critical reflective practices as a mechanism for revealing the assumptions sometimes made about students, the implications thereof for student academic progression, and possibilities for shifting praxis.

Beginning with an overview of theoretical physics, we draw on literature to highlight the nature of the discipline and the structure of the curriculum in higher education. Then, given the focus identity development, we describe the science identity framework proposed by Carlone and Johnson (2007), explaining how this was used as the conceptual framework underpinning the study. This is followed by a description of our research approach, a presentation and discussion of important findings. We conclude by highlighting important issues that lecturers should be aware of in their efforts to facilitate epistemological access and enhance retention for an increasingly diverse range of students.

Overview of the discipline of theoretical physics

To fully pursue the exploration of theoretical physicist identity development, we need to first recall that physics, as an academic discipline in science, is historically considered to be one of the hard, pure disciplines (Roberts, 2015). It is underpinned by a hierarchical knowledge structure, strong internal grammar and a strong instructional discourse emphasising disciplinary knowledge and procedures (Bernstein, 1999; 2000). The undergraduate curriculum especially tends to follow a predetermined structure and sequence, characterised by strong classification and framing (Bernstein, 1999). In other words, the boundaries of the discipline tend to be quite distinct relative to other science disciplines, and the selection and focus of curricula are largely controlled and determined by the lecturer, with little external influence. It has been argued that this curriculum format is, however, necessary to ensure that students become familiar with the discourse and concepts of physics and are afforded the opportunity to gain access to the fundamental content knowledge required to progress through the hierarchy of the undergraduate curriculum (Cornell & Padayachee, 2021).

As one advances into the more theoretical branches of physics in advanced years of study, more and more conceptual knowledge must be acquired and integrated. This may leave the experiential approaches to teaching behind, but in learning more concepts and spending more time in lectures, lecturers begin to walk students through an exercise of building piece-by-piece a mental model reflecting the one the lecturer has. This complex process is rarely sufficient to permit students to perform genuine problem-solving tasks, as well as integrating them with the range of new procedures they are learning (Middendorf & Pace, 2004).

There is, accordingly, a gradual process of cumulative knowledge building (Maton, 2014) that occurs in the education of physics students, evolving from conceptual knowledge acquisition in the undergraduate setting to mastery through a form of cognitive apprenticeship during postgraduate studies. This is achieved by moving beyond the didactic to understanding and comprehension of the knowledge, and then to the construction of new knowledge at the graduate level, as demonstrated in an investigation of question types at different levels of study in a selection of theoretical physics assessments by Cornell and Padayachee (2021). Whilst lecturers initially aim to construct disciplinary knowledge in a hierarchical manner, by beginning with hands on experiential work through laboratory sessions and practical work, this quickly becomes a repeated testing of invented threshold concepts (Wisker, 2018) such as Newton's laws to see if these concepts always hold-up under scrutiny, while developing students' understanding of complex representations and their uses in physics. Postgraduate study, on the other hand, is focussed on the development of skills for abstracting and producing new knowledge and the gradual development of the theoretical physicist identity characterised by an inquiry mind set (Dewey, 1938, cited in Towne and Shavelson, 2002) and increasing student independence and agency (Cryer, 1998).

The inquiry mindset, while triggered in undergraduate study, must be fostered more intentionally during the crucial transitional period of doctoral studies, considered key in the academic' s identity construction, or a rite-of-passage to becoming an academic or expert in the field. As highlighted by Wisker (2018), the research learning that occurs when doctoral candidates make breakthroughs in their thinking, understanding, researching and writing largely concern conceptual threshold crossing (Meyer and Land, 2003), which show both ontological change (i.e., changing the way they see themselves in the world, their identity as a researcher, and their agency) and epistemological change (a confidence in engaging with the research learning, and an active awareness of the ways of constructing knowledge and making a contribution). It can, therefore, be argued that it is at this point in the academic journey where the real shift towards a true science identity, as described by Carlone and Johnson (2007), occurs.

Science Identity Theory

Given the focus of the study on identity development, we refer to the "*science identity*" model proposed by Carlone and Johnson (2007) as the overarching theoretical framework for this study. In this model (informed by the work of Gee (2000)), science identity develops as a consequence of a complex interplay between competency, performance and recognition (Figure 1). Broadly, competence refers to the knowledge and understanding of scientific content, performance is the ability to enact or demonstrate the practices of science to others. Recognition, on the other hand refers to the self-recognition or recognition by others as a scientist (Carlone and Johnson, 2007).

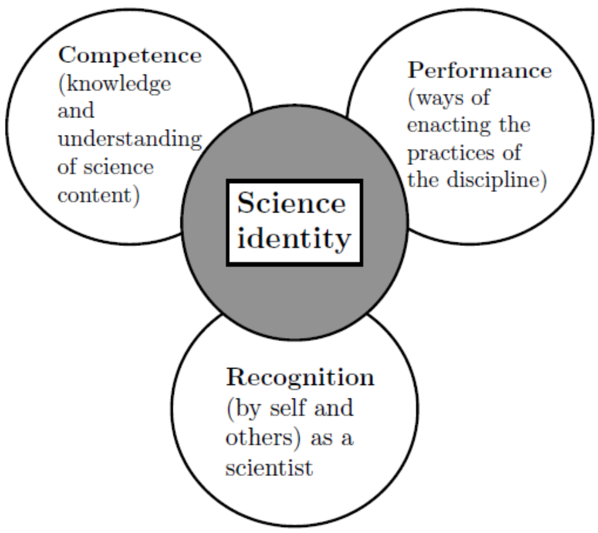

Figure 1. Model of Science Identity (adapted from Carlone & Johnson 2007).

Science identity is thus shaped as a consequence of varying levels of development in these three broad areas. It may also be argued that these domains develop through cognitive apprenticeship (Collins, et al., 1991). It should be noted that these areas intersect and are also influenced by personal agency as well as various contextual factors. Carlone and Johnson (2007) highlight, for instance, that gender, racial and ethnic identities may affect science identity, but also that an identity can only exist to the extent one is able to demonstrate that identity in a way that is recognisable and can be validated by others. Science identity, according to this model, is thus, 'both situationally emergent and potentially enduring over time and context' (Carlone & Johnson, 2007: 1192). It should be noted that for the purposes of this study, our focus is on how these three areas (i.e., competence performance and recognition) are developed within the context of the university as the site of habitus, influenced by the lecturers and postgraduate supervisors. We discuss this in relation to other factors highlighted in the literature that influence and shape identity but emphasize that it was beyond the scope of the present study to explore these factors from the students' perspective in more depth.

Contribution of the study

This study contributes towards the existing body of research on identity development in science students, and physics students in particular. Given the 'leaky pipeline' described earlier, and the well-established need for more science graduates to address current and future challenges through science and innovation, understanding the nature of theoretical physicist identity development is critical. This study aims to provide a rare insider perspective of the journey to becoming an expert in the discipline of theoretical physics, and a critical reflection on some of the areas of preparation that may need revision and adaptation to either enable or constrain students' academic progression. It also serves as a springboard to engage in deeper conversations on the impact of entrenched disciplinary norms, values and practices (as well as potential blind spots of lecturers) on both epistemological and ontological access for diverse cohorts of students.

Methodology

This study followed a qualitative research paradigm, using a facilitated reflective autoethnographic research method (Hamilton, 2021) for data generation. Data was drawn from a semi-structured interview of author 1, a theoretical physicist specialising in high energy particle physics and gravitational physics, facilitated by author 2, a science education specialist. Author 1, prompted by questions by author 2, reflected on their own developmental journey and their current postgraduate supervision practices. The interview was recorded and transcribed, and transcript was initially examined superficially to identify the dominant specialisation concepts within the data. This initial coarse analysis was followed by a more fine-grained, deductive analysis of the transcript to identify the manifestations of competence, performance and recognition (Carlone and Johnson, 2007), as well as any emergent themes arising from the data. The findings emerging from this analysis were then examined in relation shifts that a theoretical physics student may experience at the different stages of study in the progression from undergraduate studies to PhD.

We were aware of the limitations of the autoethnographic approach however, our intention was to provide an in-depth account of an individual experience of moving through a particular culture, in this case the culture of theoretical physics. As Stevens, O' Connor and Garrison (2005) argue, methodological approaches like autoethnographies can illustrate how small, sometimes idiosyncratic, experiences can have a cascading effect in students' broader trajectories. Therefore, considering the focus of this research, facilitated autoethnography was determined to be the most appropriate method, despite the limitations. Credibility was, however, enhanced to an extent, by conducting a facilitated autoethnography, while trustworthiness was addressed through the recording, transcription, and subsequent verification of the interview.

Findings and discussion

The findings confirm an emphasis on the development of knowledge competence at earlier stages of study but indicated a distinct shift in the development of different areas of performance as students advanced. For instance, the emergence of strong theme related to the prior knowledge of matriculants (school leavers) applying to study physics demonstrates the importance of foundational knowledge and understanding (i.e., foundational competence). In this case, emphasis was on applicants' mathematics and science marks. The strong value for foundational competence as a critical aspect of a nascent theoretical physicist identity was also evident in the data related to undergraduate studies. This was similarly reported in an earlier study by Cornell and Padayachee (2021), which demonstrated that at this stage of identity development, knowledge acquisition, familiarisation of students with disciplinary concepts, and the gradual understanding of core concepts tends to be foregrounded. This foregrounding of conceptual knowledge is underpinned by the enduring nature of the knowledge of physics and the notion that there is a particular "*right way*" to engage with this knowledge, as highlighted in the following quote from author 1:

> Pedagogies are very often traditional. I think there are a few places trying new things, you know, like flipped classrooms, but it's still very much the same content as probably the content of the last 100 years. The textbook from 1952 is still the same textbook content-wise, as was used in 2012. Because of the nature of physics, there's not really much that can be changed. So, it's largely presented the same way too.

The notion of "right answers" and "right procedures", coupled with the strong classification and framing of the discipline (Bernstein, 1999) is indicative of a teaching and learning paradigm in which the lecturer is positioned as the disciplinary expert, selecting and sequencing the learning episodes and gradually revealing the rules required for engagement with the knowledge of the discipline. It thus represents a subject that is both strong classified and strongly framed (Bernstein, 1999). It also confirms the centrality of knowledge competence in the identity development of a theoretical physicist and as a foundational principle in theoretical physics curriculum development. Performance development is also addressed to some extent in the course of undergraduate studies, with students entering university studies in physics faced with time intensive lectures and laboratories designed to build their conceptual knowledge base and to develop an appreciation for the methodology of basic sciences.

The findings further reveal that as a student progresses through the undergraduate qualification, the lecturer's emphasis shifts to the development of knowledge competence and performance through the deepening of conceptual knowledge and the integration of more complex procedures and practices. There is thus a distinct conceptual shift, based on author 1's experience, towards problem solving and broader application of concepts in the latter years of study, as indicated in the following quote:

> Problem solving becomes more important towards 3rd year. There's a focus on problems outside of the box – problems you can't fit into lectures.

Students may thus, experience epistemological shifts through the undergraduate curriculum, enabled (or constrained) by the lecturer's ability to facilitate epistemological access. However, ontological shifts associated with identity development may not be guaranteed and generally not a factor considered explicitly in curriculum development. Indeed, there appears to be tacit acknowledgement among physics lecturers (based on the experiences of author 1), that ontological shifts require a certain pre-existing disposition, referred to in the interview as '*an intuition possessed by some students*' that is indicative of their potential to become fully fledged theoretical physicists. This '*intuition*' is suggestive of knower attributes (Maton, 2014) and particular forms of cultural capital (Bourdieu, 1986, cited in Navarro, 2006) seemingly being important in overall theoretical physicist identity development.

Given the strong emphasis on competence and performance in the undergraduate curriculum, the acknowledgement by author 1 of 'knower' attributes being important at this early stage of identity development was somewhat unexpected, and perhaps not often interrogated in the traditional teaching pedagogies, given the focus on traditional, transmission-based pedagogies mentioned earlier. It is important to acknowledge here too, the possibility for reinforcing gatekeeping and inequalities for students who may not yet possess such scientific intuition or cultural capital. Being aware of this possibility and providing appropriate scaffolding to 'absent this absence' (Stylianou, (2017, drawing on the Critical Realists philosophy of Roy Bhaskar), was an important insight in this reflection and should, in our view, be an important consideration in the pedagogical decision-making process of theoretical physics lecturers, especially those involved in undergraduate studies.

On graduation, the data indicates lecturers' expectations that students will have developed what could be considered a 'trained' gaze (Maton, 2014), having achieved sufficient conceptual grounding (competence) and familiarity with the practices of physics (performance) to enable a shift to a more sophisticated way of engaging with the knowledge of the discipline in postgraduate studies. However, this trained gaze (Maton, 2014) might still be insufficient for legitimate peripheral participation (Lave and Wenger, 1991), as indicated in the quote below that was drawn from the data:

> There is so much you have to learn before you get to that point (of being recognised as an expert). You have to have a certain command of a lot of the language and procedures…that isn’ t always developed well in undergraduate study.

It is the focussed and intentional development of a certain command of the Discourse (as defined by Gee, 1990) of theoretical physics that is, therefore, emphasised at postgraduate level, coupled with induction or apprenticeship into the socio-cultural practices of the discipline (where the culture and disciplinary “*norms*” become visible), that arguably facilitates epistemological and ontological shifts and the emergence of the cultivated gaze (Maton, 2014) required for legitimate core participation (Lave and Wenger, 1999).

The findings also revealed the belief held by author 1 (possibly emerging through supervision experience) that the real shift signalling a move towards identifying as a legitimate theoretical physicist only really appears at PhD and postdoctoral levels. If a student has developed a sufficiently deep foundational knowledge base, they will be able to not only apply that knowledge but start to evolve the knowledge by conceptualising applications of knowledge in different, possibly unrelated contexts. An equally important shift in emphasis that occurs at this stage is the foregrounding of the skill of communication of ideas and networking. Collectively, these shifts signal the processes underlying the more significant ontological shift towards becoming a recognised theoretical physicist and the critical role of the postgraduate supervisor in facilitating access to the disciplinary community, as indicated by author 1’ s account of his own developmental journey:

> The supervisor is seen as the expert in the discipline. The PhD is the equivalent of the apprenticeship.
>
> During my PhD, I produced 5 research papers. The first few, the supervisor conceives the idea, the last few, the supervisor shifts the work of conceptualisation to the student as well.
>
> Emphasis on postdoc studies – produce papers. This shows the ability to publish but also shows the knowledge and skills. But references are also important – who you know – your network that you build during multiple postdocs (and big collaborators) is really important.

The quote above signals the importance of recognition (Carlone & Johnson, 2007) in the development of theoretical physicist identity, and the pivotal impact of publication record and networking with others. In this respect, the supervisor plays the primary role in facilitating these first connections in forming a collaborative network, and will often assist in finding their first academic and research positions. The tools and connections the supervisor provides, therefore, assist the student in their post-PhD experiences, as they build new connections of their own, through attendances at conferences and workshops. These experiences facilitate the establishment of legitimacy through publications (the impact and renown that these publications have, viewed as strong signals of ability to perform independently as a theoretical physicist), while the post-doctoral fellowships enable the development of a network of colleagues. Provision of such opportunities by PhD supervisors and the individual's own engagement in multiple postdoctoral fellowships thereafter, are thus, key factors in identity development and a vital part of the traditional academic apprenticeship. These comments also highlight the strong link between identity development and social interactions with others in communities of practice (Lave & Wenger, 2001), with access and integration into the academic tribe being facilitated largely through competence and performance:

> If I meet someone at a conference, you start chatting with this person, you can tell almost immediately if they have a certain confidence within themselves about the knowledge they're talking about. Instead of being a bit vague, they have a particular outlook. They have developed their own ideas and their own gravitas towards it. The way he or she conducts themselves or asks questions signals that they know what they're talking about.

We suggest that the 'outlook' mentioned in the above quote may be equated to the cultivated gaze (Maton, 2014) of an expert in the discipline, as a result of acquisition of a particular form of science cultural capital, a process that is as much dependent on recognition as it is on competency and performance, with the undergraduate and early postgraduate years of study focused on the latter, and recognition developed more extensively in later years of PhD and postdoctoral studies. Also emphasised is the significant role of the supervisor in creating habitus for the development of theoretical physics students' disposition, the model of supervision tending towards critical thinking (Lee, 2007) with elements of enculturation and apprenticeship. However, this structure of supervision and identity formation emphasises a one-sided power relationship, where the supervisor decides what is legitimate knowledge and practices. This is further emphasised by the suggestion within the data that emergent theoretical physicist identity is often strongly linked to the identity and values of postgraduate supervisors, with a significant part of this identity framed in terms of recognition. This once again highlights the key role of the postgraduate supervisor in socialising the student and developing the graduate's disciplinary cultural capital. However, it also suggests that there may indeed be some tension for students who do not easily identify with their supervisors and vice versa, as well as the potential for unintentional biases on the part of postgraduate supervisors. We highlight this as an important insight that requires further investigation and interrogation as this has much wider ramifications in our highly diverse higher education context.

In addition, the data also highlighted the increasing challenge that postgraduate supervisors face in enabling recognition and integration in circles outside of academia, and the possibility of including supervisors from outside academia, with different experiences, dispositions, and values. In this broadened conception of supervision, different supervision models as well as new and different graduate gazes may emerge as a consequence.

Conclusion

Science identity formation is a complex phenomenon arising from the interactions between an individual and a systematised body of scientific knowledge and practices, as well as the individual and other scientists. Within the discipline of theoretical physics, the academic identity is initially shaped by strong interactions with the knowledge and procedures of the discipline, with emphasis placed on the development of the competence and performance aspects of science identity. For theoretical physics students, particularly those who may initially lack particular forms of capital valued within the discipline, it becomes essential that lecturers make the norms and practices of the discipline explicit to students to minimise the potential for gatekeeping and to facilitate epistemological and ontological access. In other words, lecturers need be more conscious of the hidden curriculum and hidden rules that influence an individual's academic progression in theoretical physics and deliberately reveal and explain these to students. Furthermore, the findings also highlight that lecturers (especially science lecturers) cannot remain indifferent to the fact that students enter university with different ontologies which can impacts significantly on integration into the discipline and nascent science identity formation. We acknowledge this critical aspect of identity formation and note that this requires further consideration.

We have also shown that theoretical physicist identity development requires not only a solid grasp of conceptual knowledge but that other forms of knowledge and other ways of knowing also appear to play an important role in the transition from learning about physics to becoming and being recognised as a theoretical physicist, the latter attributes emerging through apprenticeship in the postgraduate supervision relationship. This transition may be more easily facilitated by supervisors who are themselves recognised as legitimate theoretical physicists, but who are also aware of the potential challenges that some students may face in this process. In this respect, we highlight the importance ongoing critical reflections by lecturers on student challenges and the assumptions made about students and learning processes. As evidenced in this study, such reflection exercises hold significant potential for transformative shifts, both in lecturers' views of students as well as praxis.

Lastly, we note the challenges to recognition building that both lecturers and students may face when students intend to enter workplaces outside of academia. However, keeping in mind Carlone and Johnson's (2007) notion of identity as emergent, and Bourdieu's suggestion that cultural capital is enduring and can be transferred from one context to another, we contend that if the theoretical physics competence and performance are well supported and adequately developed by undergraduate lecturers and postgraduate supervisors, graduates may be able to adapt relatively quickly, form their own interdisciplinary networks and apply their knowledge and competence in a wide array of contexts, and legitimacy and recognition, regardless of context, will then follow.

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