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How Actor-Network Theory Travels and Changes in Engineering Education: A Narrative Literature Review

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1. Introduction

There is a growing concern, especially in the engineering community, about the role that technology plays in creating a more sustainable, equitable, inclusive, and just society. To address these concerns, some engineering educators have drawn from work in Science and Technology Studies (STS) to help characterize the relationship between technology and society. Explanations of the technology-society relationship vary greatly. For the sake of simplicity, if viewed on a spectrum, classic approaches include Technological Determinism on one end of a spectrum, which views technology as a powerful force that follows its own path and shapes the development of society (Heilbroner, 1967), and Social Constructivism (Pinch & Bijker, 1984) on the other, which argues that social groups determine nearly all aspects of technology and, ultimately, it is people who provide meaning and direction to technological development. Other theories, including Actor-Network Theory (ANT) (Latour, 1996), and posit that both technology and society shape and inform each other, in a constant negotiation for meaning and roles.

Recently, aspects of classic ANT texts and ideas have gained prominence in engineering education research (EER). Researchers and educators have been applying ANT differently in regards to approaches, purposes, and elements of the theory. This paper explores how ANT has been implemented and transformed as it enters the field of engineering education.

Since its first development, ANT itself has undergone many transformations and has been represented by many authors. Sociology and Science and Technology Studies (STS), the fields where ANT was first developed and used, have largely moved into a "post-ANT" space, as Latour, Law, and many others have published ANT critiques, rebuttals, reflections, and reformulations (e.g. Latour 1996; 1999; 2007; 2011; Law and Hassard 1999; Gad and Jensen 2010). As Gad and Jensen demonstrate, "post-ANT" does not mean that researchers have left ANT behind, but rather that they have questioned and extended its approaches in new work. Instead of straightforwardly applying ANT concepts and methods in new contexts, most recent work in STS seeks to critique or respond to the theory in new ways.

ANT has spread to fields far beyond the sociology and STS, and scholars in these fields have also applied and adapted ANT to their own needs and interests. Among other fields, ANT is now employed in design (Yaneva 2009), media studies (Couldry 2008), urban studies (Farías and Bender 2010), political economy (Fine 2005), project management (Burga and Rezania 2017), accounting (Justesen and Mouritsen 2011), and education (Fenwick and Edwards 2010a). As the theory itself would suggest, different scholars and fields have emphasized and drawn from different ANT texts and ideas, which causes ANT to be transformed as new actors establish their own understandings and networks of meaning.

Our goal in this paper is to explore how and why ANT is being used in the discipline of EER. We also aim to analyze the transformations that ANT has experienced in EER spaces. To do this, we conducted a narrative literature review and used ANT itself as our approach to interpreting the literature, as we aim to understand how interpretations of ANT develop and travel within the EER field. In the next sections, we first briefly present some of what we consider be the main arguments and concepts of the theory, then we explain our methodology, and follow by discussing our analysis of the EER literature.

2. Background

Actor-network theory was first developed in the 1980s at the Centre de Sociologie de l'Innovation at the École nationale supérieure des mines de Paris, an engineering school and research university that is one of France's elite Grandes Écoles. Its developers and early proponents included sociologists Michel Callon, Bruno Latour, and John Law. The central concepts and approaches of ANT emerged during this time, not expressed in a single definition or text, but distributed throughout several, now canonical works in the sociology of science and technology. Callon (1984) expressed ANT as a "sociology of translation," which studies power and power relations through detailed examinations of changes in the relations between actors in a constantly shifting network. Law (1992) emphasized the material heterogeneity of the actor-network, writing that ANT understands agents, technologies, institutions, and societies themselves as "effects" that are generated within networks of diverse materials. Latour (1988) noted the methodological demands that ANT makes of its practitioners: the ANT analyst studies science "in action," rather than established scientific fact; they follow the actors and aim not to assume or impose definitions on them, but instead look at the relations and displacements between actors, seeking structural explanations for actions and events.

ANT is different from other sociological theories because it argues that *networks*, which include and constitute society, are only possible because of their material heterogeneity. That is, society emerges from the interaction between human, material and natural agents, and would not exist if it were only made up of humans (Law, 1992, p. 379). Therefore, it is impossible to understand the heterogeneous network of society without considering that the *facts* that the natural and social sciences produce, the *artifacts* that engineers design, and the *natural environment*, are fundamental parts of society (Law, 1992, p. 381)

The classic version of ANT has three main aspects (or *preoccupations*) (Latour, 1996). First, it provides the language and argument for defining a *network* and the *actors* that are part of it. Second, it is a methodological framework for identifying and recording (not building or creating) the heterogeneous elements of this network. Thirdly, it makes an ontological claim that all actors are networks and vice-versa (we will explain this claim further in the next section). Therefore, ANT does not act only as a theory, but also as a method (Latour, 1999, p. 15)(Crawford, 2004).

3. ANT Terms and Concepts

Several terms and concepts expressed in these early works became emblematic of ANT and have themselves been translated and implemented in a range of contexts beyond the sociology of science. Here, we will summarize some of the central ones.

Actor-Network: ANT's central concept, that of the actor-network, describes a collection of relations that are constantly in flux. The actor-network is not static, and as such the term "network" may feel misleading. As Latour complained in a reflection on ANT, "now that the World Wide Web exists, everyone believes they understand what a network is" (Latour 1999), when, in fact, a technical network is just one of many other possible "final and stabilized states of an actor-network" (Latour, 1996, 369). Simply speaking, an *actor* is any agent that interacts and connects with other agents, while a *network* are processes and activities generated by the interaction between the actors that compose the network (Crawford, 2004).

In ANT, the network comprises a series of transformations in the relations between actors. Crucially, the actor-network is heterogeneous, meaning that its actors include humans and non-humans (Law 1984) - people, technologies, organizations, and texts can all be actors that participate in and make up the network. For instance, in an engineering project, possible actors are the engineers themselves, standards and codes, supervisors and subordinates, the physical or digital space they occupy, drawings, prototypes, users, and many more.

Furthermore, it is these networked human and non-human actors that constitute what we think of as "the social." ANT and the idea of the actor-network oppose the perception that "social factors" or "social impacts" are anything other than the relations and transformations of the network itself. That is, according to ANT, whenever we consider the "social impacts of technology", what we are doing is trying to analyze the changes in processes and activities of a network when a new actor (in this case, technology) is inserted.

Punctualization: Relations within an actor-network are not equal. As a network transforms, certain parts of it may be rendered invisible, opaque, or essential. The developers of ANT use a range of vocabularies to describe these shifts. *Punctualization* describes the process by which complex actor-networks become reduced to a single "black box," such that their histories, controversies, and components are no longer visible and are taken for granted (Law, 1992). It usually happens when a network is highly structured, stable and its connections and behaviors are predictable and unlikely to change as it interacts with other actors or networks (Crawford, 2004). This is exactly the third *preoccupation of ANT* (Latour, 1996) we mentioned above: a punctualized network can be seen as an actor, while any actor is already a punctualized network that can be "unpacked" and analyzed in more detail. For instance, Law (1992) states that even people are what they are because of a network, since "what counts as a person is an effect generated by a network of heterogeneous, interacting, materials" (Law, 1992, p. 383). In a technological context, punctualization would occur when a television in the living room, for example, is seen only as a black-box that emits sound and image rather than a network composed of materials (e.g. components), humans (e.g. people involved in the design, manufacturing, marketing, actors in movies, audience watching it), and natural components (e.g. raw material, pollution emitted, disposal).

Obligatory Points of Passage: Obligatory points of passage (OPP) are nodes in the actor-network that become central and functionally indispensable, and which cannot be bypassed. That is, it is an element in a network where one or more actors must interact ("pass") whether because of external (e.g., barriers) or internal (e.g., objectives) factors (Callon, 1984). OPPs are privileged within the network, and they can shape the relations and translations that occur around them. In the network of a company, for example, a possible OPP can be the manager who requires every decision to have their approval, or it can be more literal, such as the door in the network of a classroom being an OPP.

Principles of Symmetry and Agnosticism: ANT demands that analysts apply a principle of *generalized symmetry* between the technical, the natural, and the social. Rather than separating observations, descriptions, or explanations between these categories, ANT asks us to use the same approach, methods, assumptions, and way of thinking when studying phenomena that might conventionally be understood as "natural," "technical," or "social" (Callon, 1984). All actors must be approached as a blank slate – *agnosticism* – where "ANT makes no assumption at all" (Latour, 1996, p. 374) or brings prior judgment about the actors. That is, whenever analyzing the impact of any technology, the engineer should not apply different approaches and methods when considering the influences of human, natural

and material actors in the network. For instance, when studying the impacts of a new pipeline, those analyzing the network should not make pre-assumptions about the needs and wants of the community, environment, economy, technology (the pipeline itself), and other actors, before the analysis. The attributes, power relations, consequences, benefits for each and between actors should emerge from the analysis.

Moments of Translation: The process of *translation* is one of the central aspects of ANT since it shows how actors transform as they interact with other actors. Callon (1984) describes the process of translation in four stages, or "moments of translation," which may overlap: problematization, interessement, enrolment, and mobilization. During the process of translation, actors' identities, roles and their interactions within a network are negotiated between the actors of that network: it is through a continuous process of translation that the actor-network is built, transformed and stabilized (Callon, 1984).

Problematization is the stage of defining a situation by making some aspect(s) of it indispensable. In this part of the process, identities and relationships between actors are presupposed and OPPs are defined. Making a parallel with the design thinking cycle, the problematization would be the equivalent to "empathize" and "define the problem", where engineers are trying to understand the problem, its requirements, and constraints.

In the second stage, *interessement*, the definitions presupposed through problematization can be stabilized, disputed, or rejected. A structure, or a system of alliances between actors, may be negotiated and constructed. However, in Callon's formulation, this stage is not sufficient to fully establish alliances between actors. This is the "ideate" and "prototype" phases of design thinking, where engineers attempt to connect different actors (e.g., theories, concepts, materials, processes, people) and see which ones fit the constraints and meet the requirements to solve the problem.

When interessement is successful, it leads to the next phase of translation: *enrolment*. During enrolment, "multilateral negotiations" between actors continue until a set of identities and roles becomes attributed to and accepted by actors. Here is where engineers "test" their prototype to see if the elements (actors) of the prototype (the network) behave as expected and the design achieves its purpose, or if they need to adjust (negotiate) the elements (actors) so they have a successful design (stable network).

In the final stage of translation, *mobilization*, the actors and networks become *mobile,* gaining the capacity to be displaced and travel through space (by becoming a book, a movie, a concept, a physical object, etc.). It is through a process of negotiation and transformations that social and natural "realities" come to be accepted. This is when a prototype is deemed successful, reaches its final version, and is mass manufactured or documented.

Spokesperson: Not all actors (usually non-humans) or networks can express themselves in all circumstances and in different networks. However, their effects and agency are still relevant and need to be communicated – and that is where the *spokespersons* emerge. When a network or actors are mobilized, the actors empowered to speak on behalf of others become their spokespersons, and may themselves represent entire networks and other actors (Latour 1993) (Crawford, 2004). The spokespersons can negotiate networks' and actors' goals, roles and identities with others (Callon, 1984). Using our previous example, a possible spokesperson for the product being mass produced is the

company itself that will speak on behalf of the product. Or the spokesperson of a group of stakeholders can be the engineer who consulted them about their needs and wants. In this last example, the group of stakeholders is *mobilized* into notes that are transported and communicated by the engineer.

4. Methodology

This paper presents a narrative literature review (Green et al., 2006) that explores how actor-network theory has been *translated* into the domain of EER. That is, how ANT has been interpreted, transformed, and used in the context of EER.

A narrative literature review – also called critical literature review (Carnwell & Daly, 2001) – aims at synthesizing information published previously, and can serve to provoke controversy, thought and discussion around a given topic. Therefore, this type of review is an excellent venue for fostering philosophical perspectives (Green et al., 2006). Narrative reviews can serve to keep the audience updated, summarize research, and to challenge ways of thinking. However, they are not an appropriate source of evidence for decision-making due to the lack of rigour in their methodology (Green et al., 2006). Since the purpose of this paper is to foster a philosophical discussion around the *translation* of actor-network theory in engineering education research, we chose narrative literature review as our methodology.

We searched for ANT literature in the *Journal of Engineering Education, European Journal of Engineering Education, Engineering Studies* and the conference proceedings of the *Canadian Association of Engineering Education* and *American Society for Engineering Education*. First, we selected all papers that contained any mention to actor-network theory and engineering in the full text. Next, we applied selection criteria to exclude papers that 1) focused on a context other than education and 2) contained only cursory references to ANT or used ANT only as a brief example. A total of 11 out of 20 papers met the criteria.

We applied ANT itself as our theoretical framework for interpreting the literature. We then used the following four questions to guide our exploration of how ANT travels and is interpreted and transformed by the actors (researchers and educators) as it enters the field of EER.

1. What is the broader goal of the paper?
2. What is the purpose of ANT in the paper?
3. What is the authors' definition of ANT?
4. What are the main references used for ANT?

5. Findings

We analyzed a total of 11 papers that used ANT in the context of engineering education using ANT itself as our theoretical framework. The purpose of the papers ranged from developing arguments about the importance of considering the environment in engineering work (Reddy & Mancus, 2021), to analyzing engineering education at program level (Tsai et al., 2018a), to observing how the interactions with non-human actors influence learning (Juhl & Lindegaard, 2013) to teaching students about the importance of considering non-human actors in engineering practice (Berne, 2018).

When looking of how ANT is used, we identified three main roles it plays when entering engineering education: 1) philosophical underpinning; 2) theoretical framework; and 3) course content. Table 1 shows the papers we analyzed, and the respective role ANT played in them.

Table 1: Each reference and the role of ANT in the paper

Reference	Role of Actor-Network Theory
Tsai et al. (2018b) Tolbert et al. (2016)	Philosophical Underpinning
Braga and Guttmann (2019) Juhl and Lindegaard (2013) McConnell (2019) Tsai et al. (2015) Tsai et al. (2018a)	Theoretical Framework
Reddy and Mancus (2021) Foley et al. (2021) Irish and Romkey (2021) Berne (2018)	Course Content

Those that used ANT as a **philosophical underpinning**, used it to justify arguments and assumptions made by the authors regarding the interaction between humans and non-humans. As a **theoretical framework**, ANT directly influences the paper by shaping the research question, methodology or analysis. Lastly, as a **course content**, authors *translate* (interpret, move and transform) ANT to the network of the classroom where it encounters other *actors* (students). Each of these roles is discussed in more detail in the following section.

Philosophical Underpinning

The use of ANT as a philosophical underpinning allowed authors to make certain arguments and assumptions regarding a higher importance and agency of *non-human actors* (objects, physical environment, and nature), their interactions with *human actors*, and how they shape each other. When ANT is employed only as a philosophical underpinning, there is usually a brief definition or citation supporting the argument that both non-human and human actors shape and influence each other when interacting in a network. In these papers, ANT does not inform or shape the methodology, analysis, or findings. The authors in these papers are using a *punctualized* version of ANT; that is, they connect a version of ANT in which the complexity is reduced to a manageable size (an argument and a citation). In these cases, if readers want to explore and understand the theory in more detail, they must refer to the original sources.

Examples of work that used ANT as a philosophical underpinning include Tsai et al. (2018b) who investigated how students moved through a mathematics course and how they interacted with other students, teachers, artifacts, and the physical space. The main roles of ANT were to justify the reciprocity of interaction between humans and non-humans and to serve as a "secondary theoretical framework", since ANT is the philosophical foundation of their main theoretical framework – Education Scales (Nespor, 2004).

Similarly, Tolbert et al. (2016) referred to ANT so they could argue for the agency of non-human actors when exploring the relationship between ambiguity, visual representations in design, and feedback. They wanted to see how material objects (visual representations) interacted with students and design instructors so the students could develop comfort with ambiguity and feedback. ANT also formed the

philosophical foundation of their main theoretical framework – Communicative Constitution of Organizations (CCO) perspective (Gibbs, 2010).

Theoretical framework

Other papers employed ANT as a theoretical framework. In these papers, the authors spent more time unpacking, interpreting, and explaining ANT to the reader. Authors used ANT to inform the research methodology, frame the problem, or deductively analyze and discuss the data. In this last case, ANT concepts and language were used throughout the entire paper. In fact, the use of ANT as a methodology was one of the three original purposes (or *preoccupations*) of the theory (Latour, 1996).

For instance, Braga and Guttmann (2019) looked at how students used the makerspace and how they *negotiated* with other students, objects and the physical space itself. The purpose was to explore how the non-humans (objects and physical space) allowed and facilitated the communication and development of tacit knowledge between humans (students). The authors in this paper provided an explanation of the theory and, even though the only concepts used in the analysis were *actors* and *networks*, ANT influenced the methodology by choosing objects and organizing the space to facilitate the interaction between actors. ANT also informed the analysis of the data, as they followed the changes and movement of actors as they negotiated their roles within the network.

Also analyzing student learning process, Juhl and Lindegaard (2013) explored how engineering students engage with visual representations in a collaborative design project, and how it helped students develop and integrate recognition. Once again, ANT is used to justify the connection between humans and non-humans. The authors apply principles of *generalized symmetry* and *agnosticism* to allow for the analysis of humans and non-humans as equals without any prior judgment and assumption (Crawford, 2004). In this paper, ANT shaped the methodology and analysis, as students had to document every step of the visual representation of the design, allowing researchers to follow the evolution of the representation and analyze the process of *translation* more closely (Juhl & Lindegaard, 2013, p. 26). In these two last examples (Juhl & Lindegaard, 2013; Braga & Guttman, 2019), the role of ANT was very similar to situated learning (Johri & Olds, 2011) since it recognized that the learning process of the students (human actors) is conditioned to the environment (non-human actors).

Focusing on the level of institutions instead of students, McConnell (2019) mapped how industry-based practices are *mobilized* through *inscription* and transported from industry networks to academic networks. In other words, they studied how engineering practice problems are presented to students across the engineering curriculum. The authors used ANT concepts to frame the research problems, especially concepts such as *mobilization* (of the problems), *durability* (of the inscriptions) and *translation* (of the examples). There was no influence of ANT in the analysis and discussion.

Also analyzing the educational setting at the program level, Tsai et al. (2015) investigated how the sophomore-year mathematics courses (and its elements – teachers, courses, physical space, culture, etc.) *translated* students that interacted with them. The authors took the time to explain the theory and many key concepts, such as the four moments of translation – *problematization, interessement, enrollment* and *mobilization*. Tsai et al. (2015) used these four moments of translation to analyze how the translation process of students occurred as they interacted with the elements of the mathematics courses.

Using a very similar process from their earlier work (Tsai et al., 2015), Tsai et al. (2018a) investigated how an engineering mathematics course is transformed as it replicated from one university to another, and how the course, in its turn, transformed students, teachers, staff, the program and the new institution. The authors used the four moments of translation to follow the actor into translation, that is, to analyze how the course was interpreted, transformed and accepted by the new institution and how it transformed students and instructors. However, rather than taking students as the main actor to follow, as in the earlier work (Tsai et al., 2015), this time the authors followed the mathematics course itself. Tsai et al. (2018a) explained every moment of translation as it occurred in the case under study – similar to Callon's original case of the domestication of scallops by fishermen in France (Callon, 1984).

As a theoretical framework, actor-network theory was present in the definition of the problem, methodology and analysis of the data. Authors used it to analyze the learning process and to evaluate the impact of courses by identifying the actors (human and non-human) in a network and following their process of transformation by interacting with each other. In ANT language, authors *followed the actors into translation*. It served to analyze the learning process and to evaluate the impact of courses and pedagogies.

Course content

The third way ANT was reported in EER was as a course content, where ANT was explicitly taught to engineering students. In these cases, ANT was incorporated in the course content with the purpose to develop certain attributes in students, usually the consideration of sustainability, impact of engineering on society, and ethics.

For instance, Reddy and Mancus (2021) used ANT to argue that considering social, technical and environmental aspects is essential for any engineering endeavor since these aspects are all interconnected. They state that through ANT, engineers can decenter human agency and see non-humans (technical and environmental actors) as active and agential in a system (Reddy & Mancus, 2021, pp. 4–5). The authors used in-class activities based on ANT to help students develop an appreciation for sustainability. In these activities, students drew the networks of a given technology and had to identify the actors (social, technical and environmental) involved in them (Reddy & Mancus, 2021, p. 5).

Similarly, Foley et al. (2021) gave the example of one activity they conducted in class using ANT as the main framework. They asked students to analyze and identify the relationships between actors in electronic healthcare records. The intention was to show students how human and non-human actors are connected and the power relations that emerge from these interactions.

Irish and Romkey (2021) also used ANT to teach the complexity of sustainability to engineering students. Their goal was to empower "students to analyze sociotechnical systems" (Irish & Romkey, 2021, p. 1) through ANT by having students identify the actors involved in a network, the connections between the actors, and the power relations that emerged from these connections. They argued that ANT is a great tool to help students consider the importance of non-human actors because modelling and visual representations, which lend themselves to ANT, are "natural for engineering students" (Irish & Romkey, 2021, p. 3). Additionally, the authors noticed that ANT creates a roadmap for identifying and addressing questions about environmental ethics, and how morality should be assigned to non-human actors.

Berne (2018) purposefully applied the lenses and language of ANT to teach engineering ethics and elucidate the complexity of inter-relationships between actors inherent in all engineering practice. In a

course on reproductive technology, the author took students to an in-vitro fertilization (IVF) clinic and used ANT to help students notice the ethical dimensions of the process. Students were encouraged to identify the actors in the network (i.e., the IVF clinic) and acknowledge the role and agency that non-human actors (mostly technology) have in the "complex sociotechnical network of infertility treatment" (Berne, 2018, p. 8).

6. Discussion

In this section, we discuss the main translations of ANT as it entered the network of engineering education: as a tool for ethical analysis, the attribution of moral agency to non-humans, and the punctualization and new spokespersons for the theory.

Engineering Ethics

Interestingly, as both Irish and Romkey (2021) and Berne (2018) recognize, ANT was not intended as a tool for ethical analysis. In fact, Law (1992) briefly mentions that ANT might be used to "sharpen ethical questions about the special character of the human effect" (Law, 1992, p. 383) when making decisions that are enabled or hindered by non-human actors. However, this thought is not developed or repeated anywhere else by Bruno Latour, Michel Callon or John Law himself.

However, when translated to the classroom in engineering courses, ANT gained the capacity to raise ethical concerns. The observations Irish and Romkey (2021) and Berne (2018) make show that, when students are identifying the human and non-human actors in a network, and analyzing their relationship the power relations become more explicit. It is this process that facilitates the discussion around ethical issues in engineering work.

Moral Agency for Non-Humans

The attribution of moral agency to non-human actors was another translation that occurred as ANT joined the network of engineering education in the role of course content. For example: "ANT would suggest that as non-human actants, the preservation tanks also have moral agency…" (Berne, 2018, p. 6). Whether non-humans have morality or not is a complex philosophical discussion that we do not intend to tackle here. However, what we can say is that there is no mention of morality in non-human actors in classic works on ANT (Callon, 1984; Latour, 1996, 1999; Law, 1992). The label "actor" does not confer moral status. Additionally, Berne (2018) does not reference it, which makes it difficult to know where the argument came from. What there is in the classic ANT literature, however, is the suggestion that non-human actors can spur moral decisions from humans (Latour, 2005), which is referred to as *moral standing* by Irish and Romkey (2021). Therefore, we can say that ANT in the *network* of an engineering course has transformed into a tool that helps evidence ethical concerns in (engineering) networks, that allows students to consider the moral agency of non-humans, and the moral agency of humans in considering the non-humans.

In the classroom, the main role of ANT is to prompt students to identify the actors in a network and recognize how human and non-human actors can influence and shape each other. Additionally, the creation of these networks can enable students to analyze ethical concerns as power relations emerge from the interaction between humans and non-humans. These characteristics are *translations* that occurred to ANT for it to be rendered appropriately (enrolled) in the network of an engineering classroom.

Punctualization and EER Spokespersons

By analyzing the main references used by the authors who employed ANT in EER, we can see what they are bringing to the network of EER and who they reach out to as spokespersons of actor-network theory. As expected, the names of Michel Callon (1984), Bruno Latour (1996) and John Law (1992) – who are seminal theorists of ANT and wrote extensively about it – were often cited together when mentioning the origins of the theory. However, when authors in engineering education were explaining ANT, they also brought more recent texts (Crawford, 2004; Fenwick & Edwards, 2010).

The number of actors that authors brought along with ANT to EER varied. Some authors pulled versions and elements of ANT from different sources in order to come up with their own translation of ANT, such as Juhl and Lindegaard (2013), Braga and Guttmann (2019) and Tsai et al. (2015) who *translated* ANT from Latour, Callon, and Fenwick. Others relied on one spokesperson to represent ANT. For example, Berne (2018) and McConnell (2019) translated their version of ANT from a single source each – Crawford (2004) and Law (1992) respectively.

Some authors made themselves spokespersons of ANT by not connecting it to any other author. Tsai et al. (2018a) and Irish and Romkey (2021) for example, referred to Latour, Law, and Callon as the originators of the theory, but did not reference any work for most of their explanation of ANT and its elements. This means that they are not bringing the punctualized and mobilized theory from another network, with its own spokesperson into EER. Instead, they are creating their own punctualized versions and taking ownership of them. This is most evident in the later papers by Tsai et al. Tsai et al. (2018a) and Tsai et al. (2018b), who position themselves as spokespersons by referencing their own work in their initial discussion of ANT (Tsai et al., 2015).

Similarly, some authors in EER (McConnell, 2019; Reddy & Mancus, 2021) are starting to recognize and cite other authors within the field as examples of work using ANT. This shows a nascent recognition of each other as actors connected to ANT, which results in the strengthening and isolation of the network. This movement strengthens the network because the new actors are recognized and another interaction is created between them, and it isolates because authors might no longer need to bring external actors from other disciplinary networks since they reference those from EER.

Overall, this shows that the *versions* and elements of ANT being translated in EER come from different sources. There is not a single version, but several coming from many authors and subjected to different interpretations. This phenomenon is not exclusive of ANT since any theory can go through this process. The interesting thing about ANT, though, is that the theory itself (and even the original authors) foresees this translation of the theory, where each author and field would transform and be transformed by ANT (Latour, 1999).

7. Conclusion

In this paper, we followed ANT into translation as it joins the network of EER. This analysis evidenced the roles of ANT and its transformations after joining this network.

In this work, we argue that ANT in the network of EER is no longer the ANT in the network of sociology or STT – and it should not be! The classic authors expected changes (translations) of ANT as it interacted with other actors and networks. The theory itself argues that actors, whenever in interaction with other

actors, change each other by negotiating meaning and roles (adapting) in order to *enroll* in a network. If ANT remained rigid and unchanged, it would likely not be enrolled in the network of EER.

We identified that ANT serves three roles. First, it is a philosophical underpinning arguing for the decentralization of humans and the assignment of agency to non-human actors in networks. Second, it plays the role of theoretical framework for analyzing the interaction and transformation of actors in an educational setting, such as looking at how students learn by interacting with other students and the environment, or how courses transform and are transformed by students, instructors, and the institution. Thirdly and lastly, ANT acts as course content with the goal of teaching students about ethics and the social and environmental impacts of engineering – mostly through the analysis of static networks and the power relations that emerge from it. Two main transformations occurred with ANT as it enrolled in engineering education: the inception of an argument about assigning morality to non-humans, and the capacity to raise ethical concerns as human and non-human interact.

When connecting ANT to other actors (referencing), the EER network shows a direct connection to the original, classic authors (e.g. Latour, Callon and Law). It also shows signs of detachment from these original authors and taking ownership of the theory. It occurs as authors elect themselves the spokespersons of ANT by not referencing other works, and when authors make "inner-citations", that is, when they reference and cite works from authors already in the EER network.

Now, we have inserted ourselves in this *engineering education research – actor-network theory (EER-ANT)* network and identified actors and suggested their roles and participation in the network, which means that, we, in a certain sense, problematized the EER-ANT network. We have also transformed ANT by analyzing and combining the translation of other actors. We, therefore, hope that other actors recognize our presence in the network, and engage in this negotiation in order to come to a stabilized translation of ANT in EER that can be *punctualized* and *mobilized* to future work in the field.

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