An Activity Theory Investigation of Tool-Use in Undergraduate Mathematics

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To Effie and Stelios

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Abstract

This mixed methods study investigates a number of aspects related to tool-use in undergraduate mathematics as seen from an Activity Theory perspective. The aims of this study include: identifying the tools that undergraduates use; seeking for an empirically-based typology of these tools; examining how undergraduates themselves can be profiled according to their tool-use; and finally identifying the factors influencing students' tool preferences. By combining results from survey, interview and diary data analyses, it was found that undergraduates in the sample preferred using mostly tools related to their institution's practice (notes, textbooks, VLE), other students and online videos. All the tools students reported using were classified into five categories: peers; teachers; external online tools; the official textbook; and notes. Students in the sample were also classified into five distinct groups: those preferring interacting with peers when studying mathematics (peer-learning group); those favouring using online tools (online-learning group); those using all the tools available to them (blended-learning group); those using only textbooks (predominantly textbooks-learning group); and students using some of the tools available to them (selective-learning group). The main factor shaping students' tool choices was found to be their exam-driven goals when examined from an individual's perspective or their institution's assessment related rules when adopting a wider perspective. Results of this study suggest that students blend their learning of mathematics by using a variety of tools and underlines that although undergraduates were found to be driven by exam-related goals, this is a result of the rules regulating how Higher Education Institutions (HEI) function and should not be attributed entirely as stemming from individuals' practices. Assigning undergraduates' exam-driven goals to their university's sociocultural environment, was made possible by combining two versions of Activity Theory (Leontiev and Engestrøm's) and analysing data at two different levels (individual and collective respectively).

Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

My interest and concern of tool-use in undergraduate mathematics have their roots in my experiences as a learner during my undergraduate and taught postgraduate studies; for a number of reasons, I had to rely on using a variety of tools in order to support my learning of mathematics and based on my experience other students were doing the same too. This interest was amplified by my inherent attraction to tools; I was always fascinated by the (physical) tools that our predecessors were crafting to aid their survival and awareness of the cosmos; in fact, my Master's thesis was devoted to the Antikythera Mechanism, an ancient Greek gear-powered computer and orrery used for predicting astronomical positions and eclipses (Freeth, Jones, Steele, & Bitsakis, 2008).

This chapter serves as a brief introduction into to the importance of the problem this study aims to solve (section 1.1), my study's research questions (section 1.2) and sociocultural context (section 1.3), and finally, my thesis' outline (section 1.4).

1.1 Importance of the problem

Independent study is a crucial part of learning in formal educational contexts at any level and undeniably any educator will argue in favour of the necessity and benefits of this. In fact, results from a recent major study in the UK suggest that undergraduates develop their skills ***better out*** of -rather than in- lecture theatres (Neves, 2016). On the one hand, universities provide undergraduates with a variety of resources ranging from textbooks to virtual learning environments (VLEs) in faith that these tools will support them during contact and out of contact hours. On the other, undergraduates are exposed to a plethora of technologies that can potentially be used alongside more traditional ones and thus ***blend*** their learning; actually, some support that this is exactly what students have always been doing, mixing different tools in order to support their learning (e.g. Masie, 2006).

Studying the role of tools in human practices is not a recent topic and early pioneers such as Lev Vygotsky underlined the importance of signs and tools as mediators of learning since the early 1920s (Vygotsky, 1978). Certainly, tools are important in mathematics (Monaghan, Trouche, & Borwein, 2016) yet, in mathematics education there seems to be some kind of historical amnesia regarding to what we consider as technologies, because humans have been using technologies since the dawn of the human species and not since the rise of electronic devices (Roberts, Leung, & Lins, 2012). Despite that, the majority of research carried out, concerns tools that are digital in nature.

However, the adherence to digital/online technologies is one side of the problem; the other is related to the legitimate recipients of learning i.e. students themselves. The literature of blended learning in higher education seems to be flooded with studies focusing on "how-to" case studies reporting on the implementation of digital technologies (69.4%) with a smaller portion (25.63%) focusing on students (Torrisi-Steele & Drew, 2013): still, only 17.65% of them deal with the student experience and most of them are reporting on institutionally-provided tools (e.g. VLEs).

1.2 Purpose and research questions of this study

Having in mind the importance of independent study time, the crucial role of tools in human practices and the gap identified in the literature, the purpose of this study is to shed light into an area that has been (to the best of my knowledge) systematically ignored: the student perspective in tertiary mathematics in relation to tool-use. The questions this study aims to answer are all related to tool-use in undergraduates mathematics. RQ1 intends to identify the tools undergraduates ***themselves*** choose and use when studying mathematics (what tools do undergraduates use when studying mathematics?). Due to the plethora of available tools and the fast pacing of new technologies, RQ2 aims at going beyond the temporal and cultural characteristics of this study by producing a typology of the tools that undergraduates use (how can the tools used by undergraduates be categorised?). RQ3's purpose is to classify undergraduates according to their tool-use preferences (how can undergraduates be profiled according to their tool-use?) and is the intermediate step in answering RQ4 i.e. identifying from an Activity Theory perspective why undergraduates choose and use certain tools (what factors can account for undergraduates' tool-choices?).

1.3 Sociocultural context of the study

The study took place in a UK research intensive university offering a variety of undergraduate and postgraduate courses in Engineering (Aeronautical, Automotive, Chemical, Materials, Civil and Building, Electronic, Electrical and Systems, Mechanical and Manufacturing), Science (Chemistry, Computer Science, Mathematics, Physics), Social, Political and Geographical Sciences, Business and Economics, Sports, Exercise and Health Science, the Arts English and Drama and Design. In total, 17,975 UK/EU and international full-time students are enrolled[1] with 60% of them being male and 40% female students[2]. The university is a single-site campus covering an area of 440 acres. In total, 792 full and part-time members of staff are employed at research, teaching and enterprise positions[3].

1.4 Outline of the thesis

In Chapter 2, the theoretical framework that guided my research is presented, Leontiev and Engestrøm's versions of Activity Theory (AT). Section 2.1 offers a historical perspective on the development of AT. In sections 2.2 and 2.3, Leontiev and Engestrøm's versions of AT are presented respectively. In section 2.4 a short

[1] Official statistics for full-time students, academic year 2016-2017.
[2] Official statistics for full and part-time students, academic year 2016-2017
[3] Official statistics for December 2016.

discussion on the similarities and differences between these two tastes of AT is offered, followed by a summary of limitations in AT approaches in section 2.5. Finally, in section 2.6 a short summary of the basic AT ideas used is presented. Placing this chapter before the literature review was a conscious decision; AT guided my steps throughout all the phases of my research and I therefore consider that before proceeding to the rest of the chapters, the reader should be first introduced to AT.

In Chapter 3, a state of the art review of the literature related to my research focus is presented. Section 3.1 introduces the reader to how my view on tools influenced the review, whereas the following sections (3.2-3.5) present tentative answers to my research questions as found in the wider literature. Finally section 3.6, describes in short my intentions in overcoming the gaps identified in the literature.

In Chapter 4, I describe the methodology followed for collecting and analysing data. Section 4.2 introduces the reader to Mixed Methods and in section 4.3 my overall research design is described. The chapter concludes with a description of my data collections methods (section 4.4) and my data analysis plan (section 4.5).

Chapter 5 presents the results of the quantitative (QUAN) strand of my study (survey) and it is organised by research question.

In Chapter 6, I present the results of my qualitative (QUAL) strand, with section 6.2 dealing with diary data and section 6.3 with interview data.

Chapter 7 summarises the results from both the QUAN and QUAL strands of my study, organised by research question (sections 7.1-7.4). The chapter ends with the limitations associated with this study (section 7.5), implications for research and practice (section 7.6), some reflections on using AT as my theoretical framework (section 7.7) and finally my plans for the future (section 7.8).

Chapter 2 Theoretical Framework

2.1 Introduction

In this chapter, I describe the theoretical framework that guided my research and shaped to an extent my way of thinking, Leontiev and Engestrøm's versions of Activity Theory (AT). I have based my understanding on a number of books and papers but among all, I consider Kaptelinin and Nardi's (2006), "Acting with Technology: Activity Theory and Interaction Design" to be the most influential. My understanding of Activity Theory is based mostly on this book and it might be limited and/or different from other interpretations found in the literature.

In the remaining of section 2.1, a short historical account of the different AT schools is presented. Section 2.2 provides an overview of Leontiev's version of AT, whereas section 2.3 presents a summary of Engestrøm's version. In section 2.4 similarities and differences between these two versions are summarised. In section 2.5 a number of limitations is presented. Finally, in section 2.6 a short summary of the main ideas used in this study is presented.

2.1.1 What is Activity Theory?

Activity Theory (AT) or Cultural Historical Activity Theory (CHAT) was initially developed as a method of scientific psychology (Leontiev, 1981a) but almost a century after its formation by Lev Vygotsky, it has been widely implemented in other disciplines too, such as mathematics education (e.g. Roth & Radford, 2011) and human computer interaction (e.g. Bertelsen & Bødker, 2003; Kaptelinin & Nardi, 2006). In general terms, AT is "a philosophical and cross-disciplinary framework" (Kuutti, 1996, p. 25), a theoretical perspective within psychology (Yamagata-Lynch, 2010) and other social sciences, aiming at studying different forms of human practices in every-day life circumstances (Kaptelinin & Nardi, 2006) by accounting both the individual and its social context at the same time (Kaptelinin & Nardi, 2006; Kuutti, 1996; Yamagata-Lynch, 2010).

2.1.2 Historical roots

AT has its theoretical roots in the 18^{th} and 19^{th} century's classical German philosophy; the genesis of the concept of activity is located in the works of German idealistic philosophers like Kant, Fichte and Hegel (Kuutti, 1996). Although Feuerbach introduced the notion of activity into materialistic philosophy (*Ibid.*), it was Karl Marx who set the theoretical and methodological basis of activity firstly presented in his Theses on Feuerbach (Engestrøm & Miettinen, 1999).

2.1.3 Generations of AT

Engestrøm (1999; 2001) suggests that the development of AT can be organised into three theoretical generations, each of which adopts a different perspective:

- First generation AT, founded by Lev Vygotsky;
- Second generation AT, as developed by A. N. Leontiev (e.g. 1981a) and Y. Engestrøm (1987) separately;
- Third generation AT, as conceptualised by Y. Engestrøm (2001)

Roth (2014) suggests that the development of AT can be organised into four generations:

- First generation AT by Lev Vygotsky
- Second generation AT as developed by A.N. Leontiev
- Third generation AT:
    - the Helsinki version as developed by Engestrøm (e.g. 1987)
    - the Berlin version as developed by K. Holzkamp and his colleagues (e.g. Holzkamp, 1993)
- Fourth generation AT which builds on third generation but also includes emotions and ethics (e.g. Roth & Lee, 2007)

The following short description of the development of AT, is based on Engestrøm's (1999; 2001) suggestion.

2.1.3.1 First generation AT

In the 1920s shortly after the Soviet Revolution, the new government asked scholars to reform psychology by incorporating Marxist philosophical principles and Lev Vygotsky was among them (Yamagata-Lynch, 2010 citing Wertsch, 1985). One of his great contributions in psychology which set the foundations of AT (Kuutti, 1996), was the notion of mediation (Vygotsky, 1978). Vygotsky introduced the concepts of tool, tool operations, goal and the motive of an activity (Leontiev, 1980). The importance of Vygotsky's contribution was that he considered as the unit of analysis not the individual but the subject-object-artefact triad (Engestrøm, 1999), where the subject is the person acting, artefacts are the (psychological)[4] tools/means that the subject uses in order to achieve something, the object (Figure 2.1).

[4] Vygotsky was mostly concerned with psychological tools.

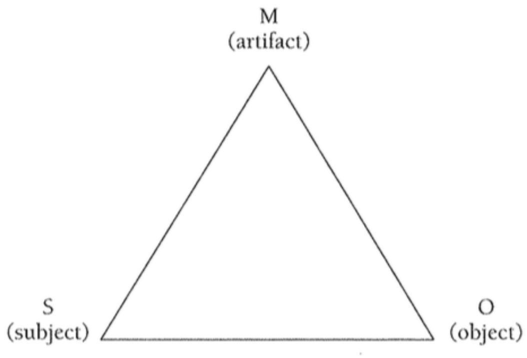

Figure 2.1: Vygotsky's basic mediational triangle (adopted from Cole, 1996, p.119). A person's (subject, S) relationship with the objective world i.e. what he wants to achieve (object, O) is mediated by tools (artefacts, M).

2.1.3.2 Second generation AT

Although revolutionary, Vygotsky's unit of analysis was focused on the individual (Engestrøm, 1999) and his description of AT was "unsatisfactory and too abstract" (Leontiev, 1981b, p. 59). The emerged limitations were overcome mainly by A. N. Leontiev's work (Engestrøm, 1999): Leontiev developed further Vygotsky's ideas, integrated a variety of other theoretical perspectives (Marx, Engels, Rubinstein and Bernstein) and introduced his own ideas into a coherent theoretical framework (Wertsch, 1981). He expanded the notion of mediation by emphasising the collective nature of human activity (Engestrøm, 1999) and proposed that activities have a hierarchy (activity, actions, operations), which distinguish the individual's goal-directed actions and the community's object-oriented activity (Yamagata-Lynch, 2010, p. 21). Although Leontiev explicitly mentioned the collective nature of human activities, he did not explore the structure and development of collective activities, neither did he propose a conceptual model for them (Kaptelinin & Nardi, 2006). Engestrøm (1999) adds that Leontiev's version of activity theory "...never graphically expanded Vygotsky's original model of a collective activity system" (p.5).

Engestrøm's contribution to the development of CHAT starts in 1987; in his seminal work "Learning by expanding: an activity theory approach to developmental research", he presented his version of Activity Theory, where he proposed a model of collective activity, extending Leontiev's model in a two-folded way (Kaptelinin & Nardi, 2012):

- firstly, he added a third element in the subject-object activity, that is community (see Figure 2.2)
- secondly, he suggested that the relationship of each of the three elements is mediated by a special type of means; tools for the subject-object interaction, rules for the subject-community interaction, division of labour for the community-object interaction. The final addition was outcome, the intended result of an activity which could be utilised by other activities.

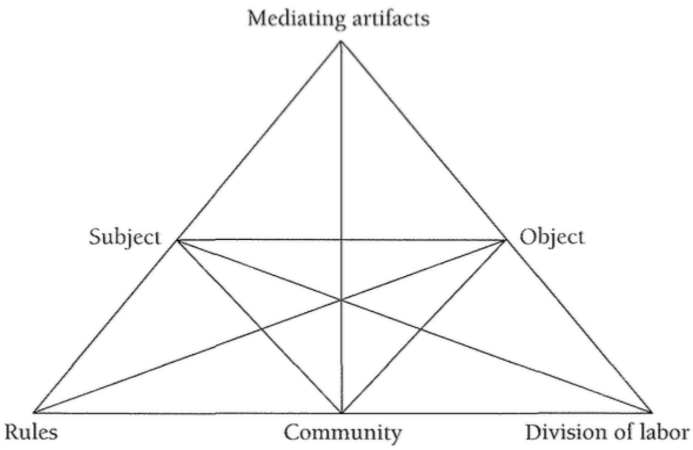

Figure 2.2: Engestrøm's representation of an activity, as an activity system. Besides the basic mediational triangle Engestrøm incorporated community and mediators for the relationships between subject and community (rules) and community/object (division of labour (adopted from Cole, 1996, p. 140).

2.1.3.3 Third generation AT

Engestrøm in his account of the evolution of AT (Engestrøm, 2001), describes that certain theoretical developments have prepared the ground for the formation of a third generation AT; the model (Figure 2.3) now is expanded in order to include two interacting activity systems as the minimal unit of analysis (Engestrøm, 2001) with researchers in developmental research usually adopting a participatory and interventionist role (Yamagata-Lynch, 2010).

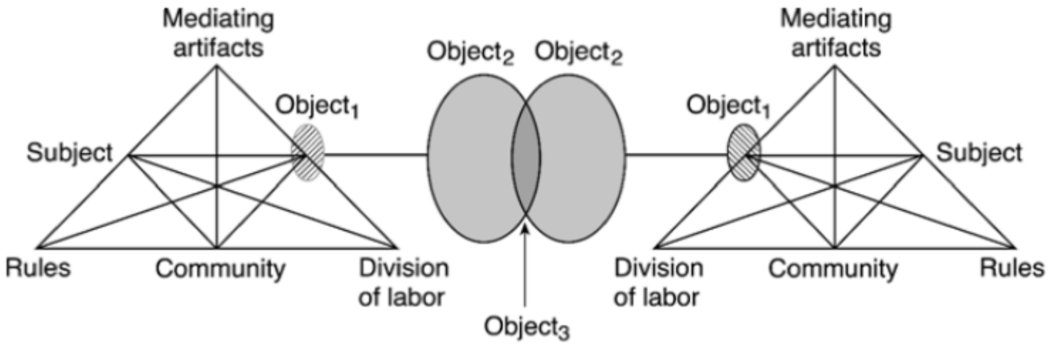

Figure 2.3: Two interacting activity systems (adopted from Engestrøm, 2001).

2.2 Description of Leontiev's version of Activity Theory

In this section, I describe Leontiev's version of AT. Although it reflects his writings, I have also included the interpretations of other scholars and the modifications that have been proposed either on a theoretical basis (the separation of motive and object by Kaptelinin & Nardi, 2006) or an empirical basis (ensembles and purposes as an intermediate level between activity and actions by González, Nardi, & Mark, 2009).

2.2.1 Needs and the notion of "activity"

The ultimate reason behind every human activity is needs (Kaptelinin & Nardi, 2006) and according to Leontiev (1981b) we engage in activities which correspond to certain needs, biological or psychological. Activity Theory is interested in psychological needs which can be categorised as “objectified”, needs associated with an object (a way to satisfy them) or “un-objectified”, needs not associated with an object (Kaptelinin & Nardi, 2006). When a need is satisfied, there is no reason for an activity to continue to live, and thus it is terminated (Leontiev, 1981b).

Activity Theory analyses “the genesis, structure, and processes [of human] activities” (Kaptelinin & Nardi, 2006, p. 31) but what counts as an “activity”? A commonly used schema to graphically represent an activity is S <—> O and the term is used for referring to a specific type of interaction between a person acting (S, subject) and what he/she wants to achieve (O, object) (Kaptelinin & Nardi, 2006). In this interaction, the object of the activity has a special status, it motivates the activity (Kaptelinin & Nardi, 2006), it is “its true motive” (Leontiev, 1977, p. 98). According to Leontiev (1981b), activities are bounded with motives in the sense that there do not exist “un-motivated” activities; activities always have a motive even if the motive is “subjectively and objectively concealed” (p.59).

Kaptelinin and Nardi (2012) note that within the AT framework, activities have two distinct characteristics: (1) subjects have needs which they try to fulfil through their interaction with the world and (2) activities and their components (subjects and objects) mutually determine each other. The latter means that subjects’ and objects’ attributes influence the activity but also the activity itself will transform the subject and the object. Based on this, I could say that what we do (activity) is determined by who we are (subject) and what we want to achieve (object); however, the opposite also applies, that is who we are and what we want to achieve is determined by what we do or were doing.

2.2.2 Motive, object or both?

The concepts of need, activity, object and motive play a central role in AT but according to Kaptelinin and Nardi (2006) there are certain theoretical contradictions arising from Leontiev’s writings, in particular:[5]

1. **Two words one meaning?** Both the motive and the object are treated by Leontiev as having the same meaning. Why having a second word for describing the same concept?
2. **How should poly-motivated activities be analysed?** A poly-motivated activity is recognised as a possibility in Leontiev’s AT version but not incorporated in a sufficient way for analysing such forms of activities. In particular, the concepts of “need”, “activity”, “motive”, “object” are problematic when used in analysis.

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[5] Here I present two of the three problems identified by Kaptelinin and Nardi (2006), namely the duplication of the meaning of object/motive and the problem of poly-motivated activities.

Kaptelinin and Nardi (2006) suggest that by separating the notions of the motive and the object, these inner contradictions can be resolved. By doing so, if there is more than one conflicting need (for example N_1, N_2), this can either result in different activities for each need (Model A, Figure 2.4) or one activity for all needs (Model B, Figure 2.5):[6]

1. Model A: each need (N_1, N_2) can be satisfied if the agent engages in different activities (A_1, A_2), with different objects (O_1, O_2). Thus, we have one activity with one object for each need: $N_1 => A_1(O_1)$, $N_2 => A_2(O_2)$. Model A is used in most analyses by Leontiev.
2. Model B: one activity (A) with one object (O) is formulated in order to satisfy all needs (N_1, N_2). If an individual has to satisfy two needs (N_1, N_2) in a given social context (SC), under certain conditions and having certain means (CM), he/she will attempt to attain two different motives (M_1, M_2) at the same time. If these two needs (and their corresponding motives) cannot follow the route described at model A (resulting in two different activities) then the subject will try to define one object and engage into one activity in order to attain the motives.

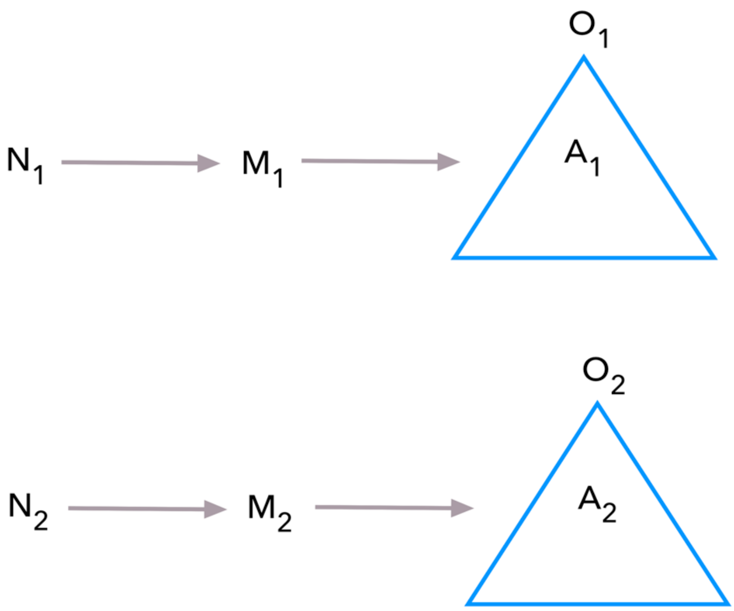

Figure 2.4: Model A (adapted from Kaptelinin & Nardi, 2006)

[6] Note that model B here corresponds to model C in Kaptelinin & Nardi, 2006.

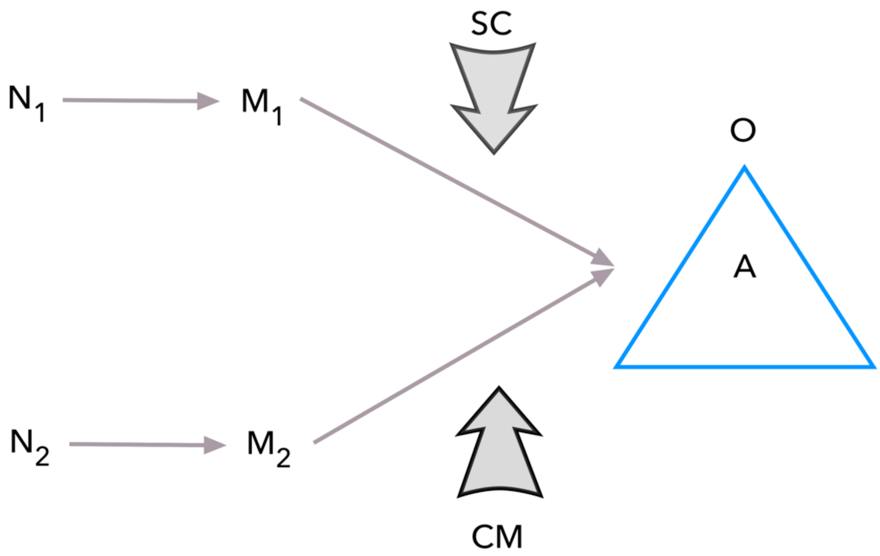

Figure 2.5: Model B (adapted from Kaptelinin & Nardi, 2006). SC: social context, CM: conditions and means.

2.2.3 Motives, motivational conflicts and conflict resolution mechanisms

Leontiev (cited in Kaptelinin & Nardi, 2006) notes that there are two types of motives:

- **sense-forming motives**, which provide the activity with its meaning (e.g. a person buying a car as a means of transportation)
- **motives-stimuli**, that provide additional motivation but do not change the meaning of an activity (e.g. buying a car of a prestigious brand)

It is common for motives-stimuli and sense-forming motives to come into conflict; usually the latter prevail over the former (Kaptelinin & Nardi, 2006). According to Leontiev there is a hierarchy of motives which decodes which motive should take over. In general, the basic motives of an activity tend to be stable although objects can change as an activity develops over time (Kaptelinin & Nardi, 2006).

2.2.4 The hierarchical structure of activities

According to Leontiev (1977; 1981b) and Kaptelinin and Nardi (2006), an activity is a hierarchical entity consisting of three levels (Figure 2.6):

1. Top level: the activity itself directed towards an object
2. Middle level: activities consist of actions which are directed to goals
3. Low level: actions in turn are comprised of operations which are directed towards conditions.

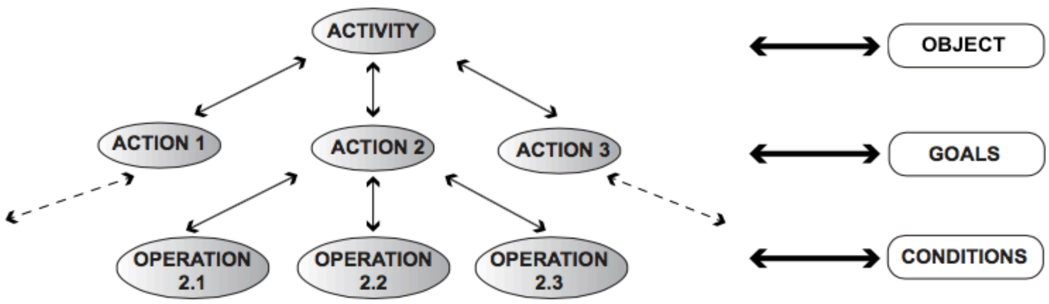

Figure 2.6: A common representation of Leontiev's hierarchical structure of an activity. Activities consist of actions directed at goals. Each action consists of operations. Please note that I have adapted the model in order to reflect the separation of the motive from the object (adapted from Kaptelinin and Nardi, 2012).

2.2.4.1 Middle level: actions and goals

Actions

Actions are the basic components of human activities and they are responsible for translating activities into reality (Leontiev, 1981b). Actions can be defined as processes "subordinated to the idea of achieving a result, i.e., process[es] that [are] subordinated to a conscious goal" (Ibid., pp.59-60, underlined in original). González, Nardi and Mark (2009) define actions in a more concrete way, as "…the specific interactions that people have with artefacts and other people…" (p.119) i.e. using a tool or interacting with other subjects.

According to Leontiev (1981b), the emergence of goal-directed practices (i.e. actions) are traced in the transition of humans to society; the division of labour led humans to perform actions not directly related with the need motivating the activity. Actions have two phases, the orientation phase (when a subject mentally plans an action using a model) and the execution phase (when the action is performed into the real world) (Kuutti, 1996). Actions may not be directly related with an activity's object but as a whole they aim at attaining the object (Kaptelinin & Nardi, 2006). Although actions constitute activities with a different motives and objects, they do not belong to one activity only: actions are relatively independent and can be transferred between activities (Leontiev, 1981b). When an action belongs to different activities (with different motives and objects), the same action has a different personal sense to a subject depending the context of each activity (Kuutti, 1996).

Goals

Actions are directed towards goals and they are all conscious (Leontiev, 1981b); in fact, goals behave like an activity's object, or in other words, a goal is the object of an action (Kaptelinin & Nardi, 2006). Leontiev (1981b) notes that "any kind of well-developed activity presupposes the attainment of a series of concrete goals, some of which are rigidly ordered" (p.61, underlined in original).

2.2.4.2 Low level: operations and conditions

Operations

At the lower level of the hierarchy, lie operations; non-conscious, routine processes, which enable a subject to adjust an action to an ongoing situation (Kaptelinin & Nardi, 2006). Operations are used for answering the conditions faced during the performance of an action (Kuutti, 1996). Operations emerge in two ways (Kaptelinin & Nardi, 2006):

- as an improvisation; when a subject spontaneously tries to adjust an action while performing it (e.g. when someone walks through a crowd)
- as an automatisation of actions; when a subject over the course of time transforms an action into a routine operation (e.g. when learning how to drive a car)

Conditions

Operations are directed towards the conditions under which a subject is trying to achieve a goal (Kaptelinin & Nardi, 2006): these are not determined by a subject's goals but "by the objective-object conditions of its achievement" (Leontiev, 1977, p. 102). In other words, conditions are factors that affect activities but are not under the subject's control, in fact conditions are embedded in the material context (Roth & Lee, 2007). For example, when someone walks through a crowd, the weather or the state of the road's surface could be accounted as conditions shaping a subject's activity.

2.2.5 Principles of Leontiev's version of Activity Theory

Kaptelinin and Nardi (2012; 2006) provide five basic principles of Leontiev's theoretical framework:[7]

1. **Object-orientedness**: the first principle states that all human activities are directed towards their objects and that an activity's object is the factor that differentiates one activity from another.
2. **Hierarchical structure of activity**: the second principle states that activities have a hierarchical structure. They are "units of life" organised into 3 hierarchical layers, as discussed earlier:
   a. Top layer: the activity itself, oriented towards an object.
   b. Middle layer: consisting of actions and goals.
   c. Lower layer: consisting of operations and conditions.
3. **Mediation**: this principle originated in Vygotsky's writings but has a different meaning in Leontiev's framework since Vygotsky was mostly concerned with psychological tools that mediate specific mental operations rather than physical tools which mediate activity as a whole. Mediation, states that our relationship

[7] The proposition of Kaptelinin & Nardi (2006) for separating the notions of the motive and the object of an activity is acknowledged here, so an activity is directed towards its object (instead of its motive).

with the “objective” world is mediated by tools: the central role of tool mediation is due to the fact that tools shape the ways we interact with reality and they reflect past people’s experiences and practices.

4. **Internalisation and Externalisation:** according to fourth principle, activities are distributed between external and internal planes. All activities contain internal and external components; in internalisation, external components become internal e.g. when a child uses her fingers (external) to count (internal) and in externalisation the opposite process takes place e.g. when a person uses paper and pencil (external) to capture an idea (internal).
5. **Development**: the last principle states that activities develop over time and consequently requires that activities should be always analysed in the context of their development.

2.2.6 The dynamics of human activities

The above described structural elements of an activity are not fixed (Bertelsen & Bødker, 2003). In contrast, activities are characterised by constant transformations (Leontiev, 1981b): each component of an activity can be transformed into another and these transformations can take place at all levels of activities (Bertelsen & Bødker, 2003; Kaptelinin & Nardi, 2006, Figure 2.7).

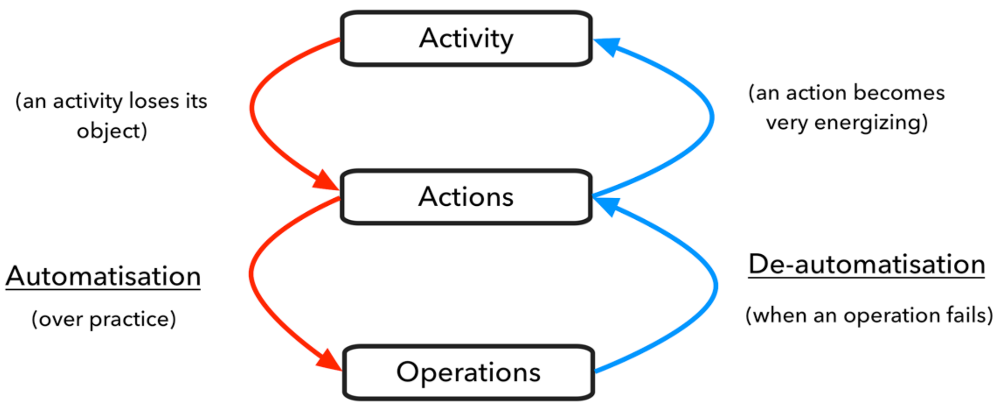

Figure 2.7: Transformations between the levels of an activity.

2.2.6.1 Transformations between actions and operations

Over the course of time a conscious action can be transformed into a routine operation; this process is called automatisation (Bertelsen & Bødker, 2003; Kaptelinin & Nardi, 2006). The opposite transformation can also happen; when an operation fails, the subject may transform it into an action. This transformation is called de-automatisation (Kaptelinin & Nardi, 2006) or conceptualisation (Bertelsen & Bødker, 2003). De-automatisation can also happen when a condition changes and therefore the corresponding operation must be altered (Kuutti, 1996) or when the goal of an action changes (Kuutti, 1996 citing Davydov, Zinchenko, & Talyzina, 1982).

2.2.6.2 Transformations between activities and actions

In the same way that an action can be transformed into an operation, an activity may lose its object and transform into an action that may then be implemented into a different activity (Leontiev, 1981b). Similarly, an action can become an activity in its own right, if it gains enough energising force (*Ibid.*).

2.2.7 Mind the gap

González, Nardi and Mark (2009) note that despite its holistic perspective, Leontiev's theoretical framework misses an important component needed to fully describe the practical aspects of activities.[8] In particular, based on empirical research and hints from Leontiev's writings they suggest that there is a need to add a fourth level into the hierarchical structure of activities, between top level (activity - object) and middle level (actions - goals) called ensembles and purposes (Figure 2.8). They define ensembles as "sets of thematically related actions defined by a purpose" (p.110). Ensembles are "grounded in localised purposes rather than the grander motivations that orient activity" (p.121) with purposes being "broader than the goals of individuals" (p.119).

Activities	→	Objects
Ensembles	→	Purposes
Actions	→	Goals
Operations	→	Conditions

Figure 2.8: The modified hierarchical structure of activities with the intermediate level of ensembles and purposes as proposed by González, Nardi and Mark (2009).

Ensembles have guiding power in the sense that they direct subjects' attention to purposes that frame sets of actions which in turn inform subjects "what to do next' (González et al., 2009). In short, the value of ensembles and purposes lies on the fact that they "make actions meaningful beyond the scope of short-term goals" (p.117), help subjects to "map actions onto higher-level practical purposes" (p.117) and "to envision and define workloads" (p.118).

2.2.8 Functional organs

Another theoretical concept of Leontiev's version of Activity Theory is functional organs (or functional systems)[9]. Its origins lie in the writings of the Russian physiologist Ukhtomsky, who broadly defined them as "any temporary combination

[8] Vladimir Zinchenko (Zinchenko & Gordon, 1975) also suggested a fourth level into the hierarchy of an activity called "functional blocks" that are below the level of operations (Kaptelinin & Nardi, 2006). I consider that this level of analysis is not suitable for my study, therefore I do not report on this here.

[9] The notion of functional organs shares similarities to the ***instrumental genesis approach*** and has its roots in both Activity Theory and French ergonomics (Kaptelinin, 1996). In fact, Rabardel (e.g. 2003) uses Leontiev's notion of functional organs.

of forces which is capable of attaining a definite end" (Ukhtomsky, 1978 cited in Kaptelinin & Nardi, 2006). Leontiev developed further the idea and considered them to be systems which combine internal (human) and external (artefactual) resources, enabling subjects to extend their natural abilities (Kaptelinin, 1996). Creating and using functional organs, requires the subject to have three types of competencies: **tool-related competencies**, **task-related competencies** and **meta-functional competencies** (Kaptelinin, 1996; Kaptelinin & Nardi, 2006). Tool-related competencies include knowledge of how a tool works and skills required for its use. Task-related competencies refer to a subject's ability in identifying the range of problems solvable by a tool (knowing which higher-level goal can be achieved by using the tool) and skills necessary for translating these goals into a tool's functions. Finally, meta-functional competencies are not directly related to a tool or a subject's goals but they rather include a subject's ability to coordinate primary and secondary goals, with a functional organ's limitations, side effects, maintenance and troubleshooting. According to Kaptelinin (1996), the concept of functional organs suggests that in education we should not only be focussing on teaching students how to operate a tool (tool-related competencies) but also on the range of problems solvable by a tool, limitations of a tool, troubleshooting techniques etc. (task-related and meta-functional competencies).

2.3 Description of Engestrøm's version of Activity Theory

In this section, I describe Engestrøm's version of AT (second generation). In doing this, I relied on his writing but I have also included the interpretations of other scholars too.

2.3.1 Description

The triangular representation of Engestrøm's version of AT consists of six components: subject, object, tools, community, rules, division of labour. The product of an activity system is called outcome. Tools mediate the relationship between subject and object, rules mediate the relationship between subject and community and division of labour the relationship between community and object (Bellamy, 1996; Engestrøm, 1987; Kuutti, 1996). All components interact with each other, with the interaction to be bidirectional in nature (Bellamy, 1996).

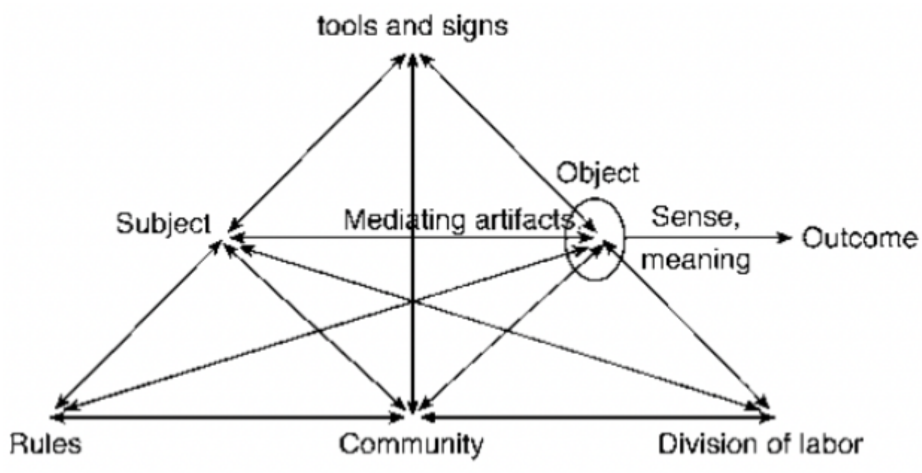

Figure 2.9: Engestrøm's model of an activity system (from Engestrøm, 1987)

Subject

Subject refers to the "individual or sub-group whose agency is chosen as the point of view in the analysis" (Engestrøm, 1990a, p. 79). In educational contexts, the subject is student's identity in relation to his or her programme of study; this could include student as a novice member of a discipline or a profession, as a member of the institution she or he attends or even as a member of another activity system (Ashwin, 2009).

Object

Object constitutes "the 'raw material' or 'problem space' at which the activity is directed and which is moulded or transformed into outcomes with the help of ... tools" (Engestrøm, 1993, p. 67). It motivates, directs (Kaptelinin & Nardi, 2006) and gives activities "attention, motivation, effort, and meaning" (Engestrøm, 2009, p. 304).

Outcome

Outcome refers to "the end result of the activity" (Yamagata-Lynch, 2010, p. 2); it is the process of transforming the object into an outcome "motivates the existence of an activity" (Kuutti, 1996, p. 27).

Tools

Alexander Luria notes that "man differs from animals in that he can make and use tools"[10] (Luria, 1928 p.493 cited in Engestrøm & Cole, 1993). AT theorists also refer to tools as artefacts; for example, Cole (1996) notes that the term artefact is broader in the sense that it can include also non-material/psychological tools (e.g. language). According to Yamagata-Lynch (2010), tools include "social others and artefacts that can act as resources for the subject in the activity" (p.2).

[10] This is an incorrect old view. See for example, Monaghan (2016b).

Community

Bellamy (1996) notes that subjects do not act in isolation and their activity is affected by participating in a community. In a broad sense, community consists of "the social group that the subject belongs to while engaged in an activity" (Yamagata-Lynch, 2010, p. 2) or more specifically to "multiple individuals and/or sub-groups who share the same general object and who construct themselves as distinct from other communities" (Murphy & Rodríguez-Manzanares, 2013, p. 38). In educational contexts, community relates to how students see themselves and the object of their activity (Ashwin, 2009).

Rules

Rules (or norms) mediate the relationship between subject and community (Kuutti, 1996). In particular, they govern (Murphy & Rodríguez-Manzanares, 2013 citing Worthen & Berry, 2006) and regulate the activity (Engestrøm, 1991). Rules are a set of "explicit and implicit regulations, norms and conventions" (Engestrøm, 1990a, p. 79) that they "constrain activity... [and] inherently guide (at least to some degree) ... the activities acceptable by the community" (Jonassen, 200 p.103 cited in Murphy & Rodríguez-Manzanares, 2013). In other words, rules constitute the formal or informal mechanisms controlling the operation of an activity system (Cowan & Butler, 2013).

Division of Labour

Division of labour describes "how the activity is distributed among the members of the community, that is, the role each individual in the community plays in the activity, the power each wields, and the tasks each is held responsible for" (Bellamy, 1996, p. 125). This distribution of workload has two axes, one vertical and one horizontal; "the horizontal division of tasks between the members of the community and to the vertical division of power and status" (Engestrøm, 1993, p. 67).

4.3.2 Principles of Engestrøm's version of Activity Theory

Engestrøm (2001) mentions five principles that summarise Activity Theory:

1. The unit of analysis should be the entire activity system situated within a network of activity systems
2. Activity systems are multi-voiced and their multi-voicedness is multiplied in networks with interacting activity systems
3. The establishment and development of activity systems take place over lengthy periods of time (historicity)
4. Contradictions act as sources for the change and the development of activity
5. Activity systems have the potential of expansive transformations

4.3.3 Contradictions

Contradictions have a central role in second[11] and third generation activity theory and are conceptualised as forces of influence within (Yamagata-Lynch, 2010) and between activity systems (Murphy & Rodríguez-Manzanares, 2013) which can put pressures on activities (Yamagata-Lynch, 2010) and motivate their change and development (Engestrøm, Miettinen, & Punamäki, 1999), thus allowing more advanced forms of activity systems to emerge (Engestrøm & Sannino, 2011). Contradictions are not directly observable, "they can only be identified through their manifestations" (Engestrøm & Sannino, 2011, p. 368). There are four levels of contradictions (Engestrøm, 1987; Kaptelinin & Nardi, 2012): **primary contradictions**, inner conflicts arising within components; **secondary contradictions**, appearing between the components of an activity system; **tertiary contradictions**, appearing between the object/motive of the dominant activity system and its culturally more advanced form; and **quaternary contradictions**, emerging between neighbour activities within a network of activities.

2.4 Similarities and differences

Having viewed Leontiev and Engestrøm's versions of AT, I think it is important here to highlight some of the similarities and differences that these two frameworks have. Kaptelinin (2005) and Kaptelinin and Nardi (2006) note that undeniably both versions of AT are complementary and they mention that both theories treat activities as a special type of interaction between subjects and their objects, they account activities to be social and finally, they emphasise the importance of culture, development and mediation. However, Kaptelinin and Nardi (2006) note that between these two versions of AT, there do exist certain differences which are usually ignored. First, although Leontiev accounted activities as social, his theory was primarily developed as a psychological framework and as such it uses ***individual activity as the unit of analysis***. On the contrary, Engestrøm's version of AT, focuses on collective activities and within his approach, ***the unit of analysis is defined as the (collective) activity system***. The second difference between the two frameworks is related to the notion of the object. For Leontiev, the object of an activity is the object of activities carried out (predominantly) individually and is related to motivation, whereas for Engestrøm the object is defined and carried out by the community and is related to production. Table 2.1 adapted from Kaptelinin and Nardi (2006) summarises the above.

[11] The notion of contradiction was also used by Leontiev in his research (Kaptelinin & Nardi, 2006; 2012).

Table 2.1: Differences between Leontiev and Engestrøm's versions of AT. Adopted from Kaptelinin and Nardi (2006)

Facets of Activity	**Leontiev**	**Engestrøm**
Activities are carried out by:	Individuals (predominantly)	Communities
Activities are performed:	Both individually & collectively	Collectively
The object of activity is related to:	Motivation, need	Production (what is being transformed into the outcome)
Application domain:	Psychology	Organisational change

2.5 Limitations and developments

Kaptelinin and Nardi (2006) note that since its formation by Leontiev AT has been under development with many researchers expanding its boundaries and enhancing our understanding. They provide us with a description of developments in activity theoretical approaches, which can be also seen as limitations of using AT in research. These are:

1. **Extending the notion of tool mediation**: As seen earlier, tools play a central role in AT since they mediate our relationship with our objects and they inherit culture to future generations. Kaptelinin and Nardi (2006) note that not all kinds of artefacts can be accounted as tools. For example, there are certain types of technologies such as computers or digital applications (e.g. email) that can be seen more as environments than tools. Currently[12], there is no clear answer to whether these types of artefacts can be indeed considered as tools mediating human activities. On the one hand the notion of mediation is not limited to tools e.g. Engestrøm's version of AT includes mediators such as rules and division of labour but on the other, in AT approaches environments are not accounted as mediators.
2. **Dealing with multiple activities.** Kaptelinin and Nardi (2006) note that one of the challenges that AT is currently facing is developing analytical tools for explaining the complex interplay and dynamic nature of the multiple activities that subjects are usually engaged with in real-life situations[13].
3. **Developing analytical tools for creating procedural representation of activities.** Kaptelinin and Nardi (2006) mention that in understanding the use of technologies in real-life situations, more work is needed in developing

[12] As in 2006.

[13] In 2001, Engestrøm (2001) proposed implementing two interacting activity systems as the minimum unit of analysis (which is a development towards dealing with multiple activities) but Kaptelinin and Nardi do not mention this. My guess, is that their focus here is on developing analytical tools for studying multiple activities that for example, a particular individual participates and not the interaction between several activity systems with different actors.

analytical tools focusing on how activities evolve over time and not just depicting the hierarchical structure of activities.

4. **Differentiating between actual and potential goals.** According to Leontiev (cited in Kaptelinin & Nardi, 2006; 1975) subjects can be aware of one goal at a time and not of all possible goals. In this sense Wertsch (cited in Kaptelinin & Nardi, 2006; 1998) suggests that the hierarchy of goals is actually a hierarchy of ***potential*** goals which become ***actual*** goals one at a time. The main issue here is that although the differentiation between actual and potential goals is acknowledged, there is no mechanism explaining how individuals select potential goals to become actual goals. A proposed mechanism is the notions of ensembles and purposes by González, Nardi and Mark (2009) described earlier.
5. **Delineating the relationship between individual and collective activities**. Kaptelinin and Nardi (2006) note that despite AT's widely accepted potential of combining the individual and the collective planes of human practice into one framework, current AT approaches focus on either individual (Leontiev) or on collective activities (Engestrøm). Stetsenko (cited in Kaptelinin & Nardi, 2006; 2005) also argues that AT has been primarily concerned with the impact of the collective on the individual and not the opposite.
6. **Integrating the study of emotions**. Kaptelinin and Nardi (2006) comment that for Leontiev emotions indicate whether an action has successfully met -or has the possibility of meeting- a subject's motives: "[emotions] reflect [the] relationships between motives (needs) and success, or the possibility of success, of realising the action of the subject that responds to these motives" (Leontiev, 1978, p. 166). So far, the nature, functions and underlying mechanisms of emotions in human practices have not been elaborated in activity (Kaptelinin & Nardi, 2006). A known attempt to incorporate emotions in AT is Roth (e.g. Roth, 2007; Roth & Lee, 2007).

2.6 Ideas incorporated in this study

The two versions of AT briefly reviewed in the previous sections are intended to be used as two lenses each providing a different focal length: Leontiev's version of AT is envisioned to be used for studying tool-use at the individual level (unit of analysis is individual activities), whereas Engestrøm's version of AT will be used as a framework providing insights about tool-use at the collective level (unit of analysis is the activity system in which subjects participate).

The main ideas used from Leontiev's perspective, include the principles of object-orientedness (all human activities are directed towards their objects), activities' hierarchical structure (activities consist of layers), mediation (our relationship with the "objective" world is mediated by tools) and development (activities develop over time). Two modifications of Leontiev's version AT will be also incorporated: the separation of motive and object (Kaptelinin & Nardi, 2006) and the addition of ensembles/purposes as a fourth layer in an activity's hierarchical structure (González et al., 2009). Figure 2.10 provides a visualisation of the principles used and Table 2.2 offers some basic AT terminology. From Engestrøm's version of AT, the model of an activity system (subject, tools, object, community, rules, division of labour) and the notion of contradictions will be used. Table 2.3 presents some short definitions of the concepts used.

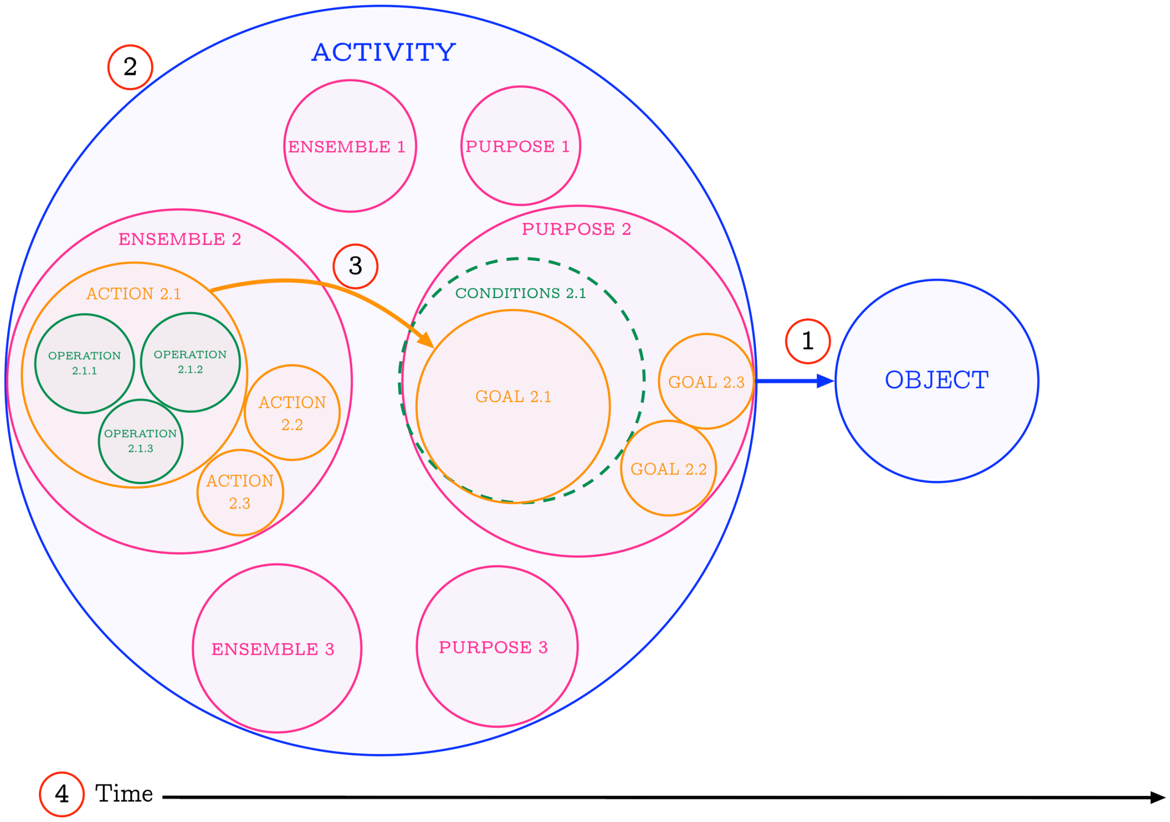

Figure 2.10: The onion-like structure of an activity: ensembles are directed at purposes (coloured pink), actions at goals (coloured orange) and operations at conditions (coloured green). Note that conditions do not act in the same way as the object, purposes or goals for the activity, ensembles and actions respectively; they are rather, circumstances shaping a subject's actions for achieving a certain goal. Numbers represent the principles used in this study: (1) object-orientedness, (2) hierarchical structure of activities, (3) mediation, (4) development.

Table 2.2: Activity Theory (Leontiev) basic terminology.

Term	Short definition
Activity	A purposeful interaction between a subject and the world (Kaptelinin & Nardi, 2006).
Object	Material or ideal (Leontiev, 1978) prospective outcomes that motivate and direct an activity (Kaptelinin & Nardi, 2006). The "why" of an activity.
Ensembles	A set of thematically connected actions directed to a purpose (González et al., 2009).
Purposes	Higher level, broad goals that frame an ensemble (González et al., 2009). The why of an ensemble.
Actions	The process of using a tool or interacting with another subject (González et al., 2009).
Goals	The "object" of an action. Goals are conscious. The why of an action.
Operations	Non-conscious, routine processes, which enable a subject to adjust an action to an ongoing situation (Kaptelinin & Nardi, 2006).
Conditions	Factors that influence the achievement of a goal but are not under the subject's control, conditions are embedded in the material context (Roth & Lee, 2007).

Table 2.3: Activity Theory (Engestrøm) basic terminology.

Term	Short definition
Subject	The "individual or sub-group whose agency is chosen as the point of view in the analysis" (Engestrøm, 1990a, p.79).
Tools	Tools are aspects of the material world that have been modified over time and have been incorporated into goal directed action (Cole, 1996).
Object	"The 'raw material' or 'problem space' at which the activity is directed and which is moulded or transformed into outcomes with the help of... tools" (Engestrøm, 1993, p.67).
Community	Community consists of "the social group that the subject belongs to while engaged in an activity" (Yamagata-Lynch, 2010 p.2).
Rules	Rules are a set of "explicit and implicit regulations, norms and conventions" (Engestrøm, 1990a, p.79) that "constrain activity... [and] inherently guide (at least to some degree) ... the activities acceptable by the community" (Jonassen, 2000 p.103 cited in Murphy & Rodríguez-Manzanares, 2013).
Division of Labour	Division of labour describes "how the activity is distributed among the members of the community, that is, the role each individual in the community plays in the activity, the power each wields, and the tasks each is held responsible for" (Bellamy, 1996 p.125).
Contradictions	Problematic situations that subjects encounter with when acting. In principle, they can be primary, secondary, tertiary or quaternary.

Chapter 3 Literature Review

3.1 Introduction

This review aims at identifying answers in the current literature related to my research questions. These are:

RQ1. What tools do undergraduates use when studying mathematics?
RQ2. How can these tools be categorised?
RQ3. How can undergraduates be profiled according to their tool-use?
RQ4. What factors can account for undergraduates' tool choices?

3.1.1 How was the search performed?

The literature review was performed by using a variety of search engines (e.g. Google scholar, Web of Knowledge, ERIC) and targeted searches at major journal publishers (e.g. Taylor and Francis). The keywords used depended on the research question and included a variety of terms and combinations of them. For RQ1 the main keywords used were "blended learning" and "tools" or "resources". For RQ2, different combinations of the terms "typology", "classification", "taxonomy", "tools" and "resources" were used. For RQ3 the keywords used included combinations of "tool-use", "profiles", "undergraduates", "students" and "cluster analysis" . Additional keywords included "mathematics", "mathematics education", "undergraduates" and "university". Finally, for RQ4 I didn't perform specialised searches but I rather used the studies previously identified as relevant (especially those for RQ3) for identifying factors accounting for undergraduates' tool choices. The search for relevant studies was an ongoing process which started early in my PhD studies (October 2014) and lasted until the late months of my studies (September 2017).

3.1.2 What problems did I encounter?

While exploring the existing literature, I encountered two major problems in finding studies related to my research questions: first, a lack of studies specifically in university mathematics and second, a lack of studies adopting a holistic approach i.e. studies researching the different tools undergraduates blend when studying mathematics not only the digital but also the more traditional ones such as textbooks or students' own lecture notes.

In my view, the limited number of studies identified for the purposes of my literature review could be a result of several factors. First, blended learning (my main area of research) seems to be dominated by a teacher perspective and many authors have criticised the current landscape by arguing that it should be called blended teaching instead (De George Walker & Keeffe, 2010; e.g. Oliver & Trigwell, 2005). Second, it seems that the appearance of new technologies made mathematics educators very excited about their potential especially in early years (e.g. Churchhouse et al., 1986; Kaput, 1992) and thus traditional tools became less the focus of relevant studies, despite the early recognitions that technology still plays a marginal role in the learning and teaching of mathematics (e.g. Cuban, Kirkpatrick, & Peck, 2001) and education in general (Cuban, 2001). Third, the notion of technology is mostly associated with online and digital tools and this manifests some kind of historical amnesia as Roberts et al. (2012) point out, since tools have been used for doing and learning mathematics since the early dawn of the human species. Finally, another factor that affected the results of my literature review was my own view of what is counted as a tool.

3.1.3 What is a tool?

Since my research questions are related to tools, I need to clarify what I mean by "tools" and how the view I adopted affected (or not) the search of the literature and my study as a whole. McDonald, Le, Higgins and Podmore (2009) note that the terms tool and artefact have been used interchangeably with little agreement on their relation. Markauskaite and Goodyear (2016) also mention that a number of scholars such as Wartofsky (1973), Säljö (1995) and Engestrøm (Engestrøm et al., 1999), use the words artefact and tool interchangeably. In relevant literature, there also exist abundant uses of the terms cultural artefacts (e.g. Cole, 1996), mediational means (e.g. Wertsch, 1998) or instruments (e.g. Guin & Trouche, 1999). For example, Wertsch (1998) acknowledges as tools (mediational means) "physical objects that can be touched and manipulated" (p.30). He also adds that:

> ...they can continue to exist across time and space, and they can continue to exist as physical objects even when not incorporated into the flow of action. These aspects of materiality are often associated with the term "artefacts" in the sense of historical artefacts that continue to exist after humans who used them have disappeared (pp. 30–31).

On the other hand, Monaghan (Monaghan et al., 2016) makes a distinction between an artefact and a tool; an artefact (a material object usually made by humans) becomes a tool only when used by a subject to do something.

To make things more complicated, there also exists an ambiguity on whether the term tools relates axiomatically to psychological or physical tools. For example, Kaptelinin and Nardi (2006) note that Vygotsky initially made no distinction between physical tools and psychological tools (i.e. signs). They mention that Vygotsky shifted his attention at a later point more to psychological tools because his studies showed that "...in many cases, subjects who used external mediational artefacts to solve a task spontaneously stopped using these artefacts and improved their performance" (Ibid., p.43). Vygotsky explains also this in his monograph "Tool and Symbol" (1978) where he supports that, "what we conventionally call tools and what we conventionally call symbols are two aspects of the same phenomenon: mediation through tools was said to be more outwardly oriented, mediation through signs was more inwardly oriented, toward "the self," but both aspects adhered in every cultural artefact" (Cole, 1996 p.6 citing Vygotsky, 1978).

From a historical perspective, it seems that the different meanings that researchers assign to these terms can be traced in the events occurring after Vygotsky's passing in 1934. After Vygotsky's death, Leontiev and Luria were forced to leave Moscow and abandon the study of mental activities (Prawat, 1999). Due to political pressures Luria, Leontiev, Galperin and Zinchenko (the so called "Kharkovites") purposefully shifted their focus from explaining human consciousness to understanding human activity (Yamagata-Lynch, 2010). This resulted a shift from the Vygotskian approach (i.e. the psychological realm of human praxis) to the "material" side of our activities. This is why although Leontiev's version of Activity Theory derives from Vygotsky's writings, it treats tools in a different way, namely it focuses mostly on physical objects. However, in recent years, the notion of a tool in Activity Theory perspectives has been expanded to include other types of mediators too such as software/digital environments (Kaptelinin & Nardi, 2006) and people (Cole, 1996).

3.1.4 My view on tools

Based on the discussion above and in accordance to my study's research objectives, I have acknowledged as tools[14] any physical (e.g. books) or digital/online (e.g. social media) object, people (e.g. peers, lecturers) and contexts/organisations (e.g. a support centre) used by undergraduates to support their learning of mathematics. As a result, my literature review may be considered limited but this is due to the adopted view of what counts as a tool and the philosophical stance I chose to aid my endeavour. Since the early days of my PhD, I was not only interested in digital/online tools or in tools provided by lecturers/university, a view that was certainly reinforced by my exposure to Activity Theory. Consequently, my view on tools may be seen expanding on three planes when compared to current/popular research approaches: (1) what is accounted as a tool; (2) the spatial/temporal uses of a tool; and (3) the division of tools themselves. For the first point, I consider as tools all "external" to the subject material objects used for achieving a goal: this certainly includes textbooks and people but also digital objects (even the pdf version of a textbook or the graph of a function on a tablet are material since they are the result of different energy levels of the electrons consisting the tablet's screen). For the second point, in the study presented here, I acknowledge tools not only used within the spatial boundaries of a university setting but also in contexts where students act when studying mathematics on their own. Finally, for the third point, tools not necessarily provided by an institution or suggested by a lecturer have been acknowledged. Therefore, while doing my literature review, a priority was assigned to studies adopting a holistic approach in tertiary mathematics. When studies in undergraduate mathematics were not available, the review was complemented by studies in general tertiary education.

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[14] I will use the terms tools, artefacts and resources interchangeably, purely for aesthetic reasons i.e. to avoid using the word tools very frequently

3.1.5 How the literature review is organised

The literature review is organised according to my research question. Section 3.2 presents what we currently know about the tools that undergraduates use when studying mathematics (RQ1); section 3.3 explores the literature related to how tools can be categorised (RQ2); section 3.4 summarises studies related to how students can be profiled according to their tool-use (RQ3) and what factors can account for their tool-use choices (RQ4); and finally, section 3.5 presents a summary of studies providing us with insights about factors related to tool-use not explored by studies in section 3.4.

3.2 What tools do undergraduates use when studying mathematics?

In this section, studies adopting a blended approach i.e. reporting on students' use of all kinds of tools, are presented. Because the literature landscape of blended learning in tertiary mathematics is scarce, studies involving undergraduates from other disciplines have also been included. The section has been divided into two parts: studies investigating the use of tools for learning and personal purposes and studies reporting on the use of tools in (formal) learning contexts only.

3.2.1 Tools used for learning and personal purposes

Conole, de Laat, Dillon and Darby (2006) conducted one of the earliest studies focusing on the ways in which undergraduates use technologies for learning (formal and informal) and personal purposes. The team surveyed a sample of 427 undergraduates in the UK across different disciplines (Economics, Languages, Medicine, Computer Science). Results showed that undergraduates use a wide range of generic and subject specialised technologies. The most popular tools included email, the internet/search engines, computers, Word and instant messaging (greater than 40% each). These were followed by PowerPoint, mobile phones, electronic libraries and VLEs (approx. 20% each). Based on the survey results (and data from interviews and audio diaries), the authors concluded that in terms of technology use, many undergraduates see ICT tools as integral to all aspects of their lives.

Thompson (2013) surveyed a sample of 388 first-year undergraduates at a large Midwestern university about their use of digital technologies for learning and personal purposes. Thompson's work is situated in the area of digital natives which asserts that students born after 1980 have a distinctive set of characteristics including preference for speed, nonlinear processing, multitasking, and social learning (*Ibid*). The questionnaire used included a list of 41 commonly used digital tools ranging from word processors (e.g. Microsoft Word) to slide presentation software (e.g. PowerPoint), audio/video/image editing software (e.g. Audacity, iMovie, Photoshop), online videos (e.g. YouTube) and games (e.g. Doom). The author identified 9 different categories of tools (see section 3.3.11 for a detailed description) and measured students' use on these categories. On a scale of 1 (never) to 8 (always), *web resource use,* e.g. using the internet to explore a topic, watch a video or listen to music, was the most frequent reported activity (6.55). This was followed by *rapid communication technologies* e.g. texting, using Facebook and chatting online (5.46); *book reading* e.g. reading books for learning or enjoyment (4.04); *productivity tool-use* e.g. using a word processor or spreadsheets (3.90); *gaming* (3.07); *active web reading and writing* (2.98); *microblogging* (2.95); *multimedia creation* (2.76); and *collaborative web tool use* (2.06). The author concluded that students use a narrow range of technologies and that they may not exploit the full benefits of these tools when using them for learning purposes.

Gallardo, Bullen and Molías (2015) interviewed a sample of 20 Education undergraduates at a Catalonian university about their use of digital technologies in their social and academic lives. Results showed that computers and mobile phones were the most frequently used resources (85% and 80% respectively) followed by Facebook (25%) and Twitter (20%). Based on the analysis of the interviews, the authors concluded that social network sites (Facebook) and instant messaging apps (WhatsApp) are the most important tools for undergraduates because they enable them to communicate and collaborate with their peers regardless of their physical location.

Costa, Alvelos and Teixeira (2016) surveyed 234 undergraduates and taught postgraduates in a Portuguese university about their use of Web 2.0 tools for both learning and leisure purposes. Participants were asked to state the average number of times per month they used a list of Web 2.0 resource for leisure and learning purposes. The list included blogs, wikis, social networks, social bookmarks, podcast, video sharing, photo sharing, slide sharing, RSS and data mash-up applications. Overall, students reported accessing Web 2.0 tools more often in a leisure context (on average 194.5 times/month) than for learning purposes (on average 69.7 times/month). The most frequently used resources for learning purposes included video sharing tools (21.1 times/month), social networks (13.2 times/month) and wikis (12.7 times/month), whereas for leisure were social networks (80.2 times/month), video sharing (65.2 times per month) and blogs (16.3 times/month).

3.2.2 Tools used in formal learning contexts

Hampton-Reeves, Mashiter, Westaway, Lumsden, Day, Hewertson and Hart (2009) surveyed 428 undergraduates over 3 different UK universities on the ways they identify, access, use and assess research content. Results showed that students use mainly computers to access research content through a home computer (54%) or a university networked computer (13.8%) and only a smaller number of them visit in person a library (28.8%). With regards to the online sites used, the team found that when accessing internet-based research, undergraduates use mostly their institution's library catalogue (80.6%), Google (60.5%), their course website (41.4%), Google Scholar (41.1%) and Wikis (17.1%). The authors were surprised by the low figures of social network sites and other Web 2.0 technologies (e.g. blogs, podcasts) use and concluded that "students tend to be passive and reactive seekers of knowledge, preferring overwhelmingly to use keyword-driven search products when identifying and accessing research content" (p.31).

Judd and Kennedy (2010) researched the on-campus use of internet of 1700 biomedical undergraduates over a period of 5 years (2005-2009) by collecting their usage log files from a large open-access computer laboratory. Overall, the authors found that the most frequently used sites and technologies were the university's VLE,[15] Google, email and Facebook. When the usage log files were analysed by year, it was revealed that the use of VLE increased (from 37% to 62%), of Google increased (from 24% to 31%), of email declined (from 68% to 38%) and finally the use of social networking sites increased (from 4% to 25%). The authors concluded that students are increasingly reliant on information retrieval tools (Google, Wikipedia); they are moving away from email and institutional email accounts to social networking tools; their use of institutional systems and services (e.g. the VLE) is high and constantly increasing; and finally that undergraduates are not frequent users of Web 2.0 tools others than social network sites.

Bullen, Morgan and Qayyum (2011) interviewed 69 and surveyed 438 second-year undergraduates at a Canadian university in order to test whether the digital natives argument[16] can be supported by data. Of interest here, is their analysis of interviews which showed that students in their sample reported using mostly email, instant messaging, mobile phones, Facebook and program-specific technical software (e.g. AutoCAD), which according to the authors comprised a limited toolkit given the variety of available institutionally supported and freely available tools.

Flavin (2013) surveyed a small sample of 28 people from a UK-based university about their use of technologies for that can be used to support learning or teaching. The questionnaire included well established tools (e.g. Wikipedia, Facebook, Twitter, LinkedIn) as well technologies such as Prezi (presentation software), Wallwisher (online notice board) and Xtranormal (film-making software), which were characterised as emergent by the Horizon Report 2010 (Johnson, Levine, Smith, & Stone, 2010). The sample included 13 undergraduates, 5 postgraduates and 10 lecturers/academic staff. Survey results showed that simple/easy to use, convenient and free technologies were the popular ones (Wikipedia, Facebook, Twitter) whereas other emergent/less established technologies were not known/used. Wikipedia was used by participants for recreation (21), informal learning (20), formal learning (15) and work (16). Facebook was used for recreation (16), work (7) and informal learning

[15] Judd and Kennedy (2010) and others use the term LMS (Learning Management System) and not VLE (Virtual Learning Environment) but for consistency reasons I use the latter throughout the literature review.

[16] The assumption that students born after 1982 "behave differently, have different social characteristics, different ways of using and making sense of information, different ways of learning, and different expectations about life and learning" (Bullen et al., 2011, p.2).

(3). Finally, Twitter was used for recreation (10), work (7) and informal learning (5). Flavin concluded that the gatekeeper role of both the lecturer and higher education institutions are changing, since there exist alternative, easy to use and free routes to acquiring knowledge.

Rønning (2014) surveyed 662 and interviewed 12 first-year engineering students for a Calculus 1 module in a Norwegian University (Norwegian University of Science and Technology, NTNU). An online questionnaire was designed in order to gain an insight of students' experiences; among others there were questions aiming to identify which tools students use for this course. In the survey, students were asked to state to what extent they were using a set of predefined learning resources: lectures, online (video recorded) lectures, other videos made at NTNU, external videos (e.g. YouTube), textbooks, the module's theory on VLE, other external web resources (not specified) and the drop-in centre. Students reported attending lectures on a regular basis (80%) and making considerable use of the textbook (90%). Online lectures were used by 46% of the students as a supplement of live lectures. These resources were followed in popularity by the drop-in centre (38%), external web resources (28%), external online videos (21%), other videos made at the NTNU and theory provided on the VLE page of the module (20%). Rønning concluded that despite the large variety of learning resources, traditional resources such as live lectures and textbooks had a very strong position among students' choices.

O'Keefe, Rienks and Smith (2014) surveyed a small sample of 55 accounting undergraduates about their use of resources and people at an Australian university. The questionnaire was exploring students' experience across three aspects: attendance and engagement with others, using learning resources, and approaches to problem completion[17]. The majority of students reported attending lectures, tutorials or workshops (90.9%)[18] and half of them reported discussing with other students in the same tutorial group (47.3%). Engagement with other students (outside their tutorial group), the lecturer or another person was relatively low (around 24% for each). Discussing with a person by posting messages on the VLE was also found to be low (10.9%). In terms of the resources used, material provided in lectures or answers on the VLE were the most popular (87.3% and 78.2% respectively). These were followed by old exam and test papers (70.9%), VLE discussions posts, announcements and outlines (60%) and reading books or accessing internet resources (43.6%). O'Keefe et al. concluded that students prefer face to face interactions by attending classes and rely mostly on lecture provided material.

Flavin (2015) observed 4 undergraduates and 3 lecturers in a UK-based university while trying to solve a given task. Both students and lecturers were given 15 minutes

[17] Here I report only on the first two.

[18] All percentages presented here, entail students who discussed with someone or used a resource at least frequently.

to do this by using a computer placed in the observation room. Students were required to write an essay on a the given topic. Observations showed that participants' method for retrieving online information incorporated a small range of technologies (Google, Google Scholar, academic journal aggregators) with the most frequently used resource being Google (6 participants), highlighting their tendency to use non-institutional technologies. Moreover, participants gathered information very quickly and did multiple searches incorporating a particular method which was reproduced across different searches.

Henderson, Selwyn and Aston (2015), surveyed 1658 undergraduates from two universities in Australia[19] about their perceptions of useful digital technologies by asking them "What has been the most useful examples of technology-based learning that you've experienced so far in your university course?". Authors did not present the results of their study by using descriptive statistics for each tool individually and thus it is not clear either the proportion of students using each tool or the extent to which a tool was used. For the purposes of this section, it is sufficient to say that the most cited by students tools were (in descending popularity): VLE, library databases/websites, laptop computers, word processing software, audio and video lecture recordings, internet search engines, social media, external online videos and Wikipedia. Many tools, were linked to certain practices with the most prominent being, organising and managing the logistics of study (46.9%, VLE). Henderson et al. concluded that although digital technologies are a central element of undergraduate education, students do not use them in the most expansive, expressive or empowering ways.

Henderson, Finger and Selwyn (2016) explored the use of digital technologies among taught postgraduate students by surveying a sample of 253 students in two Australian universities. The team organised the presentation of their findings under two main categories: institutionally and non-institutionally provided tools. For the first category, the most popular tools were the online library resources (99.6%), the library's website (97.4%), the university's VLE (97.8%), e-books/e-textbooks (84.3%) and other university websites (78%). In terms of the second category, the most popular tools were internet/search engines (100%), non-university provided scholarly websites e.g. Google Scholar (95.6%), audio/video recordings e.g. YouTube (91.6%), Wikipedia (85.7%), web-based citation/bibliography tools (79.9%), social networking sites e.g. Facebook (68.9%), web-based documents e.g. Google Docs (63%) and free online courses e.g. Khan Academy (57.4%). The authors concluded that digital technologies constitute an essential part of core academic practices (e.g. researching and retrieving information, preparing assignments) and underlined the widespread practice of using tools in video format (e.g. institutionally provided

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[19] Of them, 181 where in Engineering, Computer Science & Math and 245 in Physical & Biological sciences.

lecture recordings, YouTube videos). Finally, the team commented that postgraduates' use of technologies cannot be characterised as innovative but rather as a passive consumption of knowledge.

Shé, Mac an Bhaird, Ní Fhloin and O'Shea (2017), surveyed 394 undergraduates from 4 different higher education institutions in Ireland[20] about the resources they "found helpful for dealing with first year mathematics topics" (p.16). Shé et al. found that almost 70% of students reported using paper-based resources (lecture notes, tutorial notes, books); over 50% online resources (Khan Academy, YouTube, Wolfram Alpha); roughly 20% the MLSC and; around 15% their institution's VLE. Results for these resources were also compared by institution and several differences were identified: for example, students in the two universities relied more on textbooks whereas students from the institutions of technology on lecture and tutorial notes. The authors hypothesised that these were due to the different culture each institution has. Finally, Shé et al. comment on the fact that although most of the students reported using paper-based resources, they expressed in the survey their preference for their institutions to provide more online-based tools.

3.2.3 Discussion

This section's purpose was to document empirical studies exploring in a holistic way the tools that undergraduates use when studying mathematics. As mentioned earlier, due to the lack of studies in tertiary mathematics, investigations from other disciplines have been included too (see Table 3.1 for a summary). Two main categories of tools were identified as being used frequently by undergraduates: ***communication tools***, such as email, social network sites and instant messaging applications (Bullen et al., 2011; Costa et al., 2016; Gallardo et al., 2015; Judd & Kennedy, 2010; Thompson, 2013) and ***information retrieval tools*** i.e. search engines or online encyclopaedias such as Google and Wikipedia (Costa et al., 2016; Hampton-Reeves et al., 2009; Henderson et al., 2015; 2016; Judd & Kennedy, 2010; Thompson, 2013). With regards to other tools, VLEs have become much more favoured by undergraduates as suggested by early (Judd & Kennedy, 2010) and more recent studies (Henderson et al., 2015; 2016). Finally, it seems that traditional tools such as lectures, lecture notes and textbooks still have a strong presence in (O'Keefe et al., 2014; Shé & Mac an Bhaird, 2017).

So, what is missing currently from the literature? For starters, research in blended learning is *not blended at all*: most of the studies reviewed here acknowledge only digital or online tools (Bullen et al., 2011; Costa et al., 2016; Flavin, 2013; Gallardo et al., 2015; Hampton-Reeves et al., 2009; Henderson et al., 2015; 2016; Judd & Kennedy, 2010), despite common sense and evidence (O'Keefe et al., 2014; Shé &

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[20] Students were coming from a variety of different undergraduates programs. Two of the institutions participated in the study were universities (Dublin City University, Maynooth University) and the rest were institutions of technology (Athlone Institute of Technology, Dundalk Institute of Technology).

Mac an Bhaird, 2017) suggesting that traditional tools (e.g. textbooks) and people (e.g. lecturers) are still an essential part of learning in higher education. The small number of studies adopting a student's perspective i.e. acknowledging the tools that undergraduates *actually use* when studying on their own or with peers (and not only during a lecture or in computer labs) is by itself indicative of the gap in the literature and aligns with comments from authors that blended learning should be rather called *blended teaching* (e.g. Oliver & Trigwell, 2005). Finally, contemporary approaches neglect the important role that the *discipline of study* seems having in relation to the ways that undergraduates study (e.g. S. N. Smith & Miller, 2005) or the tools they use, especially in skills-based courses such as mathematics (e.g. Joordens, Le, Grinnell, & Chrysostomou, 2009; A. Le, Joordens, Grinnell, & Chrysostomou, 2010).

Table 3.1: A summary of the studies exploring the tools that undergraduates use

Author(s)	**Discipline**	**Purpose of use**	**Tools acknowledged**	**Popular tools**	**Comments/conclusions**
Conole *et al*. (2006)	Mixed	Learning, personal	Hardware, digital, online	Email, internet/search engines, computers, Word, instant messaging	Students see technology as an integral aspect of their lives
Hampton-Reeves *et al.* (2009)	Mixed	Learning (using research related content)	Hardware, online	Computers, library catalogue, Google, Google Scholar	Low use of Web 2.0 tools, students are passive/reactive seekers of knowledge
Judd & Kennedy (2010)	Biomedicine	Learning	Online	VLE, Google, email, Facebook	Students are increasingly reliant on information retrieval tools, moving away from using email, increased VLE use, no use of Web 2.0 tools
Bullen *et al.* (2011)	Mixed	Learning, digital natives	Hardware, digital, online	Email, instant messaging, mobile phones, Facebook, technical software	Students have a limited toolkit
Flavin (2013)	Mixed	Learning, teaching	Online	Wikipedia, Facebook, Twitter	Simple/easy to use and free tools are the popular ones, the gatekeeper role of lecturers and universities is changing
Thompson (2013)	Mixed	Learning, personal, digital natives	Digital, online, books	Web use, communication, books, productivity tools	Students have a limited toolkit
Rønning (2014)	Tertiary mathematics	Learning	Textbooks, lectures, support centre, online	Lectures, textbooks	Despite the large variety of tools, students prefer the traditional tools
O'Keefe *et al.* (2014)	Accounting	Learning	Lecture, tutorials, lecturers, peers, VLE, textbooks, internet	Lectures, peers	Preference of attending classes and using lecture provided material
Flavin (2015)	Mixed	Learning, teaching	Online	Google, Google Scholar	Tendency of using non-institutional tools
Gallardo *et al.* (2015)	Mixed	Learning, personal	Hardware, online	Computers, mobile phones, Facebook, WhatsApp	Tools enabling communication are the most important for undergraduates
Henderson *et al.* (2015)	Mixed	Learning	Hardware, digital, online	VLE, library databases/websites, computers, word processors, lecture recordings	Digital technologies are an essential part of undergraduate education, students do not use them in innovative ways
Henderson *et al.* (2016)	Mixed, postgraduates	Learning	Digital, online	Library resources, library website, VLE, search engines, Wikipedia	Digital technologies are an essential part of academic life, widespread use of video-based tools, students are passive consumers of knowledge
Costa *et al.* (2016)	Mixed	Learning, personal	Online	Video sharing tools, social networks, wikis, blogs	Web 2.0 use is more frequent for personal purposes
Shé *et al.* (2017)	Tertiary mathematics	Learning	Paper-based, online, support centre	Notes, books, online videos, W.A.	Differences between institutions may be related to different cultures, students prefer using traditional tools

3.3 How can tools be categorised?

In this section, typologies of tools relevant to my study's focus are reviewed. In total, 12 appropriate typologies were identified in the literature and are presented in an ascending chronological order. These include, Wartofsky's (1973) hierarchy of artefacts (section 3.3.1); Pea's (1987) taxonomy of functions for cognitive technologies (section 3.3.2); Engestrøm's (1990b) expanded version of Wartofsky's hierarchy (section 3.3.3); Laurillard's (2002) classification of media for university teaching (section 3.3.4); Engelbrecht and Harding's (2005) taxonomy of online courses for undergraduate mathematics (section 3.3.5); Tondeur et al.'s (2007) typology of computer use in primary education (section 3.3.6); Kidwell et al. (2008), Roberts et al. (2012) and Roberts' (2014) historical in nature typology of tools used for the teaching and learning of mathematics (sections 3.3.7; 3.3.10; 3.3.12); Conole and Alevizou's (2010) typology of Web 2.0 tools used in higher education (section 3.3.8); Eynon and Malmberg's (2011) typology of young people's internet use (section 3.3.9); and Thompson's (2013) typology of technology use for non-educational purposes (section 3.3.11). Of the studies presented here, the work of Pea (1987), Kidwell et al. (2008), Roberts et al. (2012), Roberts (2014), Eynon and Malmberg (2011) and Thompson (2013) are not aimed at classifying tools but for the purposes of this section they are treated as such.

3.3.1 Wartofsky's hierarchy of artefacts

Wartofsky (1973) considered artefacts as the genes of our cultural evolution and although his ideas share some similarities with Vygotsky's thoughts, the two approaches were developed independently (Monaghan, 2016a). Wartofsky proposed that artefacts can be classified into primary, secondary and tertiary. **Primary** are the artefacts that are directly used in the production of the means of existence of the species and include axes, clubs, needles and bowls (Wartofsky, 1973) as well as words, writing instruments and telecommunication networks (Cole, 1996); in other words, primary artefacts are considered the tools themselves (Engestrøm, 1990b). **Secondary** artefacts are "those used in the preservation and transmission of the acquired skills or modes of action or praxis by which this production is carried out" (Wartofsky, 1979, p. 202). Therefore, secondary artefacts are "modes of action using primary artefacts" (Cole, 1996, p. 121) which "synthesise the ways and procedures of using instruments and materials" (Miettinen, 1999, p. 189) and they may be seen as algorithms and rules guiding the use and formation of primary artefacts (Engestrøm, 1990b). Secondary artefacts include recipes, traditional beliefs, norms, constitutions (Cole, 1996) and manuals (Kaptelinin & Nardi, 2006). Finally, **tertiary** artefacts are those which "transcend the more immediate necessities of productive praxis" (Wartofsky, 1973, p.208) and emphasise creativity (Kaptelinin & Nardi, 2006). As an example of what constitutes a primary and a secondary artefact, Bussi and Mariotti (Bussi, Kemmerer, & Mariotti, 2008) refer to the abacus: the abacus itself is a primary artefact and the ways of using abaci for counting, keeping records or making computations represents a secondary artefact.

3.3.2 Pea's taxonomy of functions for cognitive technologies

Pea (1987) proposed a taxonomy of functions that cognitive technologies should have in order to enable students to think mathematically more frequently. By cognitive technologies Pea means any medium helping us to transcend the limitations of the mind such as symbol systems, models, theories, film and other pictorial media, computers and symbolic computer languages. Pea considers two types of functions: ***purpose functions*** which motivate students to think mathematically and ***process functions*** which aid students while doing so. Purpose functions promote students' mathematical agency and are divided into ***ownership***, helping students own their thoughts and the problems to be solved; ***self-worth***, aiding students to think of intelligence in an incremental way and consider negative outcomes as opportunities for acquiring new understanding; and ***knowledge for action***, helping students to view mathematical knowledge as having an important impact on their future career or on solving real-world problems. Process functions help students to understand and use the different mental activities involved in mathematical thinking and include: ***conceptual fluency tools*** which help students become more fluent in performing routine tasks; ***mathematical exploration tools*** emphasising discovery learning (e.g. as in the case of Dienes blocks); ***representational tools*** helping students to link different representations of mathematical concepts, relationships and processes (e.g. thinking of linear equations algebraically or as lines); ***tools for learning how to learn*** which promote reflective learning by doing (e.g. enabling students to reflect on problems they have worked and generalise from these); and ***tools for learning problem-solving methods*** which help students to develop problem solving heuristics (e.g. drawing and annotating diagrams).

3.3.3 Engestrøm's expanded version of Wartofsky's hierarchy

Engestrøm (1990b) suggested a modified version of Wartofsky's hierarchy consisting of four levels: the "what", "how", "why" and "where-to" artefacts. The **"what"** artefacts represent the tools themselves and correspond to Wartofsky's primary artefacts. "What" artefacts are usually easily noticed and defined as external physical entities (*Ibid.*). The **"how"** artefacts are partly visible and external and inform us "how a certain object shall be handled with a corresponding primary artefact" (*Ibid.*, p.188), i.e. "how" artefacts are ad hoc models of how to use "what" artefacts (Petersen, Madsen, & Kjær, 2002). **"Why"** artefacts are less easily identified and inform us "why the object behaves as it does and thus justifies the selection of a certain primary artefact" (Engestrøm, 1990b, p. 188). They include "more general models and principles that offer explanations of how the artefact works" (Petersen et al., 2002, p. 80). Both the "how" and "why" artefacts correspond to Wartofsky's secondary artefacts. Finally, the **"where-to"** correspond to Wartofsky's tertiary artefacts which offer "an overall analysis and vision of the future form of the activity system" (Engestrøm, 1990b, p. 194). Similar to Wartofsky's correspondence to Leontiev's hierarchy of activities, the "what" artefacts relate to the level of operations/conditions, the "how" and "why" artefacts to the level of actions/goals and the "where-to" artefacts to the level of activity itself.

3.3.4 Laurillard's classification of media for university teaching

Laurillard (2002) offers a view on learning in undergraduate environments that can be considered to some extent falling under the umbrella term *situated cognition* (Monaghan, 2014), since she adopts a more or less Vygotskian point of view. She considers teaching and learning as an interpersonal and personal discourse and proposes a categorisation of tools (she calls them educational media) based on the types of teaching strategies (Laurillard's Conversational Framework) they ought to serve. The 5 types of tools are: narrative media, interactive media, communicative media, adaptive media and productive media.

Narrative media refer to linear presentational tools that contain elements of printed text and graphics, audio and video and may come in the form of lectures, books, TV broadcasts, films, audiocassettes, videocassettes or digital discs (e.g. DVD). All narrative media share one core property that distinguish them from other tools such as computer-based ones, i.e. they are not interactive. **Interactive media** refer to presentational tools that include hypertext, hypermedia, multimedia resources, web-based resources and internet-delivered television. The main characteristic of interactive media is their linearity[21] and that they are delivered in a user-controlled environment. Laurillard explains that the term interactive refers to ability that these tools offer to the user in navigating and selecting content at will.[22] Interactive media offer to students resources for exploring and investigating. **Communicative media** refer to tools that enable users (lecturers, tutors and students) to discuss. The medium of communication can be text/graphics, audio, video, or any combinations of the three. Tools falling into this category include the email, telephone and videoconferencing. Laurillard notes that these tools were introduced into higher education for solving a logistical problem (distance learners) and do not serve a pedagogical purpose. **Adaptive media** correspond to computer-based tools that accept a user's input, change the state of a model and display the resulted output. One key characteristic that differentiates adaptive tools from other computer-based tools is the inherent capability of offering feedback to the user. Examples of adaptive tools include simulations, virtual environments (e.g. a virtual microscope), tutorial programs, tutorial simulations and educational games. Finally, **productive media** refer to tools that enable students to produce their own

[21] I can imagine a number of computer science researchers arguing against that, i.e. that hypertext is not linear.

[22] This contradicts with the characterisation of books as non-interactive tools. I can imagine plenty situations in which a person could navigate through and select content at will when using a (printed or digital) book, thus books are interactive too.

contributions in any medium e.g. on paper or over an internet network. Laurillard characterises traditional productive tools such as pen and paper, word processors or spreadsheets too generic for incorporating a specific learning objective and discusses in more detail productive tools that include a learning objective by design. These include, microworlds (e.g. Papert's Logo), collaborative microworlds and modelling programs. For example, for Laurillard microworlds are productive tools in the sense that they enable students to create and produce a system of their own with the designer's intention of achieving a specific learning goal embedded. Table 3.2 presents examples of all types of media and the types of actions they can support.

Table 3.2: Laurillard's typology of tools, examples and actions each type of tools supports (adapted from Laurillard, 2002).

Learning experience	**Methods/technologies**	**Media forms**
Attending, apprehending	Print, TV, DVD, video	Narrative
Investigating, exploring	Library, CD, DVD, web resources	Interactive
Discussing, debating	Seminar, online conference	Communicative
Experimenting, practising	Laboratory, field trip, simulation	Adaptive
Articulating, expressing	Essay, product, animation, model	Productive

3.3.5 Engelbrecht and Harding's typology of online courses for undergraduate mathematics

Engelbrecht and Harding's (2005) work for online courses in undergraduate mathematics is twofold. First, they present a classification of the online courses for undergraduate mathematics reflecting the different ways that web courses for undergraduate mathematics were at the time used; and second, they classify the above types along two dimensions (amount of content, amount of interactivity). With regards to the first, the authors distinguish seven different types of web-based courses:[23]

1. ***Mathematical resource sites*** containing various tools such as atlases, libraries, archives, dictionaries, Olympiad questions or puzzles.
2. ***Notice board sites*** containing mainly administrative information a course's syllabi, announcements, handouts, reference to homework problems and past papers.

[23] Authors provide examples from sites used in undergraduate mathematics for each type but due to the number of years that have passed since the publication, I didn't include them.

3. ***Content sites*** hosting resources connected to a course such as notes for specific mathematical topics, online books, graphical illustrations and maybe Java applets.
4. ***Exploration and demonstration sites*** containing mostly interactive in nature material (illustrations, animations) not necessarily connected to a traditional undergraduate mathematics topic.
5. ***Practice and quizzes sites*** containing exercises (sometimes with the aid of a computer algebra system) and are normally used in connection with a teaching programme.
6. ***Communication sites*** that provide opportunities for sharing ideas, getting answers to questions, links to resources, etc.
7. ***Full course sites*** that supply full content online and allow interactions to take place. They are usually delivered via a VLE environment.

The second aspect of Engelbrecht and Harding's work is an attempt to classify online mathematics courses along two dimensions and characterise the above mentioned types of sites accordingly: the first dimension is the *amount of content presented online* and the second, the *amount of interactivity required by the student*. The resulted model (Figure 1) has a quadrant structure and reflects **the actions that a student is required to perform**: the ***DO*** quadrant (high interaction, little content); the ***SEE*** quadrant (low interaction, little content; main action: take note of the information presented); the ***READ*** quadrant (high content, low interaction; main action: read for understanding); and the ***LEARN*** quadrant (high interaction, high content; main action: read the content and display an understanding).

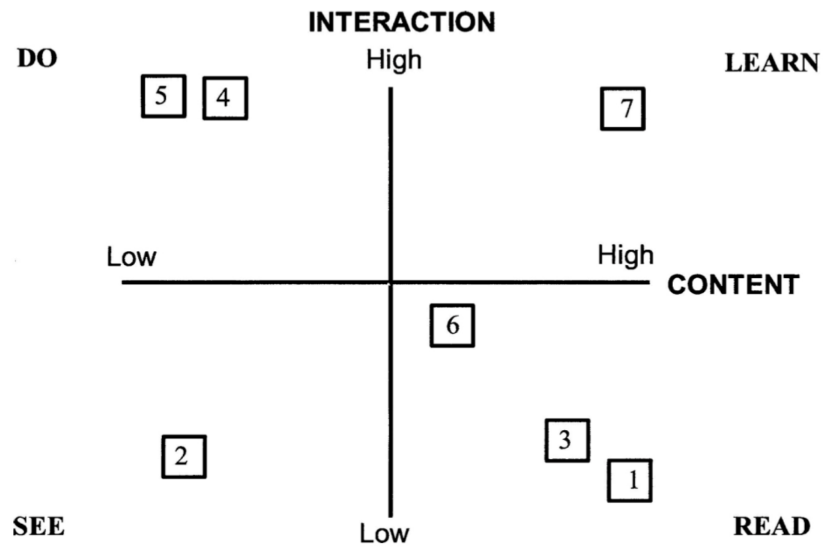

Figure 3.1: Engelbrecht and Harding's quadrant model (do, learn, see, read) and the place of the 7 reviewed types of web courses for mathematics according to this model (adopted from Engelbrecht and Harding, 2005).

3.3.6 Tondeur et al.'s typology of computer use in primary education

Tondeur, van Braak and Valcke (2007) proposed a typology of computer use in primary education by using data from a survey of 352 primary school teachers in Belgium. Their work is relevant to my research because computers can host a variety of resources and therefore their typology may be considered as a typology of tools. The survey was completed by teachers themselves who reported how they use computers but also on their pupils' uses of computers. The questionnaire contained 29 items on a 5-point scale (0 to 4, 0=never, 4=daily) assessing various uses of computers on a weekly basis, for example: "the pupils use the computer as an encyclopaedia", "I use the computer as a demonstration tool", "I teach the pupils how to make good use of the keyboard and mouse", "the pupils use the computer to practise knowledge or skills". For producing the typology, the authors used half of the sample and performed an Exploratory Factor Analysis (EFA) while the rest of the participants were used to confirm their typology (stability of factor structure) by performing a Confirmatory Factor Analysis (CFA). The EFA resulted a 3 factor structure suggesting three types of computer use in Flemish primary education (by both teachers and pupils):

- ***Basic computer skills***: this type concerns only teachers and is related to the use of computers as a school subject i.e. teaching pupils how to use a computer. It includes the items: "I teach pupils to use computer terms correctly", "I teach the pupils how to make good use of the keyboard and mouse", "I teach pupils learning basics of the operating systems used at school"
- ***Information tool***: this type involves pupils and is related to using computers as an encyclopaedia, to select and retrieve information, to store information and for writing text, whereas for teachers is related to using the computer as a demonstration tool.
- ***Learning tool***: this type concerns only pupils and is related to when they use computers to do further research on a specific subject, to elaborate learning content, to 'catch up' if fallen behind with school work and to practise knowledge or skills.

3.3.7 Kidwell et al.'s typology of tools used for the teaching of mathematics

Kidwell, Ackerberg-Hastings and Roberts' (2008) work is historical in nature and involves the tools used for the teaching of mathematics in American classrooms from 1800 to 2000. The authors' intention is not to propose a typology of the tools used in mathematics classrooms but rather to offer a historical perspective on them. However, the way Kidwell *et al*. chose to organise material provides one. The authors categorise tools into four major groups: **tools of presentation and general pedagogy** "that have been used to convey mathematical ideas" (*Ibid,* p.xiv) e.g.

textbooks, the blackboard, standardised tests, the overhead projector as well as teaching machines and programmed instruction; **tools of calculation** "used especially to teach –or to carry out- arithmetic" (*Ibid*, p.xv) such as, the abacus, the slide rule and the cube root block; **tools of measurement and presentation** used for "measuring and representing mathematical ideas" (*Ibid*, p.xvi) e.g. the protractor, various metric teaching apparatus, the graph paper, geometric models and linkages; and **electronic technologies** such as calculators, graphing calculators, computers and software systems. For the last category, the authors do not follow a similar to the previous categories approach, something probably related to the "numerous possible uses of programmable devices" (*Ibid*, p.xvii).

3.3.8 Conole and Alevizou's typology of Web 2.0 tools in higher education

Conole and Alevizou (2010) present a typology of Web 2.0 tools used in higher education, deriving from a BECTA-commissioned review of Web 2.0 tools in schools (see Crook et al., 2008). The term Web 2.0 refers to web-based tools that can be used as desktop applications via a web browser (Gwen & Schrum, 2007) and offer possibilities for more participatory and interaction practices among users (Conole & Alevizou, 2010). The authors identify 10 different types of Web 2.0 tools, with their categorisation based on the ways in which they are used. These are:

1. ***Media sharing***: tools used for the creation and exchange of different kinds of media among peers or with wider audiences.
2. ***Media manipulation and data/web mash ups***: media manipulation are web-based tools that enable users to produce and manipulate the files prior sharing them. Mash ups are tools typically used for data visualisation and require some technical skills when used.
3. ***Instant messaging, chat and conversational arenas***: tools used for one-to-one or one-to-many conversations (text or video-based).
4. ***Online games and virtual worlds***: games that follow certain rules or themed environments supporting live interactions among users.
5. ***Social networking***: websites supporting social interactions between their members, who are usually called "friends".
6. ***Blogging***: internet-based journals or diaries in which the creator can post text and other digital material and allow other users to comment.
7. ***Social bookmarking***: websites for submitting bookmarked web pages that are accessible to other users.
8. ***Recommender systems***: a website that collects users' preferences on a domain (e.g. online stories, music collections) and provides recommendations based on its users aggregated preferences.

9. ***Wikis and collaborative editing tools***: tools enabling the co-construction of content by creating, editing and posting links.
10. ***Syndication tools***: this refers to RSS feed which enables users to subscribe to websites so that they are automatically notified about any change.

3.3.9 Eynon and Malmberg's typology of young people's internet use

Eynon and Malmberg (2011) based on their own research and previous studies proposed (an a priori) typology of the ways that young people in the UK (ages 8, 12, 14 and 17-19) use the internet outside formal educational settings. The typology includes five types of internet use: ***communicating*** e.g. chatting online, using a social networking site, sending and receiving emails, posting comments or messages to a forum or updating information on a social networking site; ***information seeking*** e.g. looking for information on an interesting topic, researching products before or after buying them, buying products, keeping up with the news or looking for information on careers; ***entertainment*** e.g. watching on demand TV or videos, downloading or streaming music, ***participating*** e.g. writing a blog, adding or changing content in a wiki, putting podcasts, music or videos, reading a blog and; ***creativity*** e.g. using the computer for creative writing, writing/composing music or lyrics, creative drawing or editing photos.

3.3.10 Roberts et al.'s (2012) typology of tools used for the teaching of mathematics

Roberts, Leung and Lins (2012) organised the tools used for the teaching and learning of mathematics in Western educational contexts into four main categories: ***tools for information storage*** mostly referred to books; ***tools for information display*** which include the slate, the blackboard, the overhead projector, the visualizer and the smart-board; ***tools for demonstration*** referring to tools that could be physically manipulated and aimed at the understanding of a concept or procedure such as the cube root block, linkages, cones for displaying conic sections and geometrical models; and ***tools for calculation*** such as the abacus, the slide rule and the calculator. The authors note that the above mentioned categories are not entirely distinct especially when encountering digital in nature tools.

3.3.11 Thompson's typology of digital tools for non-educational use by undergraduates

Thompson (2013) surveyed a sample of 388 first-year undergraduates at a large Midwestern university about their use of digital technologies in general (not for educational purposes). Thompson's work is situated in the area of digital natives which asserts that students born after 1980 have a distinctive set of characteristics including preference for speed, nonlinear processing, multitasking, and social learning (*Ibid.*). The questionnaire used included a list of 41 commonly used digital tools ranging from word processors (e.g. Microsoft Word) to slide presentation software (e.g. PowerPoint), audio/video/image editing software (e.g. Audacity, iMovie, Photoshop), online videos (e.g. YouTube) and games (e.g. Doom). By performing an EFA, Thompson identified 9 categories of tools (factors) reflecting undergraduates' use of technologies:

1. ***Rapid Communication Technology***: related to texting messages on a cell phone, checking, updating, or commenting on Facebook, making voice calls, chatting online and multitasking (using several technologies at one time).
2. ***Multimedia Creation***: related to the creation of a digital image, audio file or video, editing a video and uploading a digital image or video to a file-sharing site
3. ***Active Web Reading and Writing***: related to reading, writing, and commenting on blogs, creating or maintaining a website, reading long detailed web pages, and reading entertainment web pages.
4. ***Gaming***: related to playing strategy, action and puzzle games on a computer
5. ***Web Resource Use***: related to using the web for exploring a topic in depth, for looking up a fact, watching a video online and listening to music online.
6. ***Collaborative Web Tool Use***: related to annotating a web page, using a social bookmarking sites, using a shared document (e.g., Google docs) and contributing to a wiki.
7. ***Productivity Tool Use***: related to the use of word processors, spreadsheets, databases and presentation tools.
8. ***Microblogging***: related to updating or reading a microblogging (e.g. Twitter).
9. ***Book Reading***: reading books for enjoyment or for learning. (While this factor does not pertain to digital technology like the other eight factors, it is useful as a comparison to see if use of this older technology is associated with different approaches to learning than newer digital technology.)

3.3.12 Roberts' (2014) typology of tools used for the teaching of mathematics

Roberts (2014) underlines the narrow and misleading nature of the view that the use of technology (i.e. tool use) in mathematics education begun with the appearance of electronic devices. The author follows a different categorisation to the one presented in a previous collaborative publication (Roberts et al., 2012) and categorises tools according to their origins into two primary groups: general-purpose and specialised technologies. **General-purpose tools** refer to technologies that were widely used outside classrooms before they were put into special use in educational settings. They include the ***textbook*** which "serves as a medium for storing and displaying information to be conveyed to students" (Roberts, 2014); the ***blackboard*** which's use is related to the rise of mass education that brought "the pressing need for multiple individuals to view the same information simultaneously" (*Ibid.*, p.567); the ***overhead projector*** which started to be used in classrooms as part of a movement promoting "visual education" in the early twentieth century and; the ***computer***, which was put into educational use in the 1960s after the appearance of less bulky and inexpensive computers (minicomputers). **Specialised technologies** refer to tools that are most likely to be found in science or engineering contexts with some of them particularly developed for mathematics education. They are divided into ***calculating tools*** such as the *abacus* (originated in the eastern part of Mediterranean during ancient times and probably independently developed in Asia), the *slide rule* (incorporating the Napier and Briggs' theory of logarithms for performing complicated calculations) and the (handheld) *calculator*; ***tools for drawing and display*** such as the protractor, *linkages* (a system of rods connected by pivots for converting rotary motion to straight lines or for drawing curves as well) and *graph paper*; and finally ***tools for physical manipulation*** such as the *cube root block* (a cube of side a+b which can be used to demonstrate a method of extracting cube roots based on the binomial expansion of $(a + b)^3$) and *coloured cubes or rods* (both tools were part of a wider movement in Europe and North America for using geometric models in classrooms).

3.3.12 Summary and discussion

This section's purpose was to document publications proposing a classification of tools, relevant to undergraduate mathematics. During the review process, five questions were asked for each typology:

1. What ***kind of tools*** does each typology acknowledge? For example, do authors take into account all types of tools or only digital/online?
2. What ***user perspective*** is adopted? For example, does the typology examine tools as used by teachers, students or both?
3. What is the ***context of use*** for each typology? For example, does the typology refer to tools used in everyday activities, in a work environment, in education or outside of it?
4. What **criteria** were used for classifying tools? For example, did authors classify tools according to their nature (e.g. human, digital/online, physical), use or another criterion?
5. On what ***basis*** was each typology constructed, theoretical or empirical? Are typologies based on theoretical/philosophical assumptions or are they based on empirical data?

The first three questions are related to the focus of my study i.e. tools that undergraduates use when studying mathematics whereas the rest (questions 4 and 5) are more methodologically oriented since they are linked to a typology's methodological underpinnings. Of these questions, the most elusive was question 2 (user perspective); this is because although all typologies have an end-user in mind, the ways authors classify tools do not necessarily reflecting a tool's actual use, something especially true for theoretically-based typologies. In overcoming this obstacle for each typology, I examined its theoretical or empirical foundations/rationale and characterised the adopted user perspective accordingly.

Wartofsky (1973) proposed that artefacts have a three level hierarchy and classified them into primary, secondary and tertiary. Wartofsky's classification acknowledges all the tools (material or psychological) that are used in everyday activities by anyone. The basis of his classification is theoretical and the criterion used for his hierarchy is linked to *perception* which in turn is a result of our ability to act: "We do not perceive, and *then* act; perception is itself one of the instrumentalities or modes of action" (*Ibid.* p.195, italics in the original). Thus, Wartofsky's criterion is related to the different modes of our praxis or in Activity Theory terms to the different levels of our activities. Engestrøm (1987; 1990b) notes that Wartofsky's hierarchy is closely related to Leontiev's levels of activity: primary artefacts correspond to the level of operations/conditions, secondary to the level of actions/goals while tertiary to the level of the activity.

Pea's (1987) taxonomy is not a typology of tools per se however the author refers and treats his list of process functions as categories of tools (although he could be using the term "tool" meaning utility). Pea devised this taxonomy having in mind mathematics education software, thus the tools acknowledged are computer-based i.e. digital. His taxonomy concerns the mathematics education community (educators and software designers) and is intended to be used as a heuristic tool while designing or evaluating software. Thus it reflects an instructional user perspective i.e. it corresponds to classifying tools according to how a lecturer would prefer his/her students to use these tools. The typology has a theoretical basis and the criterion used is related to the goals that mathematics education software ought to embody for supporting students' mathematical thinking.

Engestrøm (1990b) expanded Wartofsky's typology into a four level hierarchy ("what", "how", "why" and "where-to" artefacts) and drew links between each artefact and Leontiev's levels of activity. Like Wartofsky, Engestrøm acknowledges all kinds of tools, used by anyone into any context. The basis of Engestrøm's typology is theoretical and the criterion used for classifying tools is the level of the activity that the artefact is used. Engestrøm's (and thus Wartofsky's) typology shares a few similarities with Leontiev's notion of *functional organs*. Functional organs emerge when individuals combine internal and external resources for attaining certain goals that otherwise cannot be met (Kaptelinin & Nardi, 2006). In order to create and use functional organs subjects need three types of abilities (Kaptelinin, 1996): *tool-related competencies* (knowing how a tool works and having the skills to use it); *task-related competencies* (knowing the higher level goals that that can be achieved by a tool and having the skills to translate goals into the tool's functions); and *metafunctional competencies* (the ability to coordinate primary and secondary goals). Thus, Engestrøm's "how" artefacts ("how a certain object shall be handled with a corresponding primary artefact" (Engestrøm, 1990b, p. 188)) are analogous to tool-related competencies and "why" artefacts ("why the object behaves as it does and thus justifies the selection of a certain primary artefact" (Engestrøm, 1990b, p. 188)) correspond to task-related competencies.

Laurillard's classification of educational media (narrative, interactive, communicative, adaptive and productive) has been very influential in the higher education literature. She acknowledges any type of tools that can be used in tertiary educational contexts and adopts a lecturer's perspective since her typology reflects her Conversational Framework for teaching in tertiary contexts. Her typology has theoretical grounds and the criterion used is related to the types of actions that a tool can support according to her framework: attending and apprehending (conversational media); investigating and exploring (interactive media); discussing and debating (communicative media); experimenting and practicing (adaptive media); articulating and expressing (productive media).

Engelbrecht and Harding's work is related to web-based tools used in tertiary mathematics. The authors adopt a lecturer's perspective and base their typology on theoretical grounds. Two criteria are used, the ***amount of mathematical content*** present and the ***amount of interactivity*** required by a student. In my view, Engelbrecht and Harding's typology and thus their quadrant model, reflect authors' view on how students should be learning mathematics, split into 4 main groups of actions: explore and practice on certain mathematical topics (DO); take notice of administrative in nature information e.g. announcements (SEE); study for understanding (READ); and finally be assessed (LEARN). Engelbrecht and Harding seem to be adopting (without acknowledging it though) a view of learning that has been widely adopted by psychology oriented researchers, the ***knowledge construction metaphor of learning***. This view has been widely used in the design of e-learning experiences and considers learning as building a mental representation where the learner is an active sense maker and the instructor acts as a cognitive guide (Mayer and Clark, 2011). For example, Alessi and Trollip (2001) who adopt the knowledge construction metaphor of learning, they define instruction as a four-phase process: presenting information to the learner, guiding the learner, practicing, and assessing learning which is very similar to Engelbrecht and Harding's four quadrant model.

Tondeur et al.'s typology (2007) takes into account the use of computers and other resources accessed via them, by both teachers and pupils in primary education settings. The typology is based on empirical data and the criterion used is teachers and pupils' actions when using a classroom computer. In my view, Tondeur et al.'s typology has a major disadvantage, that is the "mixed" user perspective which combines both teachers and pupils actions (for example, *information tool* refers to both teachers' use of computers as a demonstration tool and pupils' actions related to retrieving or manipulating information).

Kidwell et al.'s typology (2008) acknowledges many different tools that have been used mostly in primary and secondary learning contexts. The authors adopt a teacher's perspective and the typology has a theoretical basis. The criterion used for the first three categories (tools for presentation and general pedagogy, tools for calculation, tools for measurement and presentation) is related to teachers' basic instructional actions (e.g. presenting, calculating, measuring etc.) whereas for fourth category (electronic devices) the authors do not offer a categorisation.

Conole and Alevizou's (2010) typology concerns Web 2.0 tools used by both lecturers and undergraduates for learning purposes. The basis for their typology is theoretical and the criterion used is related to the actions that each type of tool can support.

Eynon and Malmberg's (2011) typology is related to non-educational uses of the internet by young people. The typology is based on data from other studies and the criterion used is related to young peoples' actions while using the internet e.g. communicating, seeking for information etc.

Like Kidwell et al. (2008), Roberts et al.'s typology (2012) deals with a wide variety of tools that have been used in classrooms for the teaching of mathematics. The basis of their typology is theoretical and the criterion used is related to the actions that each type of tool can support e.g. storing information, displaying information, doing calculations etc. The authors adopt a teacher's user perspective as evident by tools accessed and used only by teachers (e.g. blackboard, projectors linkages) and the description of each category (e.g. tools for demonstration are aimed at the understanding of a concept or procedure).

Thompson's typology (2013) takes into account digital tools used by undergraduates for non-educational purposes. The basis of Thompson's work is empirical and the criterion used is the actions that certain tools can support e.g. creating multimedia, gaming, collaborating etc.

Roberts (2014) considers a variety of tools that have been used for the teaching of mathematics and his intention (as is the case of Kidwell et al., 2008; Roberts et al., 2012) is not to propose a typology but rather inform the reader about the place of tools in the teaching of mathematics during the last 200 years. Nevertheless, due to the relevance with my study, I have treated his work as a typology of tools. The basis of Roberts' classification is theoretical and he uses two criteria: the first, takes into account where the tools initially *originated* i.e. inside or outside classrooms (general purpose versus specialised technologies); and the second relates to a teacher's instructional actions within a classroom e.g. calculating, drawing, displaying etc. My only objection with Roberts' work is the first level of his classification (general purpose versus specialised technologies): grouping tools according to the context they were originally developed for, is problematic since sometimes tools are initially designed for purposes others than the ones currently put in action, making spin-offs the norm rather the exception (Wertsch, 1998).

Table 3.3 presents a summary of the tools each typology acknowledges, the adopted user perspective, the context of use, the basis and the criteria used for classifying these tools. In terms of the ***tools acknowledged***, Wartofsky (1973), Engestrøm (1990) and Laurillard's (2002) typologies take into account any type of tool that can be used by a subject; Kidwell et al. (2008), Roberts et al. (2012) and Roberts' (2014) take into account classroom-based tools while the rest typologies refer to digital/online tools (Conole & Alevizou, 2010; Engelbrecht & Harding, 2005; Eynon & Malmberg, 2011; Pea, 1987; Thompson, 2013; Tondeur et al., 2007).

With regards to the adopted ***user perspective***, Wartofsky (1973) and Engestrøm (1990) adopt a universal user perspective; Thompson's (2013) typology concerns tools as used by undergraduates; Eynon and Malmberg's (2011) created their typology based on the ways young people access the internet; Tondeur et al. (2007) and Conole and Alevizou (2010) adopt a mixed perspective (both students and instructors); whereas the rest of the studies (Engelbrecht & Harding, 2005; Kidwell et al., 2008; Laurillard, 2002; Pea, 1987; Roberts, 2014; Roberts et al., 2012) adopt an instructor's perspective (lecturer or teacher).

Table 3.3: Digital refers to computer based software; online refers to tools accessed via internet (e.g. Web 2.0 tools); classroom related refers to tools that have been traditionally used in classrooms.

Author(s)	Tools acknowledged	User perspective	Context of use	Criteria	Basis
Wartofsky (1973)	Any	Anyone	Any	Levels of activity	Theoretical
Pea (1987)	Digital	Lecturers	Mathematics, not specified	Goals	Theoretical
Engestrøm (1990)	Any	Anyone	Any	Levels of Activity	Theoretical
Laurillard (2002)	Any	Lecturers	Tertiary education	Actions	Theoretical
Engelbrecht & Harding (2005)	Online	Lecturers	Tertiary mathematics	Amount of mathematical content, interactivity required by the student (quadrant model reflects actions)	Theoretical
Tondeur et al. (2007)	Digital/online	Teachers & students	Primary education	Actions	Empirical
Kidwell et al. (2008)	Classroom related	Teachers	Mostly primary and secondary mathematics	Actions	Theoretical
Conole & Alevizou (2010)	Online	Lecturers & undergraduates	Tertiary education	Actions	Theoretical
Eynon & Malmberg (2011)	Digital/online	Young people	Non-educational	Actions	Quasi empirical
Roberts et al. (2012)	Classroom related	Teachers	Mostly primary and secondary mathematics	Actions	Theoretical
Thompson (2013)	Digital/online	Undergraduates	Non-educational	Actions	Empirical
Roberts (2014)	Classroom related	Teachers	Mostly primary and secondary mathematics	Origin of a tool, actions	Theoretical

In respect of the ***context of use***, Wartofsky (1973) and Engestrøm's (1990) typology deals with tools used in any context; Eynon and Malmberg (2011) and Thompson (2013) discuss tools used for non-educational purposes; Tondeur et al. (2007), Kidwell et al. (2008), Roberts et al. (2012) and Roberts (2014) refer to primary and secondary educational contexts; while the rest deal with tertiary education (Conole & Alevizou, 2010; Engelbrecht & Harding, 2005; Laurillard, 2002). Of these typologies 5 are related to mathematics (Engelbrecht & Harding, 2005; Kidwell et al., 2008; Pea, 1987; Roberts, 2014; Roberts et al., 2012) with only one devised for tertiary mathematics (Engelbrecht & Harding, 2005). With regards to each typology's ***basis*** (theoretical or empirical), only three have an empirical basis (Eynon & Malmberg, 2011; Thompson, 2013; Tondeur et al., 2007) and none of them deals with mathematics at any educational level.

Because most of the studies reviewed do not explicitly state the criterion used for classifying tools, I inferred about this based on the typology itself and when possible the methodology used. In doing this I used Leontiev's hierarchical structure of activities and tried to position each criterion within a level (activity->object, ensembles->purposes, actions->goals, operations->conditions). Relating a typology's criterion to a certain level (e.g. actions or goals) was a somewhat difficult task and is probably related to the vague definition of what an action is. For that reason, while I was reviewing each typology in order to identify the criterion used, I adopted the following approach: whenever it was difficult to distinguish between actions and goals, if the criterion under-examination could be seen as a lower, basic goal then it was considered as action. For example, when examined from a narrow perspective, information seeking (as in Tondeur et al.'s (2007) study) can be seen as a goal but by adopting a wider view (e.g. why the student is seeking online for information?) then it is an action.

In this sense, the typologies of Laurillard (2002), Engelbrecht and Harding (2005), Tondeur et al. (2007), Kidwell et al. (2008), Conole and Alevizou (2010), Eynon and Malmberg (2011), Roberts et al. (2012), Thompson (2013) and Roberts (2014) use criteria related to the ***actions*** that certain tools can support, i.e. tools are classified according to ***thematically related actions*** they can support. This interpretation is particularly consistent with the methods employed in empirically-based typologies: for example, in Tondeur et al.'s (2007) study, the second factor (using computers as an information tool) included questionnaire items such as "the pupils use the computer as an encyclopaedia", "the pupils use the computer to select and retrieve information", "the pupils use the computer for writing text" i.e. actions related to retrieving, manipulating and storing information. Even in the case of Engelbrecht and Harding (2005) although the criteria used are the amount of mathematical content and the interactivity required by the student, the resulted quadrant model reflects actions that certain tools can support. Wartofsky (1973) and Engestrøm's (1990) typologies do not use as a criterion one level but rather differentiate tools according to the ***different levels of activity*** they support, without however proposing themes of actions at each level (something the previous studies do). Pea's (1987) taxonomy was the only typology that incorporated ***goals*** as a criterion e.g. tools for learning how to learn, tools for learning problem-solving methods etc. If we remove the action/goals dichotomy, then we can observe that Wartofsky (1973) and Engestrøm's (1990) typologies classify tools across all levels whereas the rest position tools at a certain level. For example, Pea's (1987) taxonomy seems to belong at the ensembles-purposes level because tools are classified according to higher level goals (e.g. linking different representations of mathematical concepts) whereas the rest seem to fit mostly at the actions-goals level like Tondeur et al.'s (2007) typology (e.g. using computers for retrieving information, doing further research on a specific subject) or even at the operations-conditions level like Kidwell et al.'s (2008) typology (e.g. presenting, calculating, measuring etc.)

Although this section's focus was narrow in scope (identifying a typology of the tools that undergraduates use when studying mathematics), it seems that the field is still under development since only a handful of papers related to this research question were identified. As demonstrated above, current limitations are related to the types of tools taken into account (the majority of the typologies reviewed focus on digital/online tools), the user perspective (most typologies adopt a teacher-centred perspective), the context of use (only one typology is explicitly related to tertiary mathematics) and the basis for proposing a typology (only 3 typologies have an empirical basis with only one related to educational contexts). It is surprising though that even in the wider literature landscape, in publications adopting an Activity Theory perspective (which traditionally acknowledges tools as the hallmark of human development), the study of tools themselves is a less pursued route or as McDonald, Le, Higgins and Podmore (2009) describe it, "tools and artefacts are generally referred to, rather than described, or seriously studied" (p.113). A research agenda oriented towards the study of tools could help us overcome some of the current limitations of Activity Theory (see section 2.5); in an era of rapid technology development, our understanding of what is as a tool is often challenged since new technologies cannot be precisely described under the notion of tools. For example, is the email a tool or a digital environment (see for example Ducheneaut & Bellotti, 2001 arguing for the latter)? This is particularly evident in typologies having an historical basis (Kidwell et al., 2008; Roberts, 2014; Roberts et al., 2012) in which the multipurpose nature of digital/online technologies seems to be elusive since authors failed in classifying them alongside the traditional "mono-purpose" tools (e.g. books or calculators). The last point might be also related to the fact that historical in nature typologies have a theoretical basis; thus by using data to classify tools we could overcome the multipurpose nature of some tools and and create typologies of tool-use for certain contexts. Apart from the theoretical reasons for a serious study of tools, a typology of the tools that undergraduates use when studying mathematics is an important endeavour for two main reasons. First, technology changes rapidly and a typology of tools may offer methodological means for understanding emergent technologies or predicting future ones. Second, from an Activity Theory point of view, a typology of tools can offer a descriptor of culture; in our case, undergraduates' culture in learning mathematics.

3.4 How can undergraduates be profiled according to their tool-use and what factors can account for tool-use differences?

In this section, the part of the literature related to tool-use profiles in undergraduate contexts is presented. The majority of the studies reviewed here investigate how resources provided via a VLE are used in traditional undergraduate contexts (Bos & Brand-Gruwel, 2016; Lust, Elen, & Clarebout, 2012; 2013; Lust, Vandewaetere, Ceulemans, Elen, & Clarebout, 2011) or in distant learning settings (Del Valle & Duffy, 2009; Kovanović, Gašević, Joksimović, Hatala, & Adesope, 2015). Others, explore the ways that young people/undergraduates use the internet for leisure (Costa et al., 2016; Eynon & Malmberg, 2011) or educational purposes (Costa et al., 2016) and only one of them explored the different resources that students combine and use in undergraduate mathematics (Inglis, Palipana, Trenholm, & Ward, 2011).

3.4.1 VLE-use in traditional undergraduate settings

Lust, Vandewaetere, Ceulemans, Elen and Clarebout (2011) investigated how a cohort of 156 first year Educational Sciences undergraduates use the resources provided to them via the university's VLE (online lectures, course material outlines, discussion board, quizzes, web links related to the module) and three face to face support sessions. By performing a Cluster Analysis on the behavioural data, the team was able to identify three tool-use profiles: the ***intensive users*** (N=67), who used the available face to face tools, accessed VLE resources with a high frequency and consisted of two subgroups differing in their activeness of tool-use (time spent with each resource); the ***incoherent users*** (N=53), who used face to face tools and although they had a medium frequency of VLE tools, they demonstrated a clear preference to VLE tools related the face to face context of the course (course material outlines, feedback on practice quizzes); and the ***no-users*** (N=36) who did not use the face to face tools and had a low use of the VLE resources.

Lust, Elen and Clarebout (2012) analysed a cohort of first year Educational Sciences undergraduates (N=182) about their VLE tool-use and study strategies. Data for the VLE were gathered by log files whereas study strategies were assessed with the Inventory of Learning Strategies (Vermunt, 1998). The VLE included various resources such as course info, announcements, online lectures, course material outlines, web links, practice quizzes, exercises, discussion board, study tips and feedback on quizzes. By performing a Cluster Analysis on the VLE log file data, the team identified 4 study strategy and tool-use profiles: the ***undefined students*** (N=72) who did not report any specific strategy and did not use any tools except the online lectures (suggesting not clear strategy or tool-use); the ***disorganised students*** (N=47) who reported a lack of regulation strategies and accessed in a superficial way all VLE resources except the web links (suggesting that although they used all tools they were not sure how to use them adequately); the ***inconsistent students*** (N=45) who reported both surface (memorising, rehearsing) and deep learning strategies (self-regulation) and used mostly VLE tools linked to face to face aspects of the course (outlines, online lectures, study support, learning support) but in a superficial way; and ***self-regulated and deep oriented students*** (*N*=18) who reported concrete processing, critical thinking and self-regulation strategies and accessed all the available tools in a meaningful and active way (e.g. posting comments in the discussion boards, watching specific sections of online lectures).

Lust, Elon and Clarebout (2013) explored tool-use patterns among first year undergraduates (*N*=182) for one module (Educational Sciences) at a Flemish University. The resources the team took into account included digital tools offered to students via the university's VLE (course info, announcements, online lectures, practice quizzes and exercises, discussion board), live lectures and three support sessions that students could attend voluntarily. The measurements of the above mentioned tools included *frequency of use* and *time spent* with each tool (VLE). By performing a cluster analysis on the collected data the team was able to identify 4 different clusters: the no-users, the intensive active users, the intensive superficial users and the selective users. The **no users** (*N*=79) were a group of students that did not use the provided resources except the online lectures. The **intensive active users** (*N*=19) selected all the provided tools and used them actively (e.g. participating in the discussion forums, spending more time in watching the online lectures). The **intensive superficial users** (*N*=27) were the students who used all the available tools but for a short time and did not contribute in the discussion forum. Finally, the **selective users** (*N*=57) attended live lectures and support sessions but were highly selective in using the online tools provided via the VLE. Lust et al. attempt to explain these differences in terms of students' ***instructional conceptions*** (the extent to which they conceive an instructional intervention as supportive for their learning), their ***goal orientation*** (mastery-approach, mastery-avoidance, performance-approach, performance-avoidance) and their ***self-efficacy beliefs*** for regulating their learning (how certain a student is about coping with the challenging nature of learning in an academic environment e.g. note-taking, studying, test preparation). By performing a multinomial logistic regression, the authors found that only students' goal orientation could predict cluster membership and thus explain tool-use differences among clusters. In particular, students adopting ***mastery-approach goals*** (related to learning and understanding, developing new skills, and a focus on self-improvement using self-referenced standards, (Pintrich, 2003)) are more likely to have an ***intensive active tool-use*** pattern whereas students adopting ***performance-approach goals*** (related to demonstrating ability, obtaining recognition of high ability, protecting self-worth, and a focus on comparative standards relative to other students and attempting to best or surpass others, (Pintrich, 2003)) are more likely to be ***selective in their tool-use*** pattern.

Bos and Brand-Gruwel (2016) explored the different tool-use patterns by collecting lecture attendance and VLE log file data from a cohort of 516 first year law undergraduates in the Netherlands for one module. The tools offered to students included live lectures, recorded lectures, short essays questions and multiple choice questions (offered via their institution's VLE). The authors by performing a cluster analysis on the data identified 4 different clusters: students in **cluster 1** (*N*=103) used none of the provided tools except the recorded lectures; students in **cluster 2** (*N*=143) attended some of the live lectures and had an average use of the short essay and multiple choice questions; students in **cluster 3** (*N*=186) hardly attended live lectures but they did use the recorded lectures and had an above average use of short essay and multiple questions; and finally, students in **cluster 4** (*N*=84), attended well above average live lectures, their use of recorded lectures was modest and they also used above average short essay and multiple choice questions. The authors note that that their findings are similar to those from other studies in blended learning settings and named the 4 clusters as: **no-users** (cluster 1), **superficial users** (cluster 2), **selective online users** (cluster 3) and **intensive active users** (cluster 4). Consequently, the team attempted to explain those tool-use differences in terms of students' **motivational orientation towards a course** (intrinsic goal orientation, extrinsic goal orientation, task value, self-efficacy) and their **metacognitive ability to regulate learning** (critical thinking, metacognitive self-regulation, peer learning). Boss and Brand-Gruwel concluded that tool-use differences may be partially explained by the constructs of *self-efficacy* and *peer learning*. In particular, students with a low self-efficacy (feeling insecure about course performance) tend to use most of the resources available to them and they choose live over recorded lectures, whereas students with high self-efficacy (feeling confident about course performance) hardly use any of the provided resources. Finally, students with a low sense of peer learning tend to substitute live lectures with recorded ones.

3.4.2 VLE-use in distant learning settings

Valle and Duffy (2009) explored tool-use profiles in a fully online course for teacher professional development for a cohort of 59 students in a US-based university. In order to examine how students approached their studies, eight measures were made: course duration (number of days spend online for completion of the course); total sessions (a period of 30 min without course activity); average inter-session interval (average number of days between logins); proportions of time on learning resources (time spent with learning resources); proportion of learning resources accessed (number of accessed learning resources); exploration (number of times a student moved between activities in a non-linear way); and proportion of time on messenger (time spent on the internal email system). By performing a Cluster Analysis on these data, the authors identified three tool-use profiles: the ***mastery oriented/"self-driven" approach group*** (*N*=35) consisting of students that explored the course often (highest number of sessions, highest number of transitions between activities, highest proportion of resources used) something that reflects their commitment to the course and their self-driven approach; the ***task focused/"get it done" approach group*** (*N*=13) consisting of students who although had a lower than the mastery oriented group activity, they worked frequently and regularly for completing their course, something indicating their focus on completing the task; and the ***minimalist in effort/"procrastinator" approach group*** (*N*=11) consisting of students with no frequent logins who spread their work over larger periods of time and worked without any regularity. In absence of relevant statistical analysis, the authors inferred that the identified differences may be related to students' *teaching experience* (being more experienced allows spending less time on preparing teaching material and more time on the course or serves as a proxy for exploring the course material more deeply), *expectations* about the course's demanding nature (e.g. conceptions that online courses are easy to complete) and a preference/need for *working in groups* (as in face to face courses) rather than in a self-paced way.

Kovanović, Gašević, Joksimović, Hatala and Adesope (2015), investigated technology-use from 81 students enrolled in a graduate distance education engineering module (6 different cohorts over a period of 3 years). The team analysed log file data which included the number of times that students used a resource on the VLE (readings for the module, assignments and discussion boards) as well as the time spent using it. The variables capturing students' tool-use were organised in two groups: content-related (e.g. readings, assignments) and discussion-related activities (e.g. discussion boards). By performing a Cluster Analysis on the VLE data, 6 different tool-use profiles were identified:

1. **Task-focused users** (*N*=21): students with below average overall activity but above average message posting activity. They tend to spend only the necessary for completion of the course time.
2. **Content-focused no-users** (*N*=15): students characterised by their below average discussions-related activity, average content-related activity and above average use of assignment-related activities.
3. **No-users** (*N*=22): students with below average overall VLE activity
4. **Highly intensive users** (*N*=3): significantly the most active students, especially in content-related activities
5. **Content-focused intensive users** (*N*=6): students mainly characterised by their focus on the course content and their passive discussion-related activity but with overall higher use of the VLE
6. **Socially-focused intensive users** (*N*=14): students with above average discussion-related activity and average content-related activity

3.4.3 Internet/Web 2.0 use

Eynon and Malmberg (2011) explored how young people in the UK use the internet for non-educational purposes by surveying a sample of 1000 participants (four different age groups: 8, 12, 14 and 17-19). The questionnaire used measured 5 different types of internet activities, namely *communicating* (e.g. chatting online or sending and receiving emails), *information seeking* (e.g. looking for information on a topic of interest, keeping up with the news), *entertainment* (e.g. watching videos on the computer, downloading or streaming music), *participating* (e.g. writing a blog, adding or changing content in a wiki) and *creativity* (e.g. writing or composing music or lyrics, creative drawing, improving/editing photos). By performing a Latent Profiles Analysis on the survey data the authors identified 4 different internet-use profiles (Figure 3.2): the ***peripheral group*** (N=237), characterised by relatively low use of the internet across all five types; the ***normative group*** (N=238), specified by its use of the internet for information seeking, communication and entertainment at levels very close to the mean but below the mean for the rest; the ***all-rounder group*** (N=177), distinguished by an above average internet-use on all five types; and finally, the ***active participator group*** (N=102), which included users having above average use of the internet on all five types but characterised by a tendency to engage in online participatory behaviours.

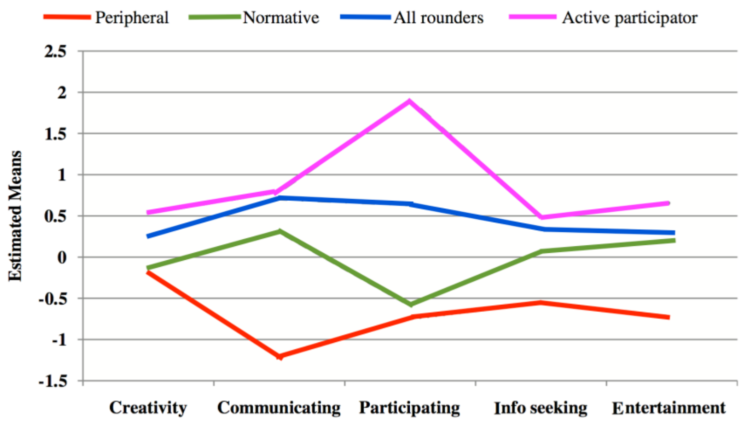

Figure 3.2: The four clusters from Eynon and Malmberg's (2011) study.

By performing a Multinomial Regression Analysis the authors inferred whether certain individual and contextual aspects could account for the identified internet-use differences. Of the aspects included in the analysis, age, internet self-efficacy, technical problem solving approach (individual characteristics), home internet access, friends and parental regulation (contextual factors) were found as important in predicting group membership. In particular, users from the peripheral group were younger, perceived themselves to be less skilled at using the internet and were less likely to have internet access at home when compared to the other three groups. On the contrary, users from the active participator group were characterised by employing a more problem solving approach to technology.

Costa, Alvelos and Teixeira (2016) surveyed 234 undergraduates and taught postgraduates in a Portuguese university about their use of Web 2.0 tools for both learning and leisure purposes. The tools surveyed included blogs, wikis, social networks, social bookmarks, podcast, video sharing, photo sharing, slide sharing, RSS and data mash-up. By performing a Cluster Analysis they identified three different tool-use profiles for learning purposes: the ***occasional users*** (*N*=189) characterised by their low use of Web 2.0 tools; the ***social intensive group*** (*N*=22) who reported the highest use of social networks and video sharing tools; and the ***information consumers group*** (*N*=17) characterised by the high use of blogs, wikis , slide sharing and data mash-up tools. With regards to the use of Web 2.0 tools for leisure purposes, the team identified four profiles: the ***communication group*** (*N*=12) who reported using mostly blogs and social networks; the ***social group*** (*N*=22) using mostly social networks; the ***occasional users*** (*N*=113) who had a lower than every other cluster use on all Web 2.0 tools; and the ***sharing information group*** (*N*=69) including students using mostly video sharing tools.

3.4.4 Tool-use profiles in tertiary mathematics

Inglis, Palipana, Trenholm and Ward (2011) investigated how a cohort of 534 mathematics and engineering undergraduates from a UK based university use the resources provided to them. The team recorded how often students were attending (live) lectures, watching online lectures or visiting the mathematics support centre. By performing a cluster analysis on the behavioural data, the team identified 4 different tool-use profiles, all incorporating the use of one or none of the provided resources: students using online lectures (cluster 1, *N*=70); students attending lectures (cluster 2, *N*=214); students visiting the support centre (cluster 3, *N*=65); and finally students not using any of these resources (cluster 4, *N*=185). In explaining the tool-use differences, the authors examined results in terms of subject specialism (mathematics, engineering) and students' gender. Subject specialism was significantly related to cluster membership, with 96% of cluster 1 (online lectures) being engineering undergraduates and 80% of cluster 3 (support centre) being mathematics undergraduates. For students' gender a borderline significant relationship was identified with more men accessing online lectures.

3.4.5 Discussion

Despite the differences in scope and context, all of the studies reviewed in this section (see Table 3.4 for a summary) underline the presence of two extreme types of users (as expected), the ***no/low-users*** (Bos & Brand-Gruwel, 2016; Costa et al., 2016; Eynon & Malmberg, 2011; Inglis et al., 2011; Kovanović et al., 2015; Lust et al., 2012; 2013) and the ***high/intensive users*** (Bos & Brand-Gruwel, 2016; Del Valle & Duffy, 2009; Eynon & Malmberg, 2011; Kovanović et al., 2015; Lust et al., 2011; 2013). However, when the quality of engagement is also taken into account (e.g. in terms of the time spent on using a resource), these extreme points become less clear-cut and they appear having variations, such as ***intensive active*** vs ***intensive superficial*** users (Lust et al., 2013) or ***no-users*** vs ***content-focused no-users*** (Kovanović et al., 2015). In between these poles and their variations, research has identified "middle" cases such as the ***selective*** or ***incoherent users*** who chose to use only some of the available to them tools (Bos & Brand-Gruwel, 2016; Lust et al., 2011; 2013). These nuances in tool-use profiles seem to get even more complex when other aspects related to students' tool-use are being examined, for example the ***self-regulated and deep learning*** students in Lust et al.'s study (2012) who were characterised as such because of their scoring on a learning approaches questionnaire. Finally, when the types of tools used by a group of students are also taken into account, then we can distinguish students preferring exclusively one tool e.g. online lectures (Inglis et al., 2011) or similar functioning tools e.g. the ***social-intensive students*** (Costa et al., 2016) distinguishable by their high use of social networks and file sharing tools or the ***socially-focused intensive users*** (Kovanović et al., 2015) characterised by their above average use of discussion related activities. Subsequently, explorations of undergraduates' tool-use behaviours may be located on the space defined by three dimensions: the first is a tool's frequency of use, the second is the time spent using a tools and the third varies according to the focus of a study (e.g. type of tools used by a group, or scores on a scale measuring usually an individual characteristic).

In terms of explaining differences in tool-use, things are less clear and universal since not all the studies reviewed here attempted to explain them (on an empirical basis). Of those which did, a number of contextual and individual factors has been suggested to influence tool-use preferences. Younger users with low sense of self-efficacy and no home internet access tend to use less the internet, whereas users characterised by technical problem solving approach are more likely to use the internet in an active, participatory way (Eynon & Malmberg, 2011). Students with goals related to learning and understanding are more likely to use all the available tools intensively and actively whereas the ones with goals related to performance are more likely to be selective in their tool-use (Lust et al., 2013). Undergraduates characterised by a low sense of self-efficacy tend to use most of the available to them resources and prefer live over online lectures, whereas those with a low sense of peer-learning tend to substitute live with online lectures (Bos & Brand-Gruwel, 2016). Finally, the discipline of study was found to be related with tool-use behaviour, with engineering students being heavy online lectures users whereas mathematics undergraduates prefer to use mostly the dedicated support centre (Inglis et al., 2011).

Still, seeking for the factors influencing undergraduates' tool-use preferences is not the only limitation in the area. Currently, empirical studies in tertiary mathematics are absent (despite the evidence supporting for tool-use differences across disciplines) with most tool-use studies in undergraduate settings focusing only on digital/institutionally provided tools.

Table 3.4: A summary of the studies reviewed in this section.

Author(s)	**Tools/Context**	**Tool-use profiles**	**Explaining differences**
Valle & Duffy (2009)	VLE Distant education	1. mastery oriented/self-driven group 2. task focused/get it done group 3. minimalist in effort/procrastination group	
Eynon & Malmberg (2011)	Internet Non-educational	1. peripheral group 2. normative group 3. all-rounder group 4. active participator group	- individual characteristics - contextual factors
Inglis et al. (2011)	Live & online lectures, support centre Tertiary mathematics	1. online lectures users 2. live lectures users 3. support centre users 4. no-users	- subject specialism
Lust et al. (2011)	VLE Tertiary education	1. intensive users 2. incoherent users 3. no-users	
Lust et al. (2012)	VLE Tertiary education	1. undefined users 2. disorganised users 3. inconsistent users 4. self-regulated/deep oriented users	
Lust et al. (2013)	VLE Tertiary education	1. no-users 2. intensive active users 3. intensive superficial users 4. selective users	- goal orientation
Kovanović et al. (2015)	VLE Distant education	1. task-focused users 2. content-focused no-users 3. no-users 4. highly intensive users 5. content-focused intensive users 6. Socially-focused intensive users	
Bos & Brand-Gruwel (2016)	VLE Tertiary education	1. no-users 2. superficial users 3. selective online users 4. intensive active users	- self-efficacy - peer learning
Costa et al. (2016)	Web 2.0 tools Tertiary education	1. occasional group 2. social intensive group 3. information consumption group	

3.5 Other factors

Besides the studies reviewed in the previous section (related to tool-use profiles), a number of other studies offering additional insights into the factors influencing undergraduates' tool choices have been identified. These are presented here in an ascending chronological order.

Povey and Ransom (2000) recruited 34 undergraduates (engineering, mathematics, science) in a UK-based university to construct diaries about their experience (e.g. general thoughts, feelings, usefulness) in using the hardware provided by the university (computers, graphic calculators) and software (spreadsheets, Logo, dynamic geometry) for learning mathematics. Although most of the students held positive views on using technologies for supporting their learning of mathematics, analysis of the diaries showed that some expressed reservations about using technology in learning and doing mathematics. In particular, students reported viewing technology as a threat to their understanding, in provoking a sense of being out of control and involving a waste of the power and potential of human beings.

Smith and Miller (2005) explored the relationship between learning approaches with assessment type (multiple-choice or essay format), discipline of study and gender by surveying a sample of 248 psychology and business undergraduates in an Australian university. For measuring students' learning approaches Biggs' (Biggs, 1987) Studying Process Questionnaire was used: deep motive: intrinsic interest in particular academic subjects; deep strategy: reading widely, interrelating with previous relevant knowledge; surface motive: meet requirements minimally; surface strategy: doing the bare essentials, reproducing through rote learning; achieving motive: based on competition, obtain highest grades; and achieving strategy: behaving as a model student. Results revealed that assessment type did not have a significant effect on approaches to learning. However, discipline and gender were identified as having a significant main effect on students' learning approaches. In particular, psychology students had significantly higher scores on deep motive and deep strategy and significantly lower scores on surface motive and surface strategy. In addition, female students were found having higher scores on achieving strategy.

White and Liccardi (2006) surveyed a sample of 286 students (224 undergraduates, 62 postgraduates) from a wide range of disciplines in a UK-based university. The authors followed a classification of disciplines into hard pure (e.g. Maths), hard applied (e.g. Engineering), soft pure (e.g. Economics) and soft applied (e.g. Art). The survey included questions about the e-learning methods students were using for learning purposes and the perceived usefulness of using them. Overall, survey results showed that students from the hard subjects (N=174) prefer more traditional lectures whereas students from the soft subjects (N=112) prefer more online teaching with discussion components. When compared within each main subject, students in the hard-applied subjects (N=116) expressed a desire for more online tests (98%) whereas students in the hard-pure subjects (N=58) did not prefer online tests (15%). In addition, most students from the hard-pure subjects reported that they would like more computer-based materials for helping them visualising problems (89%).

Conole, de Laat, Dillon and Darby (2006) surveyed a sample of 427 undergraduates in the UK across different disciplines, interviewed 14 and collected also audio diary data from 85 about their use of technologies for both learning and personal reasons. Students reported a range of reasons as to why they particularly liked using technologies and included easiness of use, effectiveness (in terms of doing what students wanted), efficiency (in terms of saving time), multi-functionality (undertaking a range of activities at once) and accessibility. By analysing data across the three sources, the team identified the following factors determining or influencing technology use: (1) ***environment***: students are immersed in interactive and? engaging environments in their personal lives (e.g. gaming) and this has increased their expectations of similar levels of quality for learning materials; (2) ***usability***: students are critical of a technology's usability in terms of its appearance, structure and availability of search engines; (3) ***accessibility***: students favour technologies which enable users to appropriate them; (4) ***ownership and personalisation***: students place greater value on technologies they have and can be personalised and offer a sense of control; (5) ***discipline demands***: for example, in mathematical sciences technologies for manipulating data are more commonly used whereas in political sciences, students use more technologies for accessing up to date authoritative information on current world events; (6) ***learning strategies***: students use different technologies depending on their learning strategies; (7) ***support and community***: students value and capitalise technologies affording social interactions (8) ***institutional infrastructure***: students demonstrated a lack of enthusiasm in using VLEs.

Orton-Johnson (2009) interviewed 16 undergraduates in a UK-based university about their use of web resources provided for their Sociology course, more general uses of technology and their understandings of online and offline academic work. Her work was initiated because of the identified non-use of the blended-learning materials provided for the course via a custom build website. Analysis of interviews revealed three main factors shaping students' non-use: adherence to the course's reading lists (seeing reading lists as anchors structuring and guiding their work); concerns about identifying "proper" academic information (perceiving books as more academic, fear of getting lost in information of unknown quality and relevance when using online material); and perceptions of what is expected of them as undergraduates.

Joordens, Le, Grinnell and Chrysostomou (2009) explored how undergraduates in mathematics from a Canadian university use online lectures. The team used VLE log data from two cohorts of mathematics students (N_1=196, N_2=292) and an online survey. Joordens et al.'s main focus was to compare how mathematics (current study) and psychology students (N=205) use online lectures. Data for psychology students were taken from a similar study led by members of the same team (Bassili & Joordens, 2008). Analysis of data showed that mathematics students used the pause and seek features extensively and more frequently than psychology students (14%-20% more frequently). Moreover, around 75% of mathematics students used the pause feature for writing notes whereas only 46.7% of psychology students did the same. Finally, overall use of the seek feature was more frequent for mathematics students (50%-53%) than for psychology students (42%).

Cano and Berbén (2010) surveyed a large cohort of undergraduates in a Spanish university. In total, 680 first year students from different disciplines (e.g. Mathematics, physic, economics) were surveyed about their conceptions of mathematics (Crawford, Gordon, Nicholas, & Prosser, 1998b), approaches to learning (Biggs, Kember, & Leung, 2001), course experience (Ramsden, 1991), achievement goals (Elliot & McGregor, 2001) and perceptions of classroom goal structure (Urdan, 2004). Analysis of the survey data suggested that (1) achievement goals and approaches to learning are linked to both the way students conceive of the nature of mathematics (conceptions of mathematics) and the way they perceive their academic environment (course experience); (2) variations in students' achievement goals, their conceptions of mathematics and course experience are related to their approaches to learning; (3) the two aspects of the academic environment (course experience and perceived classroom goal structure) might be related and (4) different aspects of approaches to learning and achievement goals are interrelated. The authors concluded that students' approaches to learning mathematics are ***not only*** related to their ways of conceiving the subject (conceptions of mathematics) and their personal goals (achievement goals) but also to their ***perceptions of teaching quality*** (course experience) and to the ***types of goals emphasised by instructional practices*** (perceptions of classroom goal structures).

Challis, Jarvis, Lavicza & Monaghan (2011) examined the software used by staff and students in an undergraduate mathematics degree program at a UK-based university (well known for its extensive integration of technology) and found that despite the variety and availability of different specialist mathematics software (e.g. Mathematica, SAS), Excel had a privileged position. In order to seek the reasons behind this, the team conducted a series of semi- structured interviews with ten members of staff and six students from the mathematics department. Their three fold analysis of data revealed that: (1) from an Activity Theory perspective (Engestrøm, 2001) Excel is consistent with a rule (anti-black box rule) and the object (employability) of the activity system (the UK based university); (2) from a mediated action (Wertsch, 1998) point of view, the staff's mastery and appropriation of Excel-use not only went hand-in-hand but evolved over years, resulting a privileged place for Excel; and finally (3) based on the disciplinary agency theory (Pickering, 1995) the authors inferred that the "anti-black box" rule and employability exerted agency with regards to the choice of the tool.

Jaworski, Robinson, Matthews and Croft (2012) explored the use of GeoGebra in a first-year engineering mathematics module as part of a research project aiming at promoting student engagement and deeper conceptual learning of mathematics at a UK-based university. The team surveyed 48 students and conducting two focus groups (2x4 students) about their impressions of the newly designed module. Perhaps the main finding of the study was that while some of the students conceived the use of GeoGebra and inquiry-based designed tasks helpful, many considered it "as irrelevant or unhelpful in providing what they need to pass the exam" (p. 148). By employing third generation Activity Theory (Engestrøm, 2001), the team conceptualised the issues rising from students' epistemological positions regarding the use of GeoGebra as tensions within students' activity system (rising from their exam-driven approach) and between students' and teachers' activity systems (emerging from differences in the perceived value and depth of understanding in the process of learning).

Saunders and Hutt (2014) surveyed 84 undergraduates and conducted focus groups with 15 of them in a UK-based university. The purpose of the study was to explore students' engagement with online provided material (audio podcasts, audio-narrated slides, short video segments and full- video lecture capture). Analysis of survey data showed that the provided material was most commonly used for revision purposes and filling gaps in lecture material (e.g. reviewing particular points of understanding), a facility especially valued by non-native English speakers who comprised the majority of the cohort. The authors concluded that non-native English speakers valued highly any resources that help them to overcome the language barrier and optimise their learning.

Henderson, Selwyn and Aston (2015), surveyed 1658 undergraduates from two universities in Australia[24] about their perceptions of useful digital technologies by asking them what technologies have been particularly helpful for their studies and why. Cited reasons were organised by the team into 11 categories (named as practices): (1) ***organising and managing the logistics of study*** e.g. managing schedules and timetables (46.9%); (2) ***flexibility of place and location*** (32.7%); (3) ***time-saving*** (30.6%); (4) ***reviewing, replaying and revising*** e.g. catching up on missed material (27.9%); (5) ***researching information*** (27.9%); (6) ***supporting basic tasks*** e.g. text editing with word processors (26.4%); (7) ***communicating and collaborating*** (16.8%); (8) ***augmenting university learning materials*** e.g. watching online videos outside university (14.6%); (9) ***seeing information in different ways*** e.g. visualising concepts through a video or animation (11.7%); (10) ***cost saving*** (4.4%); and (11) ***gauging a sense of progress*** e.g. receiving feedback from live polls in lectures (4.2%). The authors concluded that although digital technologies are a central element of undergraduate education, they are not transforming the nature of university teaching and learning since students do not use them in the most expansive, expressive or empowering ways.

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[24] Of them, 181 where in Engineering, Computer Science & Math and 245 in Physical & Biological sciences.

3.5.1 Discussion

This section set out in gathering additional information about factors that could be related to students' different tool choices (Table 3.5). The studies included here were treated as relevant to my study but none of them explicitly explored factors affecting undergraduates' tool choices. Thus, their function is complementary, in the sense that they point towards aspects of students' learning that could possibly be related to tool-use.

Table 3.5: A summary of the studies reviewed in this section.

Author(s)	Main finding(s)	Factor(s)
Povey & Ransom (2000)	STEM students resisting using digital tools (perceptions of technology as a detrimental to learning, not having control over it, waste of human beings' potential)	Perceptions of the role of technology in learning mathematics (discipline)
Smith & Miller (2005)	Discipline and gender have an impact on students' approaches to learning	Discipline, gender
White & Liccardi (2006)	Students in the hard subjects prefer traditional teaching methods when compared to students from the soft subjects (who prefer online)	Discipline
Conole et al. (2006)	Wider environment, features of a tool in relation to students' practices (usability, accessibility, ownership and personalisation, affording social interactions), discipline demands, learning strategies,	Wider environment, a tool's design, discipline, learning strategies
Orton-Johnson (2009)	Adherence to course's reading lists, perceptions of what counts as academic information, perceptions of what is expected of them as undergraduates	Learning strategies,
Joordens et al. (2009)	Mathematics students use differently online lectures than psychology students	Discipline
Cano & Berbén (2010)	Approaches to learning are related to conceptions of mathematics, achievement goals, perceptions of teaching quality, goal structure emphasised by instruction	Subject- and context-related factors
Challis et al. (2011)	The anti-black-box features of Excel and an institution's orientation to employability, granted a privileged place for Excel	Institutional practices
Jaworski et al. (2012)	Students' exam driven goals create tensions when a tool emphasising other goals is introduced in teaching practice	Students' epistemological positions
Saunders & Hutt (2014)	Non-native English speakers favour online lectures	First language
Henderson et al. (2015)	Students find most helpful tools that enable them to manage the logistics of their studies	Students' goals

Probably, the most commonly occurring theme was that ***discipline*** seems to matter when it comes to undergraduates' tool choices. Here I use the term as a descriptor in summarising a set of factors related to tool-use but not necessarily well articulated in the literature. This was the case of STEM students' perceptions of technology's place in learning mathematics (Povey & Ransom, 2000); the different ways mathematics students use online lectures when compared to psychology students (Joordens et al., 2009); the preference of students from hard subjects for traditional lecturing (White & Liccardi, 2006); and disciplinary demands in using certain tools when studying for a subject (Conole et al., 2006). Moreover, subject specialism has been associated with other constructs that may be also related to undergraduates' tool choices, namely approaches to learning (S. N. Smith & Miller, 2005).

Students approaches to learning (SAL) is a (well-articulated) construct that could potentially be related to students' tool choices, in the sense that approaches to learning could account for differences in tool-use. A number of factors has been identified to have an impact on SAL such as subject-centred factors such as (conceptions of mathematics, achievement goals) and context-centred factors (perceptions of teaching quality, goal structure as emphasised by instruction) (Cano & Berbén, 2010); and gender (S. N. Smith & Miller, 2005).

A number of other studies not following the SAL perspective (or another well-articulated construct), suggests that students' learning strategies (related mostly to their goals) relate to whether students do not use a tool (Orton-Johnson, 2009); find the use of a tool for the learning of mathematics irrelevant (Jaworski et al., 2012); or favour tools enabling them to take care the logistics of their studies (Henderson et al., 2015). Finally, institutional practices not necessarily related to learning e.g. employability (Challis et al., 2011), students' first language (Saunders & Hutt, 2014) and a tool's design (Conole et al., 2006) are among the other factors that have been found to be related with undergraduates' tool choices.

3.6 Looking forward

The review of the literature provided a solid basis for starting up my research but it also revealed several gaps related to my four research questions. In a nutshell, the issues identified by this review are related to omitting the student's perspective, excluding the blended side of learning (focusing on digital or institutionally provided tools) and the absence of studies in tertiary mathematics. Torrisi-Steele and Drew's (2013) literature review of blended learning in higher education revealed that 69.4% of the studies focus on examples and guidance in implementing various technologies, 4.96% have a focus on academics whereas 25.63% on students. Of the latter, 7.98% focus on the effectiveness of blended learning implementations and 17.65% on student experience. If we take into account the results of this review, we can imagine this proportion to be considerable smaller.

In addressing the identified gaps presented at sections 3.2.3, 3.3.12 and 3.4.5, my intentions are: (1) to adopt a student's perspective by acknowledging what tools undergraduates use to support their learning of mathematics in and out of lecture halls or computer labs; (2) to expand the notion of "technology" and include any means undergraduates use, whether these are digital/online technologies, traditional resources or even people; (3) to follow a mixed methods approach in an attempt to amplify my understanding of tool-use in undergraduate mathematics and minimise limitations stemming from purely qualitative or purely quantitative methods; and (4) to acknowledge the wider sociocultural environment in which undergraduates act within by adopting an Activity Theory perspective.

Chapter 4 Methodology

4.1 Introduction

In this chapter, the methodology followed for collecting and analysing data is described. First, a short introduction to mixed methods research is provided (section 4.2), followed by the reasons I chose mixed methods over other commonly used monomethod approaches (section 4.2.1). Then I proceed into describing briefly my research design (section 4.3). In the following section (4.4), I mainly describe the instruments used for collecting data, and how the data were collected. This part also includes the main findings of my pilot study and how it informed my main study, a description of the questionnaire, the interview protocol and the diary protocol, how participants were chosen and why, the timeframe for data collection and ethical considerations. Finally, in section 4.5, a short description of the data analysis followed is provided.

Once more, I would like to remind to the reader my research questions. These are:

RQ1. What tools do undergraduates use when studying mathematics?

RQ2. How can these tools be categorised?

RQ3. How can undergraduates be profiled according to their tool-use?

RQ4. What factors can account for undergraduates' tool choices?

4.2 What is Mixed Methods?

According to Tashakkori and Creswell (2007) mixed methods (MM) is defined as "research in which the investigator collects and analyses data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study or program of inquiry" (p.4). Mixed methods research is associated with ***pragmatism***, "a deconstructive paradigm that debunks concepts such as 'truth' and 'reality' and focuses instead on 'what works' as the truth regarding the research questions under investigation" and "rejects the either/or choices associated with the paradigm wars, advocates for the use of mixed methods in research, and acknowledges that the values of the researcher play a large role in the interpretation of results" (Tashakkori and Teddlie, 2003, p.713). Teddlie and Tashakkori (2009) note that the mixed methods tradition is less known than the quantitative (QUAN) and qualitative (QUAL) traditions because it emerged as a separate approach only during the last 20 years (as of 2009). In mathematics education, Hart, Smith, Swars and Smith (2009) report that 29% of the work published in prominent educational journals during the period 1995-2005 are utilising mixed methods and note that commentaries about the prevalence of mixed methods research (e.g. Johnson and Onwuegbuzie, 2004) are also true for mathematics education research.

Teddlie and Tashakkori's (2009) typology of MM research designs distinguishes between two major groups of MM designs: the ***monostrand designs***, consisting of one phase but incorporating both QUAL and QUAN components; and the ***multistrand designs***, which include at least two research strands with both QUAN and QUAL approaches included. Multistrand designs are divided into 5 families of designs: parallel mixed designs, sequential mixed designs, conversion mixed designs, multilevel mixed designs and fully integrated mixed designs. ***Parallel mixed designs*** are designs having at least two parallel and relatively independent phases, one with QUAL research questions, data collection and analysis techniques and the other with QUAN research questions, data collection and analysis techniques. ***Sequential mixed designs*** are designs where at least two research strands occur in a chronological manner (e.g. first QUAN then QUAL or first QUAL and then QUAN) with results of the first strand leading to the design of the second. ***Conversion mixed designs*** are multistrand, parallel in nature designs in which the mixing of QUAL and QUAN approaches occur while one type of data are transformed (qualitised or quantitised) and then analysed in a both qualitative and quantitative manner. ***Multilevel mixed designs*** are multistrand, parallel or sequential designs in which QUAL and QUAN data are collected at different levels of analysis (e.g. QUAL for student, QUAN for class). Finally, ***fully integrated mixed designs*** are multistrand parallel designs in which the mixing of QUAL and QUAN approaches takes place throughout all the stages of research in a dynamic, reciprocal and iterative way.

4.2.1 Why use mixed methods?

Since the ultimate goal of any piece of research is to answer the questions related to a project's aims, Teddlie and Tashakkori (2009) note that there are three areas where mixed methods (MM) research is superior to single approach designs: (1) MM research enables researchers to address simultaneously ***confirmatory*** (demonstrating that a particular variable will have a predicted relationship with another variable) and ***exploratory*** questions (answering how and why the predicted relationship occurs) i.e. to ***verify*** and ***generate theory*** in the same study; (2) MM research provides ***stronger inferences*** because they offer triangulation and complementarity mechanisms; (3) MM research offers opportunities for a ***greater assortment of divergent views*** by allowing different voices and perspectives to emerge from the generated inferences.

In relation to my study, the reasons for using mixed methods had to do with the nature of my research objectives: I was interested in simultaneously investigating different aspects of undergraduates' tool-use, with some research questions best answered by QUAN methods (RQ1, RQ2, RQ3) and others by QUAL or both (RQ4). In relation to the points outlined by Teddlie and Tashakkori, first, mixed methods enabled me to confirm or reject hypotheses related to the factors affecting undergraduates' tool-use (QUAN strand) and seek why these hypotheses were confirmed or rejected (QUAL strand) thus allowing me to both verify and generate theory. Moreover, I was able to strengthen the quality of my inferences by juxtaposing results and their interpretation from the QUAN and QUAL strands of my study. Finally, mixed methods allowed multiple perspectives of my study to emerge while combining QUAN and QUAL inferences into a meta-inference.

4.3 Research design

Having presented a short introduction of mixed methods research, the purpose of this small section is to briefly describe how my work is placed within the mixed methods tradition. My study follows a parallel mixed methods design with two relatively independent strands, one quantitative (QUAN) and one qualitative (QUAL). The quantitative strand was designed in answering all my research questions (RQ1, RQ2, RQ3, RQ4) and incorporated a questionnaire as the data collection method. The QUAN strand was accompanied by statistical analysis procedures. The qualitative strand aimed at answering RQ4 i.e. identifying factors that could account for undergraduates' tool choices. It incorporated interviews and diaries as data collection methods and involved qualitative data analysis (Figure 4.1). Details about the data collection methods and my overall analysis plan are provided in the following sections of this chapter.

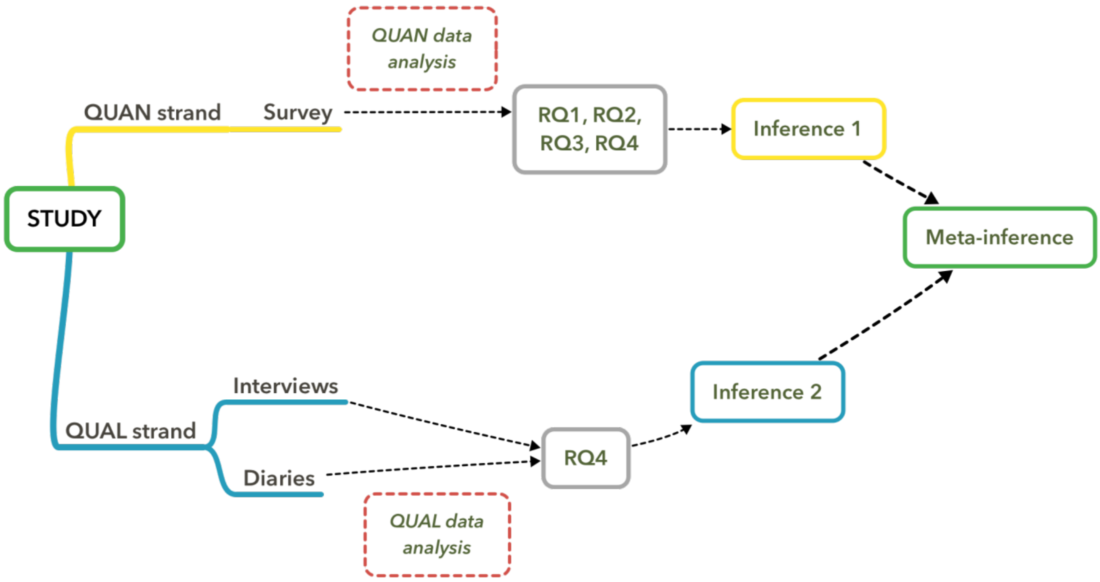

Figure 4.1: A brief description of my research design. I followed a parallel mixed methods design with two strands, one quantitative and one qualitative.

4.4 Data collection methods

4.4.1 Pilot study

During the academic semester 2015-2016 and over a period of 6 weeks, five participants were recruited and interviewed (3 females, 2 males; 2 foundation students, 2 first-year engineering students, 1 second year mathematics student) as part of my pilot study. The purpose of my pilot study was to inform the design of a questionnaire intended to be used during my main study. Students were recruited by visiting a lecture hall, my tutorial (convenience sampling) and from invigilations (opportunity sampling). They were verbally informed about the purpose of the study and advertising leaflets were given to them. Interviews were semi-structured and lasted for 30 to 60 minutes. A consent form was signed by each student prior each interview.

The protocol used for the pilot interviews was designed by using Engestrøm's version of Activity Theory and in a retrospective way, Murphy and Rodríguez-Manzanares' (2013) coding protocol. It consisted of 18 open-ended questions (Appendix A) designed to gather data for each node of Engestrøm's activity model, subject (students' background and conceptions of mathematics), object (students' goals while studying mathematics), outcome (students' perceived future results from learning mathematics), tools (resources used while studying mathematics), rules (what counts as acceptable or not when studying mathematics), community (who supports students when studying mathematics) and division of labour (the role that each member has in this community). Interviews were then transcribed and coded by using seven major codes (subject, object, outcome, tools, community, rules, division of labour) and several sub-codes for each main code. Assigning text to each code was performed by using a modified version of Murphy and Rodríguez-Manzanares' (2013) coding protocol which included definitions for each component (code) and example questions that helped me with the coding process.

Initially, I was planning to design my main study's questionnaire to include questions related to all seven components of Engestrøm's activity model (subject, object, outcome, tools, community, rules, division of labour). However, based on the richness of data for the components subject, tools and object as well as practical considerations about the length of a questionnaire implementing Engestrøm's full model, it was decided to design a questionnaire focusing on the upper part of Engestrøm's activity model i.e. Vygotsky's mediational triangle. Thus, the main findings from my pilot study that were incorporated in the design of the questionnaire were related to the nodes subject, tools and object. These indicated that students in this sample used a variety of tools such as Google, online videos (YouTube, Khan Academy), online encyclopaedias (Wikipedia, MathWorld), Wolfram Alpha, Social media (Facebook), resources hosted at the university's VLE (online tests, past papers, online lectures, online lecture notes, perception tests), lecturers, recommended textbooks, the HELM workbooks, books with problems they choose, their notes, instant messaging apps (WhatsApp), peers (friends, flatmates), family members, their tutors and the support centre. With regards to their intentions while studying mathematics, students reported goals such as to pass the maths module, to obtain as high grades as possible, to understand mathematics and to enjoy mathematics. Finally, their conceptions about the nature of mathematics included views such as "a way of modelling", "the core/root of everything", "above every subject", "a tool for connecting reality with design", "solving problems" or as "entirely truth knowledge".

4.4.2 Questionnaire

4.4.2.1 Overall structure, conceptual basis and rationale

The questionnaire's (Appendix B) purpose was to collect data for answering RQs 1, 2, 3 and 4. It was designed in order to depict Vygotsky's mediational triangle (1978) as discussed by researchers working within the Activity Theory tradition (e.g. Cole, 1996; Kaptelinin & Nardi, 2012; 2006). The reasons for incorporating Vygotsky's mediational triangle into the design of my questionnaire were threefold: first, the nature of my study itself (focusing on tools) "dictated" adopting a theoretical approach that takes tools seriously (Monaghan, 2016a); second, Leontiev's version of Activity Theory (the main theoretical framework used in this study) is closely related to Vygotsky's writings and in fact mediation is one of the basic principles of Leontiev's version of AT (Kaptelinin & Nardi, 2006); and finally, the original work of Vygotsky, Leontiev and Luria incorporated the analysis of QUAN data (e.g. "Leontiev's parallelogram" on children's memory performance see Kaptelinin & Nardi, 2006). Thus, following the structure of Vygotsky's mediational triangle, the questionnaire was divided into three main parts, each corresponding to the nodes of ***subject*** (part I), ***tools*** (part II) and ***object*** (part III). In particular, part I (subject) aimed at collecting data for four qualities conceptualised as belonging to the subject, namely, a student's mother language (English as a first language or not), year of studies (first or second), degree (mathematics or engineering) and conceptions of mathematics (the way students conceive the nature of mathematics); part II (tools) intended to identify what tools undergraduates use when studying mathematics and how often; whereas part III was designed for collecting data about undergraduates' goals when studying mathematics. The rationale for collecting data about the resources undergraduates use, the goals they aim for when studying mathematics and assigning them to the nodes of tools and object respectively, was straightforward and related to the focus of my study on tools and how Vygotsky conceptualised the way our praxis is structured: our interaction with what we want to achieve (object, goals) does not only happen in a direct (natural) way but also in an indirect (unnatural) way by using cultural products i.e. tools (Cole, 1996). However, deciding upon what qualities of undergraduates should be used in the questionnaire and assigned as belonging to the subject needed more thought.

Part I: subject

With regards to the first question (what counts as belonging to the subject?), I have treated the node subject as containing qualities that a student has and may affect (or not) the ways she/he acts: this can include age, gender, ethnicity, previous experiences, skills, knowledge on a topic, conceptions, emotions about a person or a situation etc. Thus, the way I treat the term subject can be seen as a much smaller subset of Gee's (2000) definition of *identity*, i.e. "being recognised as a certain 'kind of person', in a given context" (*Ibid.*, p.99). Another important aspect of how I have treated the node subject, relates to the *locus of identity* i.e. whether a person's qualities are context free or not (the so-called structure-agency debate Kaspersen, Pepin, & Sikko, 2017). For this, I have adopted Kaspersen, Pepin and Sikko's (2017) view who do not consider the locus of identity as dichotomous (completely context-free, completely context-bound) or static. Thus, I acknowledge that the qualities that have been assigned to the subject's node and treated as a student's qualities could be in fact a result of his/her interaction with the wider sociocultural environment, something commonly assumed in Activity Theory approaches although there are some disagreements about the locus of identity within the Activity Theory community (Kaspersen et al., 2017).

In relation to deciding which "subject-centred factors" should be included in the questionnaire, I took into account insights from my pilot study, the results of my literature review and common sense. Thus, including language as a subject's quality was based on hints from the wider literature indicating that non-native English speakers perceive tools such as online lectures (hosted on their university's VLE) as particularly helpful for their learning (e.g. Saunders & Hutt, 2014). Including year of studies as a subject's quality was based on insights from the pilot interviews (there were examples indicating that peers or lecturers may introduce students to new tools, for example a specific YouTube channel or Wolfram Alpha) and the common-sense assumption that undergraduates are acting in a sociocultural environment (university) which may result the adoption of new tools and/or the abandonment of old. With regards to a student's degree, as we saw in the literature review, there exists evidence supporting the relationship between discipline of study with the tools undergraduates use (Inglis et al., 2011) or not (Povey & Ransom, 2000), and with learning approaches (Smith & Miller, 2005; White & Liccardi, 2006) especially when contrasting STEM students with other disciplines. Finally, conceptions of mathematics have been identified as relating to approaches to learning (Cano & Berbén, 2010; Crawford, Gordon, Nicholas, & Prosser, 1998a; 1998b) and achievement goals (Cano & Berbén, 2010) i.e. goals oriented towards learning (mastery goals) or concerning the demonstration of abilities (performance goals) (Pintrich, 2003).

Year of studies and degree were not included as questionnaire items but rather known in advance since hard copies of the questionnaire were distributed during lecture or tutorial time. For language, a simple question was used (is English your first language?) whereas for conceptions of mathematics, Crawford et al.'s (1998b) questionnaire was used, which included 19 items. Conceptions of mathematics were measured on a 5-point semantic differential scale ranging from 1 (strongly disagree) to 5 (strongly agree) instead of a 5-point Likert scale originally used by Crawford *et al*. (1998b). Semantic differential scales are variants of typical rating scales which operate by putting two polar opposites in textual form at each end of the scale and numbers (not accompanied by words) in between (Cohen, Manion, & Morrison, 2011). A semantic differential scale is easy to understand and fill (Al-Hindawe, 1996) and this is why it was used instead of a typical Likert scale i.e. to avoid vagueness issues related with words used in typical Likert scales (e.g. strongly, sometimes, mostly or mostly, most of the times, sometimes etc.) especially since many of the students were expected to be non-native English speakers.

Part II: tools

Part II (tools) included a list of 15 items, intended to measure how often a student uses a tool from a predetermined list: own written lecture notes, online videos (e.g. YouTube, Khan Academy), recommended textbooks/HELM Workbooks for mathematics modules[25], social media (e.g. Facebook groups), the Learn website (university's VLE), Review Lecture Capture (online lectures hosted on the Learn website), online encyclopaedias (e.g. Wikipedia), instant messaging (e.g. WhatsApp), other textbooks chosen by students (e.g. textbooks with problems), Wolfram Alpha, pre-university notes (e.g. A-level notes), other students, lecturers (e.g. after a lecture or via email), staff at tutorials (e.g. a lecturer or a PhD student) and the Mathematics Learning Support Centre. Two additional open ended items were included in case students were using tools not listed in the questionnaire. The list of tools was based on the literature review and my pilot study. For the items assessing tool-use frequency, a 6-point semantic differential scale ranging from 1 (never/not applicable) to 6 (always) was used. This was done in order to avoid central tendency (reporting more often using a tool "sometimes"/"half of the times"). Part II included also two questions about lecture attendance and perceived lecture usefulness again on a 6-point semantic differential scale. Finally, Part II included also another item asking students to rank the 5 tools they use the most (top-5 list of tools).

Part III: goals

Part III (goals) included a list of 10 goals related to students' aims while studying mathematics on a 6-point semantic differential scale ranging from 1 (disagree) to 6 (agree) was used. These were: (1) to get a high mark (60% or above), (2) to pass your maths module (+40%), (3) to acquire mathematical skills, (4) to understand mathematics, (5) to understand the applications of mathematics, (6) to enjoy mathematics, (7) to understand the theory of mathematics, (8) to acquire a mathematical way of thinking or philosophy, (9) to satisfy your intellectual curiosity and (10) to open your mind. Of those, goals 1, 2, 4 and 6 were based on my pilot study's results whereas the rest come from the work of Wood, Petocz and Reid (2012). The team interviewed 22 undergraduates majoring in the mathematical sciences (statistics, mathematical finance, operations research) and categorised their views about learning mathematics into a three-dimensional space: ***intentions***, statements referring to future plans or aims; ***approach***, students' descriptions of what they do when learning mathematics; and ***outcome***, statements referring to what

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[25] **H**elping **E**ngineers **L**earn **M**athematics (HELM) is a major curriculum development project undertaken by a consortium of five English universities - Loughborough, Hull, Reading, Sunderland and Manchester (led by Loughborough). The HELM learning resources comprise of 50 workbooks. For more information, see http://helm.lboro.ac.uk/.

students believe they will have acquired after completing their course.

When examined from an Activity Theory perspective, the dimension intentions is related to goals, approach to ensembles as defined by a purpose and the dimension outcome to an activity system's outcome. Since my aim was to design items for goals, I only used the dimension intentions (see Table 4.1). However, because some of the intentions were more related to Activity Theory's notion of outcome, I did not use them. For example, "to get a [better] job, status, money" is a student's anticipated result and not related to the goals of his/her current activity. In addition, some intentions were divided into two or more goals. For example, it was hypothesised that some students may prefer focussing on understanding the applications of mathematics (especially engineering students) while others on the theoretical aspects of mathematics (especially mathematics students), thus the intention "to understand mathematics, practice, theory, applications" was split into goals 4, 5 and 7.

The rationale for adopting parts of Wood et al.'s (2012) work into my questionnaire was linked to its context specific nature and relevance with my study (tertiary mathematics). In addition, findings from my pilot study related to undergraduates' goals were similar to those in Wood et al.'s (2012) study. Nevertheless, before incorporating and adapting Wood et al.'s (2012) work, I searched the wider literature related to goals and I identified two main areas of research as potentially useful: ***goal content approaches*** and ***achievement goals orientations***. Both areas are concerned with what motivates students in classrooms but each has a different focus.

Goal content approaches assume that students may pursue multiple goals e.g. social or academic related and research in the area is focused on the interactions between multiple goals in educational settings (Pintrich, 2003) whereas achievement goals orientations are considered as "the reasons and purposes for approaching and engaging in achievement tasks" (*Ibid.* p.676) and focus on students' orientations towards mastery or performance goals. Although there do exist inventories for achievement goals orientations (e.g. Elliot & McGregor, 2001; Elliot & Murayama, 2008), both areas were considered as inappropriate for my study mainly because they are to some extent incompatible with Activity Theory, since goals are treated solely as individual attributes and not as a product of societal forces. In addition, Activity Theory provides a more concrete theoretical account on multiple goals i.e. multiple activities that subjects are engaged in, with different objects (and thus goals) potentially causing contradictions between different activities.

Table 4.1: Intentions from Wood et al.'s (2012) study (first column from left), my rationale for including or not an intention into my questionnaire (second column) and the corresponding items for goals (third column).

Intention	**Comment**	**Corresponding item for goals**
To pass the subject or course	Similar to my pilot study's results	
To get a [better] job, status, money	Not used (outcome)	
To acquire mathematical tools and skills	Used but without the word "tools"	(3)
To understand mathematics, practice, theory, applications	Partially used. Split into 3 goals (one similar to my pilot study's results)	(4), (5), (7)
To help others with mathematics	Not used (outcome)	
To acquire a mathematical way of thinking or philosophy	Used	(8)
To open one's mind, to satisfy intellectual curiosity	Used but split into 2 goals	(9), (10)

Finally, part III included another item asking students to rank the 5 goals they consider to be the most important (top-5 list of goals). This was done because while testing the questionnaire with my fellow PhD students (5 in total), they all commented that they would like to pursue all of the listed goals (thus results would be skewed). By including a top-5 item would "force" undergraduates to think more critically and prioritise some of their goals, which would then allow me to differentiate which goals are more important to undergraduates.

4.4.3 Interviews

The purpose of the interviews was to collect data that would enable me to answer RQ4 (what factors can account for undergraduates' tool choices?) which would be otherwise omitted by survey data. Interviews were semi-structured and the interview protocol (Appendix C) was developed by incorporating Leontiev's version of Activity Theory and his notion of functional organs. In particular, the interview questions were designed in a way that reflected in a direct or indirect way the 5 principles of Leontiev's version of AT: object-orientedness, hierarchy, mediation, externalisation/internalisation and development.

My first step in developing the interview protocol was to visualise the way activities are structured (hierarchical structure of activities) and work out how the 4 remaining principles (object-orientedness, mediation, externalisation/ internalisation and development) would fit in such a schema. In doing so, I incorporated Kaptelinin and Nardi's (2006) modified version of AT (who suggested that the object and the motive are separate) and Goodchild's (2001) representation of the structure of an activity. The result is presented at Figure 4.2.

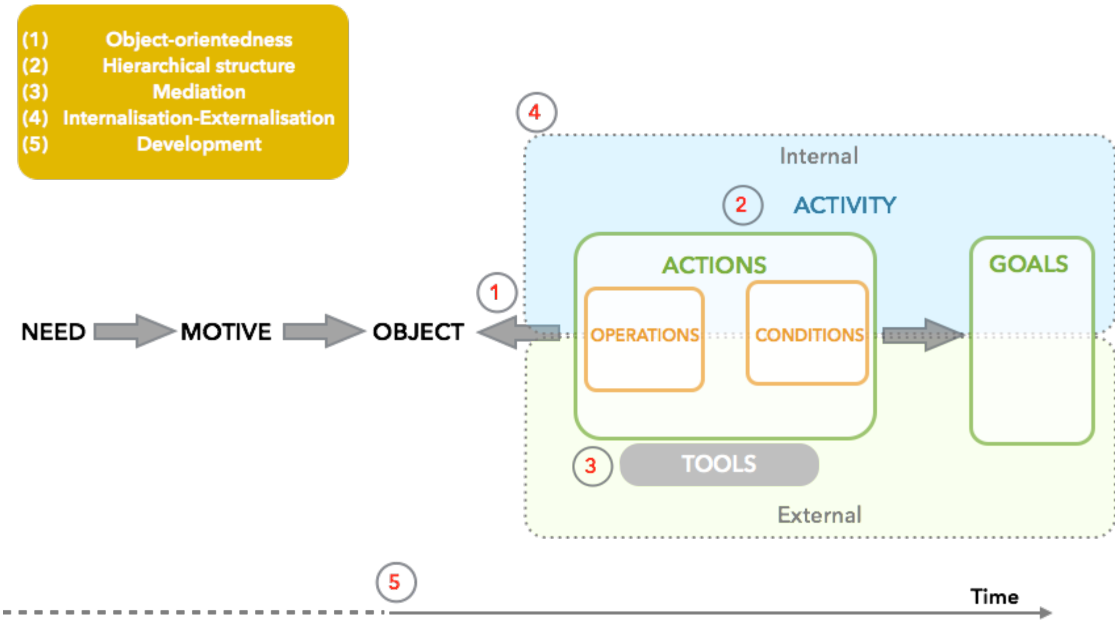

Figure 4.2: My visualisation of Activity Theory's principles with the structure of human activities. All activities have an object and each activity is directed at its object (1); activities are hierarchically structured and consist of actions/goals, conditions/operations (2); tools mediate our interaction with the world (3); activities are distributed between internal and external planes; and finally, activities develop over time (5).

The second step in creating the protocol was to utilise Figure 4.2 and "translate" what was required for my envisioned analysis of Activity Theoretical constructs into interview questions, easily understood by students. In particular, some components of a subject's activity (motive, actions/goals, tools, operations) and Activity Theory's principles (hierarchical structure, mediation, development) were incorporated into the interview protocol.

With regards to an activity's components, needs and operations were not incorporated into the interview protocol because both were not the focus of my study and the latter refers to non-conscious, routine processes difficult to be accessed while interviewing a subject. The principle of object-orientedness was also not used in the interview protocol, however it had been already incorporated into how I had conceptualised students' activity. As Russell (2002) notes, "the world does not come neatly divided into activity systems" (p.67), the researcher is responsible for defining the activity system based on the purposes of the research study. Thus, I theoretically defined mathematics students' activity as "studying for a mathematics degree" and for engineering students "studying for an engineering degree". Consequently, the object was also theoretically defined for mathematics ("mathematics degree") and engineering students ("engineering degree"); this is why the object was also not included in the interview protocol design. The principle of internalisation and externalisation was also not directly incorporated in the interview protocol since the focus of my study was on non-psychological tools that undergraduates use when studying mathematics. However, I acknowledge that even these tools and every aspect of students' activity have external and internal components.

Table 4.2: Interview questions for mathematics and engineering students. Questions are either related to an Activity Theory construct that could help me answer my research questions or directly related to them.

Interview protocol question	Activity Theory construct, RQs
(1)Why did you decide to study Mathematics/Engineering?	Motive
(2) Do you feel that the same reasons described before stand also for today?	Motive, Development
(3) Do you use other resources besides the ones listed in the questionnaire? (4) Do you use the same resources for other modules as well? (5) Do you think there is a difference of how you use online resources as opposed to attending lectures, getting help from other students/friends, etc.?	Tools
(6) Why using these resources (your top-5) instead of others? (7) Why using a tool at all? What makes you say, "Ok, now I need to use this (a resource) in order to do that"?	Tools + Reasons
(8) When did you start using these resources? (9) Does the use of these resources vary throughout a semester or stays the same?	Tools + Development
(10) Do you use resources that a friend, a lecturer or another person have suggested to you since you've entered University?	Tools + Social context
(11) Could you please give me some examples of how you use your top-5 list of resources?	Actions/Goals
(12) Do you use these tools in the same way for all of your modules?	Actions/Goals + Transferability
(13) Using more than one resource at the same time? Examples?	Using multiple tools
(14) What kind of difficulties do you encounter with when studying mathematics? (15) Are there times that you want to do something but you feel restricted?	Conditions
(16) Do you feel that these tools and the way you use them help you to get the "answers" and support your learning of mathematics? (17) Based on which criteria do you conclude that a tool was successfully used and the goal has been achieved?	Functional organs (introductory questions)
(18) How confident do you feel regarding how well you can use a tool?	Tool-related competencies (knowledge and skills for using a tool)
(19) How do you recognise which task (group of problems) can be "solved" with a particular tool?	Task-related competencies (range of solvable tasks)
(20) Do you think you can map what a tool can do (its functions) with what you want to do (your goal)?	Task-related competencies (translating goals into tool functions)
(21) How do you decide that a tool is "not good for the job"?	Meta-functional competencies (limitations)
(22) What do you do when a tool malfunctions?	Meta-functional competencies (troubleshooting)

Interview question 1 related to the motive of a student's activity and 2 was designed to capture potential changes in the motive although according to Kaptelinin and Nardi (2006) motives are more stable than other components of a subject's activity. Questions 3-10 and 13 referred to tools, how their use develops over time and factors that could potentially affect their choice. Questions 11-12 were related to the level of actions/goals and questions 14-15 to the level of conditions/operations (conditions were conceptualised as a subset of the factors shaping/restricting undergraduates' actions/goals). Finally, questions 16-22 related to the notion of functional organs. These were not a central part of my research design but they were included as questions that could offer additional insights of tool-use if time permitted. Table 4.2 summarises all the above.

4.4.4 Diaries

The purpose of diaries was to collect more detailed and accurate data of students' tool use over a period of time, related to RQ4 (what factors can account for undergraduates' tool choices?). In doing so, solicited diaries (Bartlett & Milligan, 2015) were used. The diary protocol followed a semi-structured design i.e. it consisted of pre-defined questions but in an open-format manner and intended collecting data qualitative in nature. The protocol was primarily inspired by basic concepts of Leontiev's version of Activity Theory (tools, actions, goals), some elements from his notion of functional organs (tool-related competencies, task-related competencies and meta-functional competencies) but it was also guided by my research questions (i.e. the diary protocol included questions not directly addressed by Activity Theory such as why a person is using a particular resource). In sum, six diary questions were used (Figure 4.3). These aimed at collecting data for the tools that undergraduates used (diary question 1); their actions (diary question 3) and goals (diary question 2) while studying mathematics; why they chose to use a particular tool (diary question 4); their self-evaluation of achieving or not their goals (diary question 5); and the difficulties they possibly faced while using a particular resource (diary question 6).

	DIARY QUESTIONS	
1	WHAT?	What resource(s) if any did you use? Which one was most useful?
2	PURPOSE?	What did you want to achieve?
3	HOW?	Describe how you used the most useful resource.
4	WHY?	Why did you choose this particular resource?
5	EVALUATION?	Did you finally achieve your goal?
6	DIFFICULTIES?	Did you encounter any difficulties while using this resource?

Figure 4.3: The diary protocol questions. This picture was forwarded to the students via the WhatsApp application as a reference point while producing the diaries.

The sampling design was a combination of signal-based and event-based techniques (Bartlett & Milligan, 2015), meaning that the students were instructed to create a diary entry every time they studied mathematics (event-based) or when the researcher (me) was sending a reminder to them for reporting their activities (signal-based). The diaries were obtained by using a popular instant messaging mobile application (WhatsApp: www.whatsapp.com) and students were given printed and electronic instructions on how to use alternatively a desktop version of WhatsApp in case they were finding difficult to create diary entries with their smartphones e.g. due to the small size of the virtual keyboard that smartphones usually have (Appendix

D). However, all participants reported feeling very comfortable with using WhatsApp on their smartphone.

4.4.5 The data collection period

4.4.5.1 Overall data collection process and timeframe

The data were collected in three sequential phases (survey, interviews, diaries; see Figure 4.4). First, depending on availability, large cohorts of mathematics and engineering students were surveyed by visiting them and distributing hard copies of the questionnaires to them during lecture or tutorial time. Second year engineering and mathematics students were surveyed during November-early December 2015, whereas first year engineering and mathematics students during February-early March 2016. The total number of participants was 628. At the end of each questionnaire, a dedicated space allowed students to indicate whether they were willing to be interviewed at a later stage of the study. For those who agreed, emails explaining in more detail the interview process were sent and in total 14 students volunteered and were interviewed. Depending on availability, interviews took place during January-April 2016. Each interview lasted for 45-60 minutes. At the end of each interview, students were asked whether they wanted to participate further in the study by constructing a digital diary of their everyday activities and in total 4 agreed to take part. Originally, it was intendent to recruit more diarists (ideally the same number as interviewees) but this was not possible due to the commitment required on behalf of the students constructing the diaries (many students kindly refused to participate due to their workload) and practical issues related to some students' course structure (i.e. not having mathematics modules during the diary data collection period). The data collection period for diaries, spans form late February to early June 2016.

Throughout all the data collection phases, convenience sampling was used. Convenience or opportunity sampling is used for selecting participants who are easily accessible to the researcher. When convenience sampling is used, the sample is not considered to be representative of the wider population and cannot serve as a basis for generalising findings (Basit, 2010). Details about participants and when they were surveyed are presented in Table 4.3, details about the interviews in Table 4.4 and details about the diaries are presented in Table 4.5.

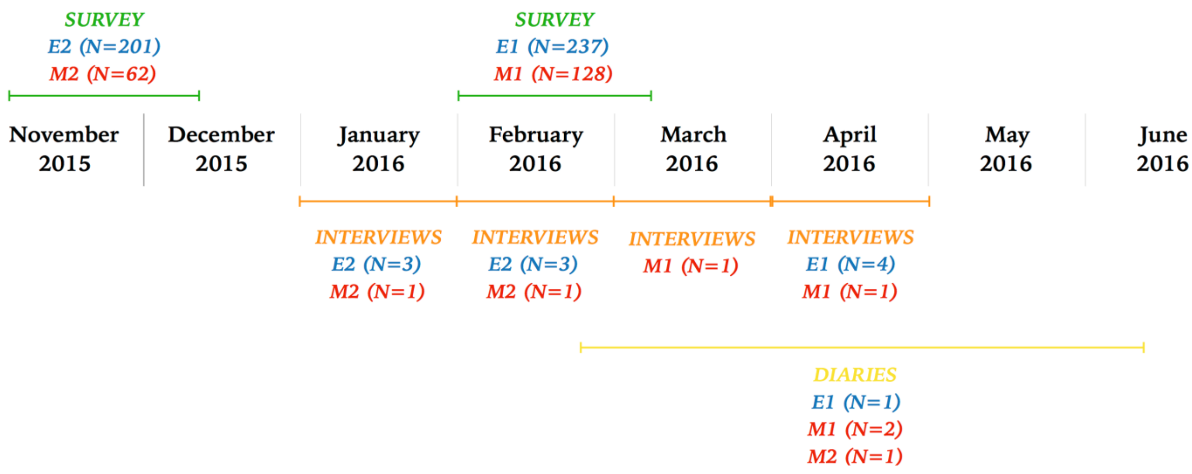

Figure 4.4: The data collection period (green for survey, orange for interviews, yellow for diaries). E1 and E2 refer to first and second year engineering students respectively. M1 and M2 refer to first and second year mathematics students respectively. *N* indicates the number of participants.

Table 4.3: Details about survey participants (*N*=628).

Degree	**Year of studies**	***N* (number of participants)**	**Survey date**	**Semester/Week**
Mechanical Engineering	2	39	20/11/2015	S1.W8
Materials Engineering	2	22	23/11/2015	S1.W9
Mathematics (single & joint honours)	2	62	23/11/2015	S1.W9
Aeronautical & Automotive Engineering	2	76	26/11/2015	S1.W9
Electrical Engineering	2	64	1/12/2015	S1.W10
Mathematics (single & joint honours)	1	128	12/2/2016	S2.W2
Mechanical Engineering	1	64	9/3/2016	S2.W6
Aeronautical & Automotive Engineering	1	93	10/3/2016	S2.W6
Manufacturing Engineering	1	80	16/3/2016	S2.W7

Table 4.4: Details about interview participants (N=14).

Participant's code	Degree	Year of studies	Interview date	Semester/Week
SI1	Mathematics (single honours)	2	11/1/2016	S1.W13
SI2	Materials Engineering	2	26/1/2016	S1.W15
SI3	Mechanical Engineering	2	28/1/2016	S1.W15
SI4	Mechanical Engineering	2	29/1/2016	S1.W15
SI5	Mechanical Engineering	2	2/2/2016	S2.W1
SI6	Mechanical Engineering	2	3/2/2016	S2.W1
SI7	Mathematics (joint honours)	2	9/2/2016	S2.W2
SI8	Mechanical Engineering	2	26/2/2016	S2.W4
SI9	Mathematics (single honours)	1	9/3/2016	S2.W6
SI10	Mechanical Engineering	1	21/4/2016	S2.W8
SI11	Mathematics (single honours)	1	22/4/2016	S2.W9
SI12	Aeronautical & Automotive Engineering	1	22/4/2016	S2.W9
SI13	Aeronautical & Automotive Engineering	1	29/4/2016	S2.W9
SI14	Aeronautical & Automotive Engineering	1	29/4/2016	S2.W9

Table 4.5: Details about diary participants (N=4).

Participant's code	Degree	Year of studies	Diary period	First/last entry week	Total number of weeks/entries
SD1	Mathematics (single honours)	1	23/04 - 11/06/2016	W8 – W15	8/26
SD2	Mathematics (single honours)	1	11/03 - 12/06/2016	W6 – W15	14/34
SD3	Mathematics (joint honours)	2	6/03 - 13/06/2016	W5 – W16	16/30
SD4	Aeronautical & Automotive Engineering	1	24/04 - 23/05/2016	W8 – W12	5/21

4.4.5.2 Ethics

Prior to any data collection phase (survey, interviews, diaries) an ethical clearance checklist was submitted and approved by the Ethics Approvals Sub-Committee. The first page of each questionnaire functioned as a consent form and included information about the researchers involved in the study (me and my supervisors Prof Carol Robinson and Prof Stephen Lerman), the purpose and structure of the questionnaire as well as a section underlying ethical aspects of students' participation in the study. In particular, students were informed about the voluntary nature of their participation and they were reassured that all of their personal details (name, student ID number) will be accessed only by the principal researcher (me) and that each participant's responses will be anonymised and data will be securely stored. No incentives were provided to students for their participation in the survey.

Before each interview, students informed that for practical reasons they will be audio recorded during the interview and I reassured them of confidentiality and anonymity. It was also mentioned that results (including findings) might be published in my dissertation or in journals or professional presentations. Finally, it was emphasised that they were free to refuse to answer a question or to withdraw at any time. Students were then invited to carefully read and sign the consent form, informing them about all the above. The aspect of anonymity and confidentiality was repeated several times during each interview; in this way, I was able to build a trustful relationship with the interviewees, which enabled the students to feel comfortable and speak freely. No incentives were provided to students for participating in the interviews.

At the end of each interview, students were briefly informed about the third phase of my study (diaries) and asked whether they would like to participate. For those who accepted a consent form explaining in more detail procedural and ethical aspects was provided. As with interviews, students were invited to carefully read and sign the consent form. In addition, students were given printed and digital instructions for using the web version of the instant messaging app (WhatsApp) in case they were finding it difficult to type on a smartphone's small keyboard as well as specific details about how they should answer the diary questions (Appendix D). Due to the commitment required for producing a diary over a period of weeks, participants were offered incentives depending on the diary period (ranging from £30 to £50).

4.5 Data analysis plan

In this section, a short account of the steps taken for analysing the quantitative and qualitative data for my study are presented. In aiding the reader following my narrative, details about the analyses I undertook are presented in chapters 5 (analysis and results of quantitative data) and 6 (analysis and results of qualitative data). Section 4.5.1 serves as an introduction to pre-analysis considerations and data analysis techniques in mixed methods. In section 4.5.2 I describe how the survey data were analysed in order to answer RQs 1, 2, 3 and 4. Finally in section 4.5.3, I describe my plan for analysing qualitative data from interviews and diaries.

4.5.1 Pre-analysis considerations and analysis techniques in Mixed Methods

Teddlie and Tashakkori (2009) discuss the following considerations to be thought prior any analysis in mixed methods (MM) approaches:

- ***What is the purpose of the MM study?*** For example, is the purpose complementary (thus a parallel design should be used) or expansion (thus a sequential design should be used)?
- ***Will the MM study be more variable or case oriented?*** For example, will the researcher look at the phenomenon under examination within its context (case oriented, QUAL research) or will seek identifying important variables (variable oriented, QUAN research)?
- ***Will the MM study be primarily exploratory, confirmatory or both?***
- ***Will the QUAN and QUAL analyses inform each other?*** To what extent does the researcher anticipate that each strand will inform each other? For example, if the strands are going to be relatively independent then a parallel design/analysis should be used, if each strand depends on the other then a sequential design/analysis should fit.
- ***Is the researcher aware of the assumptions that underlie both QUAN and QUAL data analysis techniques?***
- ***What kind of data analysis tools will be used?*** For example, will the analysis be aided by software tools?

The purpose of conducting a mixed methods study has been already described in section 4.1.2 (nature of my research objectives, verify and generate theory, strength the quality of my inferences, assort divergent views). In relation to choosing a certain MM design (question one above), the purpose of using QUAN and QUAL data was complementary, thus a parallel design was used. With regards to being more variable or case oriented, I have adopted a middle approach by allocating equal importance to both QUAN and QUAL components of my study. Third, my study has both exploratory (RQ1, RQ2, RQ3) and confirmatory (RQ4) purposes. In relation to the fourth point, my study follows a parallel design with two relatively independent strands, thus it was anticipated that QUAN and QUAL analysis will not inform each other. Regarding the assumptions underlying QUAN and QUAL data analysis, I consulted well established texts about statistical analysis (A. Aron, Coups, & Aron, 2013; e.g. Field, 2013; Tabachnick & Fidell, 2013) and QUAL approaches (Cohen et al., 2011; Schreier, 2014) and when necessary sought statistical advice in my university's dedicated centre and from my supervisors. Finally, with regards to data analysis tools, I anticipated aiding my analysis with software tools (SPSS for QUAN data and MAXQDA for QUAL data).

Following their proposed typology of mixed methods designs, Teddlie and Tashakkori (2009) identify 6 different strategies for analysing MM data: ***parallel mixed data analysis*** (QUAN and QUAL data are analysed in separate processes); ***conversion mixed data analysis*** (QUAL data are converted into QUAN or QUAN data are converted into QUAL); ***sequential mixed data analysis*** (analysis on the QUAN strand depends or emerges from the analysis on the QUAL strand and vice versa); ***multilevel mixed data analysis*** (QUAN and QUAL analytical techniques taking place at different levels for answering interrelated research questions); ***fully integrated mixed data analysis*** (when QUAN and QUAL analyses are mixed in a iterative, reciprocal and interdependent way); ***applying analytical techniques from one tradition to another***.

The present study follows a parallel mixed methods design, so this type of MM analysis technique will be discussed further here. In parallel mixed data analysis, QUAN and QUAL analyses are independent but each strand provides an understanding of the phenomenon under investigation, when combined into meta-inferences by linking or integrating the QUAL and QUAN inferences (Teddlie & Tashakkori, 2009). The amount of influence that each analysis will have on the other is up to the researcher to decide. The following processes take place when analysing data in a parallel manner (Teddlie & Tashakkori, 2009):

1. QUAN and QUAL strands are designed and implemented for answering related aspects of the same phenomenon. Each pair of parallel strands (at least two) are relatively independent with separate QUAN and QUAL research questions.
2. QUAN and QUAL data are collected separately.
3. QUAN and QUAL data are analysed in a parallel fashion. Separate inferences are drawn for the QUAN and the QUAL oriented research questions.
4. Inferences/conclusions from each strand are synthesised into *meta-inferences*. Parallel inferences may lead to convergent or divergent meta-inferences. Agreement between inferences is not necessarily an indicator of methodological or data quality problems and in fact, ***divergent inferences may offer complimentary perspectives or reveal the conditions under which a inference may apply or not***.

4.5.2 QUAN strand

The quantitative strand of my study involved answering all of my research questions by analysing the survey data in a statistical fashion. In answering RQ1 (what tools do undergraduates use when studying mathematics?), I used descriptive statistics, in particular each tool's mean (resulting from a 6-point semantic differential scale). This analytical phase can be considered as focusing on the Tools node from Vygotsky's mediational triangle. In order to answer RQ2 (how can these tools be categorised?) I performed an Exploratory Factor Analysis (EFA), a common approach when a researcher is interested in identifying latent constructs (i.e. identifying a typology present in the data) from QUAN data. Details about how EFA works and how the analysis was performed are provided at relevant sections in chapter 5 (Analysis and results of quantitative data). EFA results were then interpreted by using Wartofsky's hierarchy of artefacts (Wartofsky, 1973) and Leontiev's version of Activity Theory (Kaptelinin & Nardi, 2006; Leontiev, 1981b). When examined from both a Wartofskian and Activity Theory perspective, this analytical phase can be considered as projecting Vygotsky's mediational triangle on a three level vertical axis i.e. Leontiev's hierarchical structure of activities. With regards to RQ3 (how can undergraduates be profiled according to their tool-use?), I performed a commonly used statistical technique, Cluster Analysis, which assigned students to different groups (clusters) depending on their reported tool-use. Details about how Cluster Analysis functions and how the analysis was performed are provided in relevant sections in chapter 5. This analytical phase entails the classification of subjects by focussing on the Tools node i.e. the tools that undergraduates use. Finally, in answering RQ4 (what factors can account for undergraduates' tool choices?), I performed two types of analyses. First, based on the survey's descriptive statistics, I hypothesised that discipline (mathematics or engineering) relates to the types of tools that undergraduates use (mathematics students differ in the tools they used when compared to engineering students) and a Mann-Whitney test was performed. Second, I performed a Multinomial Logistic Regression analysis for predicting cluster membership and thus identifying factors affecting undergraduates' tool preferences. The factors included in the Multinomial Logistic Regression analysis were undergraduates' type of degree (mathematics or engineering), year of studies (first or second), conceptions of mathematics (cohesive, fragmented) and their goals while studying mathematics. Language was not used because of missing data (many students did not answer the question about their first language). Details about the Mann-Whitney test, Multinomial Logistic Regression and other related analyses are provided at relevant sections in chapter 5. This part of the QUAN data analysis, can be viewed as exploring how the Subject (type of degree, year of studies, conceptions of mathematics) and the Object nodes (goals) from Vygotsky's mediational triangle relate to the Tools node i.e. undergraduates' tool preferences.

4.5.3 QUAL STRAND

The qualitative strand of my study concerned answering RQ4 (what factors can account for undergraduates' tool choices?) from a QUAL perspective. In doing this, interview and diary data were analysed by using a Qualitative Content Analysis approach (Schreier, 2014). Results from both methods were interpreted by using both Leontiev and Engestrøm's versions of Activity Theory. In particular, Leontiev's framework was used for analysing data at the individual activity level whereas Engestrøm's framework was used for interpreting results at the activity system level. Details about Quantitative Content Analysis and how the two versions of Activity Theory were used are provided in chapter 6 (Analysis and results of qualitative data).

Chapter 5 Analysis and Results of Quantitative Data

5.1 Introduction

In this chapter results from the quantitative strand of my mixed methods study are presented and discussed. Section 5.1.1 summarises the research questions that needed a quantitative approach and outlines my overall analysis strategy. In section 5.1.2 the assumptions made while analysing the survey data are described. Results are presented throughout section 5.2 and are organised by research question: section 5.2.1 for RQ1, section 5.2.2 for RQ2, section 5.2.3 for RQ3 and section 5.2.4 for RQ4. At the end of each of these sections, a summary of the main findings is presented, and conclusions are drawn and discussed.

5.1.1 Research Questions and Analysis Strategy

The research questions that this study tried to address and needed a quantitative strand are the following:

- **RQ1**: What tools do undergraduates use when studying mathematics?
- **RQ2**: How can these tools be categorised?
- **RQ3**: How can students be profiled according to their tool-use?
- **RQ4**: What factors can account for undergraduates' tool choices?

In order to outline my overall quantitative data analysis strategy, I first need to remind to the reader my questionnaire's structure (Appendix B) and its relation to Vygotsky's mediational triangle. As mentioned in the Methodology chapter, the instrument used for the quantitative strand of my study was a questionnaire which was designed with the intention to capture data related to Vygotsky's mediational triangle. Each of the questionnaire's three parts corresponded to the three nodes of Vygotsky's mediational triangle (subject, tools, object) and contained several variables. For simplicity, the correspondence between the questionnaire's parts and variables with Vygotsky's mediational triangle are presented at Table 5.1.

Data analysis took place in four sequential phases, each characterised by different types of statistical tests/procedures and linked to a different research question (Table 5.2): **(1)** data were explored by using descriptive statistics for identifying to what extent undergraduates use certain tools (RQ1); **(2)** an empirical-based typology of the tools that undergraduates use was produced by performing an Exploratory Factor Analysis (RQ2); **(3)** students' tool-use profiles were created by performing a Cluster Analysis (RQ3); and finally **(4)** differences in tool-use were sought to be explained by performing a Multinomial Logistic Regression.

Table 5.1: A short description of the questionnaire's parts, number of variables included in each part (numbers in parentheses) and their correspondence to the nodes of Vygotsky's mediational triangle.

Part	Description and Number of Variables	Mediational Triangle
Part I	Year of studies (1) Degree (1) Conceptions of mathematics (19)	Subject
Part II	Tools used when studying mathematics (17) Top-5 list of tools (5)	Tools
Part III	Goals when studying for mathematics modules (11) Top-5 list of goals (5)	Object

Table 5.2: Research questions and statistical analysis performed in answering them.

Research Question	Statistical Test/Procedure
RQ1: What tools do undergraduates use when studying mathematics and to what extent?	Descriptive statistics
RQ2: How can these tools be categorised?	Exploratory Factor Analysis
RQ3: How can students be profiled according to their tool-use?	Cluster Analysis
RQ4: What factors can account for undergraduates' tool choices?	Multinomial Logistic Regression

5.1.2 Assumptions

In general, two camps of researchers can be identified in the literature regarding the appropriateness of using ordinal data in parametric statistical analyses (Grace-Martin, 2008): researchers who maintain that ordinal data cannot be treated as continuous and thus only non-parametric tests can be used (e.g. Jamieson, 2004); and those who support that using parametric tests is valid in some situations (e.g. Rhemtulla, Brosseau-Liard & Savalei, 2012). Data gathered from the questionnaire are ordinal in nature (6-point semantic scale) but for the purposes of my study I treated them as continuous. This was done because the intended analyses for answering my research questions required that variables are continuous. For example, the mean was chosen as a descriptor of central tendency (instead of the median) and standard deviation as a measure of dispersion (instead of the interquartile and semi-interquartile ranges).

5.2. Analysis and Results

5.2.1 What tools do undergraduates use when studying mathematics and to what extent?

The part of the questionnaire related to the tools that undergraduates use included in total 22 items. Of them, 17 were inviting students to state how frequently they use a tool (either from a list of 15 predetermined tools or 2 open-ended items) and 5 were asking them to rank the resources they use most frequently (top-5 list of resources). From the pre-determined list, one tool (online lectures) was available only to a subset of the students surveyed (engineering students, N=348, M=2.68) and therefore this variable was not included in the analysis. Responses from the additional 2 open-ended items reveal a few other resources not listed in the questionnaire (Table 5.3) but these were related to a resource already listed in the questionnaire: for example, past papers, tutorial question sheets and lecturer's notes are resources hosted on the LEARN website; DESMOS and online calculators are similar to Wolfram Alpha and Khan Academy is similar to YouTube videos (Khan Academy has also a YouTube channel). In total 25 participants filled in the open-ended items which might be an indication of the questionnaire's exhaustiveness in terms of the tools that undergraduates use or a negative side effect of the questionnaire's length (which was three and half A4 pages).

Table 5.3: Results from the open-ended items (tools that were not included in the questionnaire). Numbers in parentheses next to each tool indicate how often a resource is used (1: Never, 6: Always). Frequency indicates how many students stated using each tool.

	Frequency
DESMOS (5)	2
Khan Academy (5)	3
Lecture notes (4)	1
Online calculators	2
Past papers (4, 6)	3+3
Small group tutorials (6)	1
Students in higher years or other universities (6)	1
Personal tutor (2)	1
Tutorial question sheets (4)	8
Total	**25**

In order to answer RQ1 (what tools?), descriptive statistics for the 15 close items were examined. Students in the sample were both engineering and mathematics undergraduates and summary statistics were first examined for all students (section 5.2.1.1). Since relevant literature suggests that discipline is a factor affecting the ways undergraduates study, the hypothesis that mathematics and engineering students use tools differently was tested (section 5.2.1.2). The analysis was complemented by the examination of frequency tables for all students' top-5 list of resources (section 5.2.1.3).

5.2.1.1 All students

Figure 5.1 presents descriptive statistics for all the students in the sample (N=606, listwise). As we can see, when examined as a whole, undergraduates in the sample mostly use their notes (M=4.77), the Learn website (M=4.71), other students (M=4.16) and textbooks (M=4.12). Based on the mean of each item, resources were categorised in a way that reflects both their frequency of use and the context of the study: the highest and lowest mean values were 4.77 (own written notes) and 2.16 (MLSC) respectively, therefore I used these values as limits to approximately group the resources. In this way, resources were categorised into three main groups: resources with a mean between 4 and 5 were characterised as ***high-use*** resources ($4 \leq M < 5$), those with a mean between 3 and 4 were assigned into the ***mid-use*** group ($3 \leq M < 4$) while resources with a mean between 2 and 3 were put into the ***low-use*** group ($2 \leq M < 3$). This categorisation is utilised only as a way for roughly making sense of the results and I acknowledge the limitations of this approach (i.e. these are results from ordinal data and no equal intervals can be assumed).

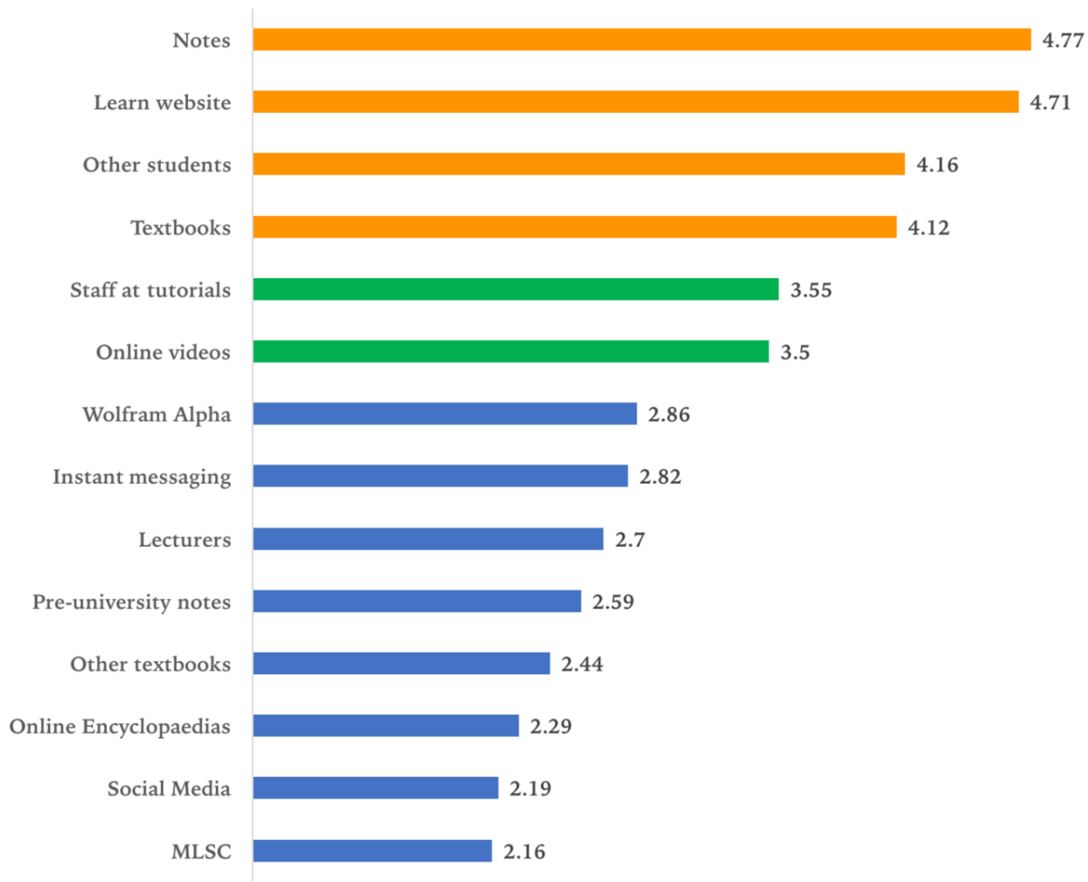

Figure 5.1: Categorisation of the resources based on their mean (high-use: orange, mid-use: green, low-use: blue).

5.2.1.2 Engineering and mathematics students

Since mathematics and engineering students' mathematical activities are to some extent different, it was hypothesised that these two groups would use different tools or use tools more/less frequently. This is due to the fact that (1) mathematics students have different timetable loads (6-12 mathematics modules per academic year) when compared to their engineering peers (1-2 modules per academic year) and (2) from an Activity Theory perspective, mathematics students' object of activity is more broad when compared to engineering students: for mathematics students their object varies from gathering credits for a pre-determined number of mathematics modules (joint honours students) to obtaining a mathematics degree (single honours students), whereas engineering students' object is usually restricted to attending 1-2 modules per academic year. Indeed, examination of descriptive statistics for engineering and mathematics students (Table 5.4) revealed that although there were tools that engineering and mathematics students reported using to somewhat the same extent (notes, online videos, pre-university notes, staff at tutorials, lecturers) there were others in which differences were found, with the most notable being for textbooks.

In order to test the hypothesis of whether there are differences between mathematics and engineering students, a multivariate analysis of variance (MANOVA) was decided to be performed with tools as dependent variables and degree as an independent variable. MANOVA is a statistical procedure used to test differences between groups across several dependent variables simultaneously. In order for a MANOVA to be valid, dependent variables and residuals[26] should be normally distributed and variances in each group should be roughly equal - homogeneity of variance- (Field, 2013). Because multivariate normality cannot be checked with SPSS, univariate normality was tested instead. Kolmogorov-Smirnov and Shapiro-Wilk tests showed that both the dependent variables ($p<.001$) and the residuals[27] ($p<.001$) are not normally distributed. A quick check of the ratio of the absolute value of kurtosis over its standard error for each variable and group (|kurtosis|/standard error of kurtosis), revealed values above the permitted limit of 2 (Glass et al., 1972). Finally, Box's test of equality of covariance was found to be significant ($F(105,438997.7)=1.825$, $p<.001$) and Levene's test of equality of error variances was found to be significant for several variables (social media: $F(1,604)=18.796$, $p<.001$; Learn website: $F(1,604)=29.245$, $p<.001$; online encyclopaedias: $F(1,604)=4.423$, $p=.036$; other textbooks: $F(1,604)=4.717$, $p=.030$; Wolfram Alpha: $F(1,604)=4.046$, $p=.045$; MLSC: $F(1,604)=5.054$, $p=.025$), which meant that homogeneity of variance cannot be assumed (variances of those two groups are different). Because the assumptions of MANOVA were not met, the hypothesis was tested with a non-parametric test (the Mann-Whitney test).

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[26] Residuals are the errors between the values that a model predicts and the values observed in the data (Field, 2013).

[27] When these tests are significant, data/residuals are not normally distributed.

Mann-Whitney is a non-parametric test used to check whether two independent groups of participants differ significantly on one variable when assumptions of parametric tests are not met (Field, 2013). In our case, the two independent groups were engineering and mathematics students but because multiple comparisons were performed (number of comparisons is equal to the number of variables compared, here 14), instead of using the typical .05 significance value, a Bonferroni corrected value was used. This was calculated by dividing the .05 significance value by the number of comparisons (number of variables) performed, which resulted a .05/14 = .0035 significance value[28]. The Mann-Whitney test revealed statistically significant differences for textbooks (U=5,891.50, p<.001), the Learn website (U=56,942.00, p<.001), online encyclopaedias (U=48,263.50, p=.001), instant messaging (U=52,782.50, p<.000), other textbooks (U=35,160.50, p=.001), Wolfram Alpha (U=47,562.00, p=.002) and other students (U=49,485.50, p<.001) (Figure 5.2).

In sum, engineering students were found to use more textbooks (absolute mean difference: 2.69) and other textbooks (absolute mean difference: .39) than mathematics students but mathematics students were found to use more the Learn website (absolute mean difference: .75), online encyclopaedias (absolute mean difference: .35), instant messaging (absolute mean difference: .79), Wolfram Alpha (absolute mean difference: .42) and other students (absolute mean difference: .40) when compared to their engineering peers. The extent to which mathematics and engineering students differ in using the above tools can be assessed from Figure 5.3 where each bar represents the difference of the mean for each tool: positive numbers indicate that engineering students use a tool more whereas negative numbers indicate that mathematics students use a tool more.

Table 5.4: Descriptive statistics by degree (listwise). Differences in the mean above .5 are in boldface.

	Degree	
	Engineering (N=420)	Mathematics (N=186)
Notes	4.73	4.86
Online videos	3.54	3.39
Textbooks	**4.94**	**2.25**
Social Media	2.07	2.46
Learn website	**4.48**	**5.23**
Online Encyclopaedias	2.18	2.53
Instant messaging	**2.58**	**3.37**
Other textbooks	2.56	2.17
Wolfram Alpha	2.73	3.15
Pre-university notes	2.60	2.56
Other students	4.03	4.43
Lecturers	2.63	2.86
Staff at tutorials	3.57	3.51
MLSC	2.09	2.31

[28] The exact version of the Bonferroni formula for p variables is: $\alpha=1-(1-\alpha_1)\ (1-\alpha_2)\ldots\ (1-\alpha_p)$ but a good approximation (which was used here) is given by the formula $\alpha=\alpha_1/p$ when $\alpha_1=\alpha_2=\ldots=\alpha_p$ (Tabachnick & Fidell, 2012).

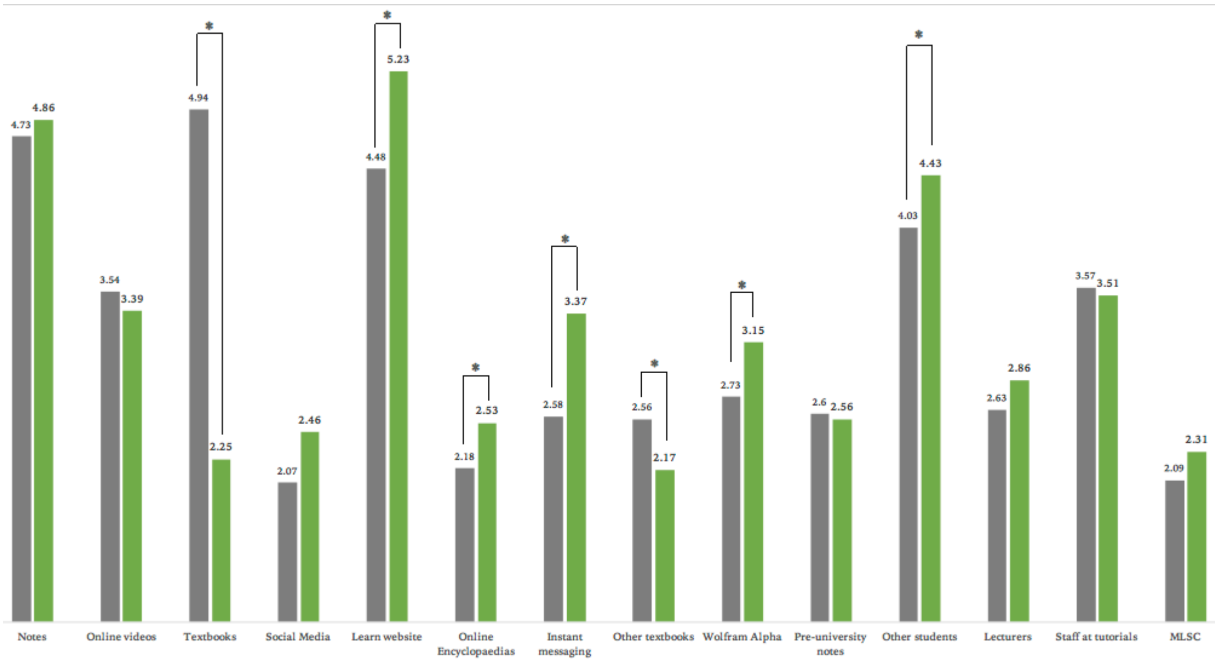

Figure 5.2: Statistically significant differences between engineering (grey) and mathematics students (green) indicated by an asterisk above each pair of bars.

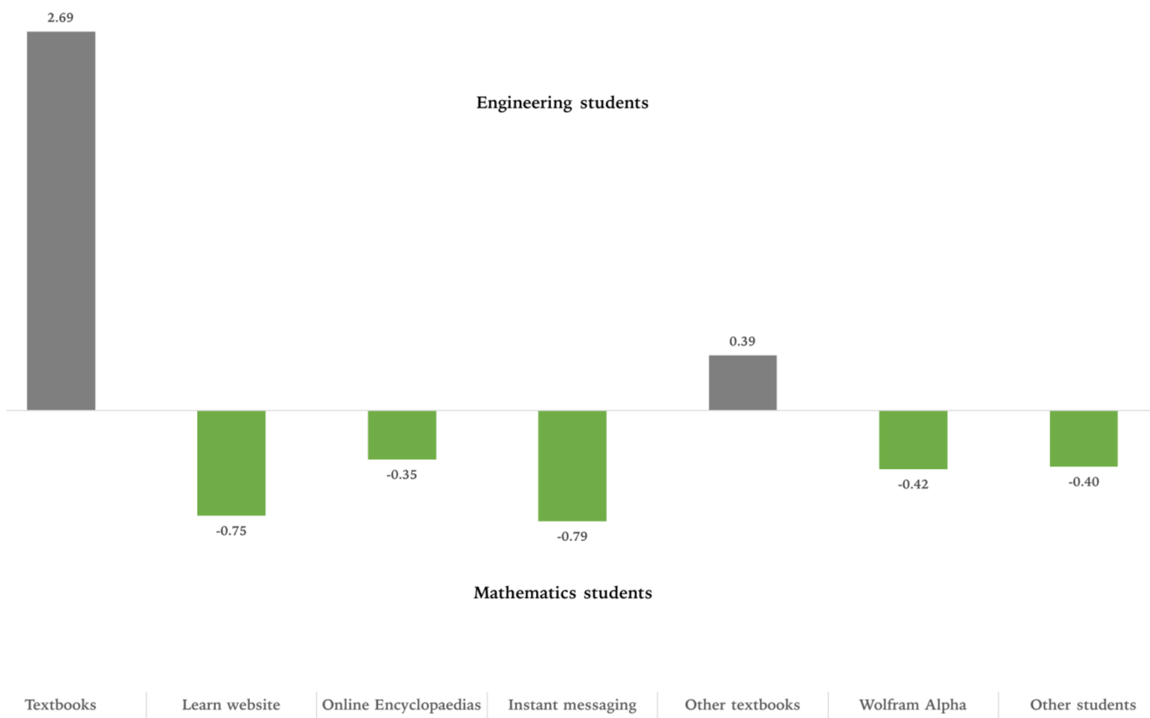

Figure 5.3: The extent to which engineering (grey) and mathematics students (green) differ in using a tool. Only tools with statistically significant differences are included.

5.2.1.3 Which tools do students value the most?

The tools that students reported as using the most (top-5) and their rank are presented at Table 5.5. Each column (top-1, top-2 etc.) corresponds to the five ranks of the top-5 and for each rank only those resources that their cumulative percentage is just above 90% have been included. For example, the second column (Top-1) shows the tools that students reported as their first choice: notes 39.8%, textbooks 23.5%, the Learn website 20%, online videos 4.2% and other students 3.1%. From Table 5.5 we can observe that:

- There are certain resources appearing at all ranks (textbooks, LEARN website, online videos, other students) while others start appearing only at lower positions (e.g. Wolfram Alpha).
- As we move on from the first to the fifth choice we have an ***increased variability of resources***; for example, 90.6% of first choices consist of 5 resources while 90% of fifth choices consist of 12 resources.
- The number of students decreases as we move to lower ranks (top-1: N=620, top-5: N=584), indicating that ***some students may tend to use mainly up to 3 or 4 resources***.
- ***Humans as resources have high percentages at lower ranks*** (lecturers, staff at tutorials, other students, the MLSC): for instance, other students as a resource appears at the first place of the top-5 having a 3.1 percentage while tutorials appear for the first time at the second place with a 5 percentage and lecturers appear for the first time at the third place having a 1.9 percentage.

Table 5.5: All students' top-5 list of resources (accounting approximately 90% of choices).

	Top 1 (N=620)	Top 2 (N=615)	Top 3 (N=618)	Top 4 (N=604)	Top 5 (N=584)
Notes	39.8%	20.3%	10.5%	6.0%	
Textbooks	23.5%	19.7%	10.5%	6.5%	5.0%
Learn website	20.0%	19.0%	18.3%	10.6%	7.5%
On-line videos	4.2%	10.6%	10.5%	11.1%	8.6%
Other students	3.1%	11.4%	16.2%	16.4%	17.5%
Wolfram Alpha			5.7%	7.9%	7.0%
Instant messaging		2.6%	3.6%	4.6%	5.5%
Staff at tutorials		5.0%	8.3%	12.4%	12.8%
Lecturers			1.9%	4.6%	7.0%
Social media		1.6%			4.5%
Other textbooks			2.6%		
MLSC				3.5%	4.3%
Online encyclopaedias				3.0%	5.3%
Pre-university notes			3.2%	4.6%	5.7%
Cumulative Percentage	**90.6%**	**90.2%**	**91.3%**	**91.2%**	**90.6%**

In order to allow popular resources to emerge from the above ranked data, a score for each resource appearing in the top-5 list was produced. This was done by multiplying each resource's percentage by a weight depending on the place that a resource was found: 5 for the first most used resources (top-1), 4 for the second (top-2), 3 for the third (top-3), 2 for the fourth (top-2) and 1 for the fifth (top-1). For example, textbooks received a total score of 2.46 (5×0.235 + 4×0.197 + 3×0.105 + 2×0.065 + 1×0.05) and the LEARN website a total score of 2.60 (5×0.2 + 4×0.19 + 3×0.183 + 2×0.106 + 1×0.075). This is presented at Figure 5.4 and as we can see students' notes, the LEARN website and textbooks are again the most popular choices, followed by other students, online videos and staff at tutorials.

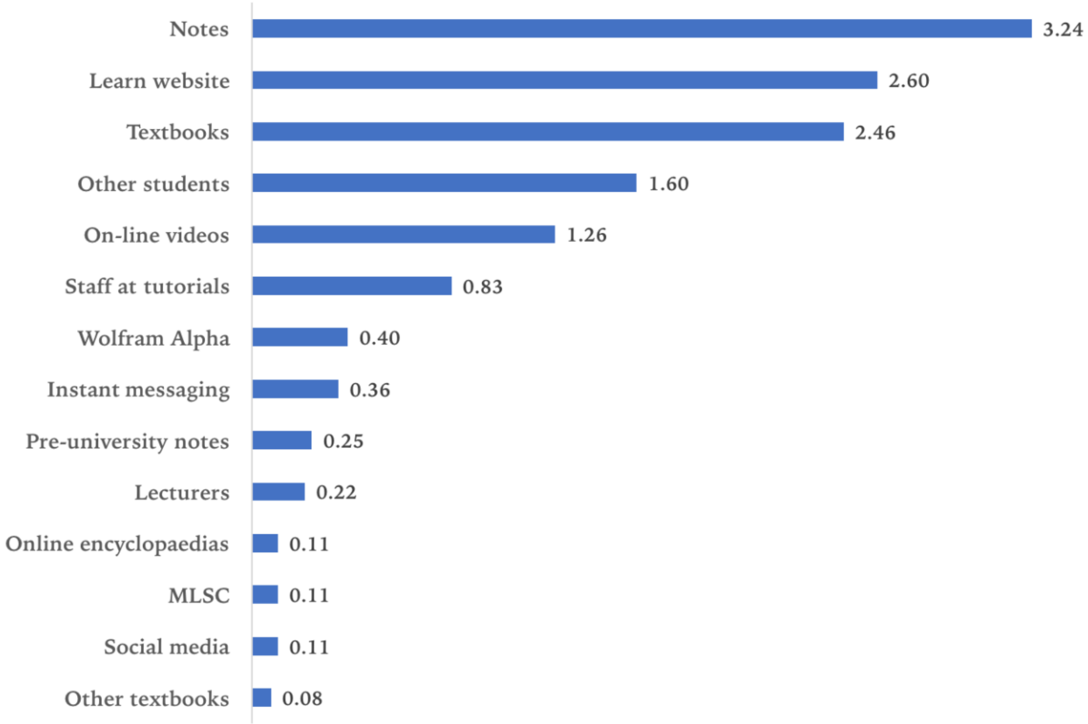

Figure 5.4: Scores of all students' top-5 list of resources.

Ranked data were also examined separately for engineering (Table 5.6) and mathematics students and (Table 5.7) and as before, a score for each resource was calculated in order to identify popular resources. As Figure 5.5 shows, the most popular resources among engineering students were textbooks, notes and the Learn website. These are followed by other students and online videos. Results for mathematics students were quite similar as Figure 5.6 shows, except that textbooks were not as popular as with engineering students.

Table 5.6: Engineering students' top-5 list of resources (accounting approximately 90% of choices).

	Top 1 (N=431)	Top 2 (N=426)	Top 3 (N=429)	Top 4 (N=421)	Top 5 (N=408)
Notes	36.00%	20.40%	11.70%	7.60%	
Textbooks	33.60%	27.70%	14.00%	7.40%	5.10%
Learn website	12.80%	15.30%	20.30%	11.90%	9.30%
Online videos	5.60%	10.30%	10.30%	11.20%	8.80%
Other students	2.60%	7.00%	14.20%	16.20%	18.90%
Wolfram Alpha		1.60%	4.40%	7.40%	6.60%
Instant messaging		1.60%	2.10%	3.60%	4.70%
Staff at tutorials		6.30%	7.20%	11.40%	12.70%
Lecturers			1.20%	3.60%	7.40%
Other textbooks			2.60%	3.60%	3.70%
MLSC					3.70%
Online encyclopaedias				2.60%	4.40%
Pre-university notes			3.00%	5.70%	4.90%
Cumulative Percentage	**90.60%**	**90.20%**	**91.00%**	**92.20%**	**90.20%**

Table 5.7: Mathematics students' top-5 list of resources (accounting approximately 90% of choices).

	Top 1 (N=189)	Top 2 (N=189)	Top 3 (N=189)	Top 4 (N=183)	Top 5 (N=176)
Notes	48.70%	20.10%	7.90%	2.20%	3.40%
Textbooks				4.40%	4.50%
Learn website	36.50%	27.50%	13.80%	7.70%	
Online videos		11.10%	11.10%	10.90%	8.00%
Other students	4.20%	21.20%	20.60%	16.90%	14.20%
Wolfram Alpha			8.50%	9.30%	8.00%
Instant messaging	3.20%	4.80%	6.90%	7.10%	7.40%
Staff at tutorials		2.10%	10.60%	14.80%	13.10%
Lecturers		2.10%	3.70%	7.10%	6.30%
Social media		2.60%	2.10%	3.30%	6.80%
Other textbooks			2.60%	1.60%	
MLSC					5.70%
Online encyclopaedias				3.80%	7.40%
Pre-university notes			3.70%	2.20%	7.40%
Cumulative Percentage	**92.60%**	**91.50%**	**91.50%**	**91.30%**	**92.20%**

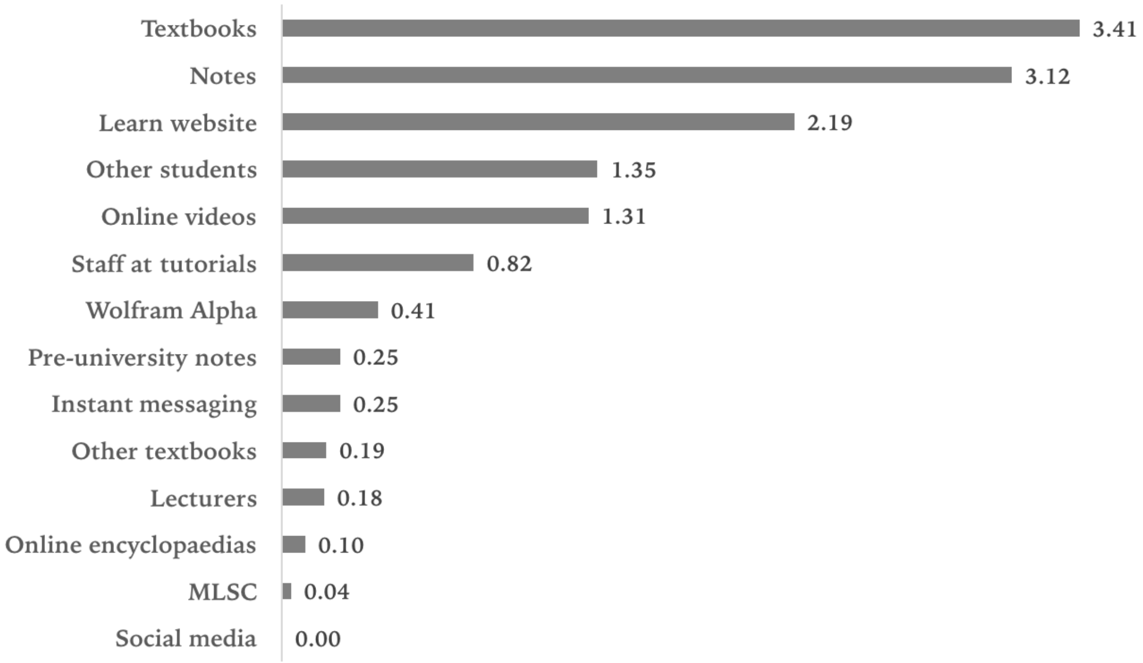

Figure 5.5: Engineering students' scores for their top-5 list of resources.

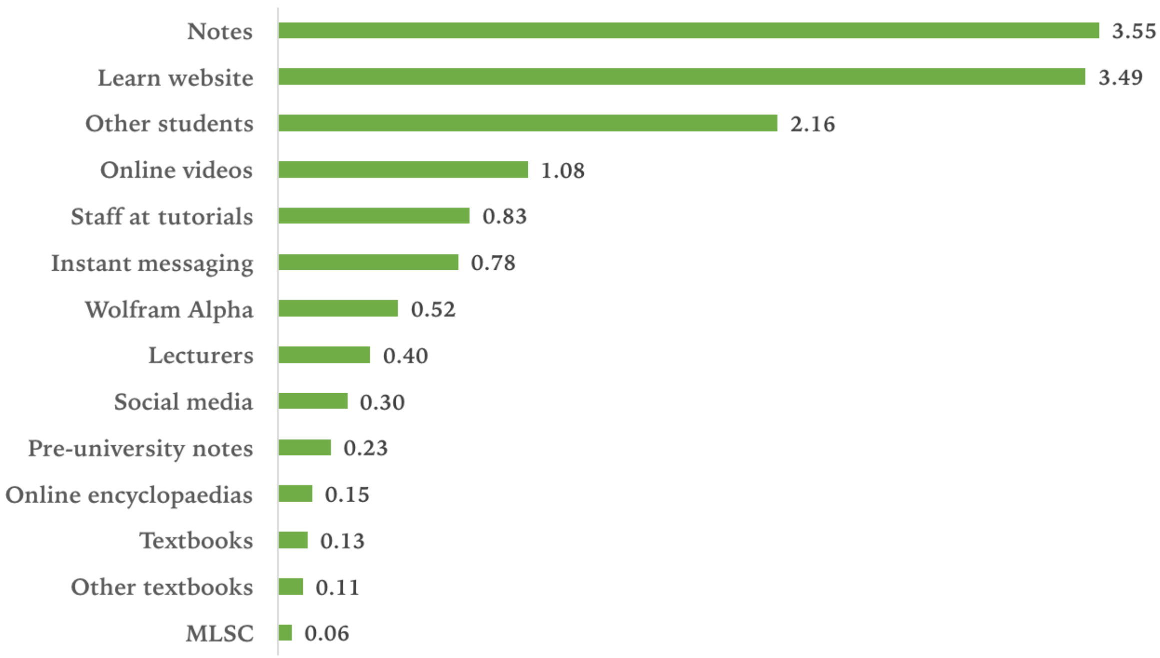

Figure 5.6: Mathematics students' scores for their top-5 list of resources.

5.2.1.4 Summary and Discussion

In answering my first research question (what tools do undergraduates use when studying mathematics?), descriptive statistics for the entire sample (N=606) were examined. Among a predetermined list of 15 tools, four of them were found to be particularly popular among undergraduates: their notes (M=4.77[29]), the Learn website (M=4.71), other students (M=4.16) and textbooks (M=4.12). These tools were followed in popularity by staff at tutorials (M=3.55) and online videos (M=3.50). Similar results were also found when the ranked data (top-5) were examined (Figure 5.4); the most popular tools included students' notes (score=3.24), the Learn website (score=2.60) and textbooks (score=2.46).

Due to the differences of mathematics and engineering students' activities, it was hypothesised that these two groups would use tools differently. This hypothesis was verified for 7 tools: textbooks, other textbooks, instant messaging, the Learn website, Wolfram Alpha, other students, and online encyclopaedias. In particular (Table 5.4), engineering students (N_{eng}=420) were found to use textbooks substantially more (M_{eng}=4.94, M_{maths}=2.25) and to a smaller degree other textbooks (M_{eng}=2.56, M_{maths}=2.17), while for mathematics students (N_{maths}=186) it was found that they use more instant messaging (M_{eng}=2.58, M_{maths}=3.37), the Learn website (M_{eng}=4.48, M_{maths}=5.23), Wolfram Alpha (M_{eng}=2.73, M_{maths}=3.15), other students (M_{eng}=4.03, M_{maths}=4.43) and online encyclopaedias (M_{eng}=2.18, M_{maths}=2.53). Again, examination of the ranked data revealed a similar picture: engineering students (Figure 5.5) ranked higher textbooks (score=3.41), their notes (score=3.12) and the Learn website (score=2.19), whereas mathematics students (Figure 5.6) ranked higher their notes (score=3.55), the Learn website (score=3.49) and other students (score=2.16).

Differences between mathematics and engineering students are not surprising and they can be explained in terms of the different way that each course is structured. First, mathematics students (single and joint honours) have substantially more modules with mathematical content (engineering students have one or two modules per academic year) and thus it is reasonable finding them using the Learn website, Wolfram Alpha or online encyclopaedias more. This could also explain why mathematics students communicate more with their peers (either in person or with instant messaging apps): mathematics students simply spend more time doing mathematics (either individually or collaborative) than their engineering peers[30]. Finally, engineering students are provided freely with a main textbook for their mathematics modules (the HELM workbooks) while mathematics students are provided only with a list of recommended textbooks that they can borrow from the university's library. From an Activity Theory perspective, the differences between mathematics and engineering students can be accounted by the *different rules* that their activity systems have (different course structure, different available resources).

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[29] 1: never using the tool; 6: always using the tool when studying mathematics.

[30] Students were specifically asked to report on the tools they use for their mathematics modules only.

5.2.2 How can tools used by undergraduates be categorised?

As we saw in section 5.2.1, undergraduates used mostly tools that they are provided with (e.g. textbooks, Learn website) and to some extent others found outside their institution (e.g. Wolfram Alpha, online videos). Having in mind the diversity of tools used in mathematics education since the 1800s and the bloom of new technologies during the last 20 years, it is reasonable to assume that if this study was conducted in a different era and/or culture then results would be different. In my view, some of the limitations related to the temporal and cultural characteristics of my study's context can be detoured by creating a *typology* of the tools that undergraduates in my sample reported using. Such an approach would go beyond the temporal/cultural specificities of a resource and would offer a more meaningful answer to the question "what tools do undergraduates use?". In essence, here I argue that it is more important to be able to categorise the tools that undergraduates use and know to which *category* a tool belongs, rather than identifying these tools per se. This is mainly because tools used for the learning of mathematics may change/disappear over time but generally speaking a typology of tools would be more stable since culture advances in a less rapid rate than new resources/technologies appear[31].

So how does one go about creating such a typology? Should one base such a categorisation on an a *priori* criterion i.e. according to the nature (e.g. physical, digital), the division (e.g. institutionally provided, external) or the *actual/reported use* of a tool? For the purposes and focus of my study the most appropriate answer to that question was to use an empirical based criterion i.e. produce *a typology of tools that reflects their actual use as reported by students*. Since the data capturing a tool's use were quantitative in nature (survey data) Exploratory Factor Analysis (EFA) was chosen as the suitable statistical method for producing the typology of tools.

5.2.2.1 Introduction to Exploratory Factor Analysis (EFA)

EFA is a statistical procedure for grouping together variables that have something in common (i.e. they correlate) and it is similar to what Thematic Analysis and Grounded theory do for qualitative data (Teddlie and Tashakkori, 2013). The whole process of EFA, enables researchers to identify latent constructs in the data that cannot otherwise be measured directly; each group of variables is then called a "factor" and the variables constituting each factor are thought to be measuring *the same underlying construct* (Field, 2013). In order to perform an EFA the following steps are required (Coolican, 2009): (1) a sample of people is measured on several variables; (2) correlations between every possible pair of variables are calculated and arranged in a matrix (called the **R** Matrix or simply the Correlation Matrix); (3) the matrix of correlations is fed into the factor analysis program (which looks for groups of variables that all correlate well together) and a solution is offered; (4) when the most economical or elegant explanation of the data is reached, the factors that

[31] Nevertheless, I acknowledge that there might be resources that cause changes in the culture, new groups of resources to emerge, others to merge or even disappear.

emerge are recognised and named intuitively[32]. It is worth noting that the actual basis of EFA is not the scores on measured variables but rather the Correlation Matrix **R** and as such, all steps of EFA can be accomplished even without access to the original data (Thompson, 2004).

My main sources for performing the Exploratory Factor Analysis (EFA) were Field (2013), Tabachnick and Fidell (2013), Stevens (2002) and Rummel (1970). In order to reach a final solution, a number of EFAs was performed and each time I examined whether certain criteria were met; if necessary, variables were excluded from the subsequent analyses. The overall procedure consisted of two main steps: first I inspected the suitability of data by carrying out a number of initial checks (Table 5.8); and then the main analysis was performed which included (i) determining the number of factors present in the data; (ii) identifying the number of variables per factor; and finally (iii) naming the factors found (Table 5.9).

Table 5.8: The first step of the analysis included checking the factorability of R and the fit of model with data.

Requirement	Matrix/test to check	Criterion used
Factorability of R	R (matrix of correlations between variables)	The matrix should include several sizable correlations; if no correlations greater than .3 are found reconsider using EFA (Field, 2013)
		Numerous pairs of correlations in the matrix should be significant (Field, 2013)
		The determinant should be greater than .00001 (Field, 2013)
	Anti-Image Correlation Matrix (contains the negative of partial[33] correlations between pairs of variables, used to assess the KMO statistics for each variable)	Individual KMO statistics (diagonal elements) should be greater than .5 (Field, 2013)
		Partial correlations (off-diagonal elements) should have small values (Field, 2013)
	Bartlett's test of Sphericity (tests the null hypothesis that the R matrix of the population is the identity matrix)	The test should be significant (rejecting the null hypothesis) (Field, 2013)
	Kaiser-Meyer-Olkin measure of sampling adequacy	Should be greater than .5 (Field, 2013)
Fit of model with data	Reproduced correlations matrix	Non redundant residuals should be smaller or equal to 50% for the EFA to be valid (Field, 2013)

[32] More details on the ways that EFA results are interpreted will be discussed in section 5.3.3

[33] A measure of the relationship between two variables while 'controlling' the effect of one or more additional variables on both.

Table 5.9: The second step of the analysis included deciding on the numbers of factors to be kept, the number of variables per factor and naming the factors.

PROCEDURE	CRITERION
Number of factors (Field, 2013)	- If communalities are greater than .30 and variables are less than 30: use Kaiser's criterion - If the average of communalities is .60 and the sample size sample greater than 250: use Kaiser's criterion - If the sample size is greater than 200: use the Scree plot
Number of variables per factor	- Identify which loadings are statistically significant (Stevens, 2002) - Of those loadings that are significant, use .3 (Tabachnick & Fidell, 2013) or .4 (Stevens, 2002) as a cut off value for the final number of variables per factor depending on the sample size.
Name the factors	- Name factors in a descriptive, causal or symbolic way (Rummel, 1970).

5.2.2.2 Exploratory Factor Analysis Results

Initial Analysis

Initially, an EFA (principal axis factoring) was performed on all the 14 variables for a sample of 606 cases in a listwise manner. My main focus at this stage of analysis was to check the suitability of data, determine the number of factors and identify whether there were variables that should be excluded from the final analysis. I tried both oblique (Direct Oblimin) and orthogonal (Varimax) rotations and results yielded the same factor structure. However, since correlations between factors in the case of the oblique rotation were weak (below the .3 range), I decided to proceed with an orthogonal rotation (Varimax).

Inspection of the **R** matrix (Table 5.10) provided evidence for its factorability: the matrix had numerous significant correlations near or above .3; its determinant was well above .00001; the Kaiser-Mayer-Olkin measure verified the sampling adequacy for the analysis (KMO=.725) and Bartlett's test of Sphericity was found to be significant ($\chi^2(91)=1249.9$, $p<.001$). All but one individual KMO values (Table 5.11) were found to be well above .5; the variable "recommended textbooks/HELM Workbooks" had an individual KMO of .491 but since its value was very close to .5, it was decided to be also included in the main analysis. Finally, all partial correlations in the Anti-Image Correlation Matrix (Table 5.11) had small values and nonredundant residuals were well below the recommended 50% threshold (5%) suggesting a good fit of the model with the data. The above described screening suggested that the **R** matrix was factorable and I therefore procced in identifying the number of factors and the factor structure. Because of the sample size (N=606) the scree plot was chosen as the criterion for identifying the number of factors in the data; an inspection of the scree plot suggested the presence of 4 factors (Figure 5.7, number of dots on the left of the intersection point). Examination of the Rotated Factor Matrix (Table 5.12) revealed a clear and meaningful structure of the factors. However, the variables "own written lecture notes' and "pre-university notes" had loadings below .3 and it was decided to be both excluded from the following analysis.

Table 5.10: Correlations between tools (R matrix).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) Notes[34]	**1**													
(2) Online videos	.05	**1**												
(3) Textbooks[35]	-.01	.08	**1**											
(4) Social Media	.05	.09	-.01	**1**										
(5) Learn website	.11**	.16***	-.16***	.16***	**1**									
(6) Online Encycl.	-.01	.25***	-.11**	.13**	.24***	**1**								
(7) Instant messaging	.12***	.16***	-.14***	.45***	.13***	.20***	**1**							
(8) Other textbooks	.00	.17***	.24***	.02	.07	.11**	.06	**1**						
(9) Wolfram Alpha	.04	.24***	-.08	.07	.22***	.27***	.07	.13**	**1**					
(10) Pre-univ. notes[36]	.13***	.10**	.13**	.12**	.11	.00	.15***	.26***	.14***	**1**				
(11) Other students	.16***	.15***	-.05	.34***	.24***	.09**	.51***	.04	.12**	.24***	**1**			
(12) Lecturers	.15***	.16***	.00	.12***	.24***	.15***	.12***	.27***	.17***	.23***	.21***	**1**		
(13) Staff at tutorials	.16***	.08	.11**	.17***	.11**	-.03	.14***	.10**	.05	.16***	.25	.36***	**1**	
(14) MLSC[37]	.09	.21***	.05	.09	.15***	.05**	.08	.29***	.17***	.21***	.11**	.45***	.32***	**1**

*** $p \le .001$. ** $p \le .01$. Determinant = .124

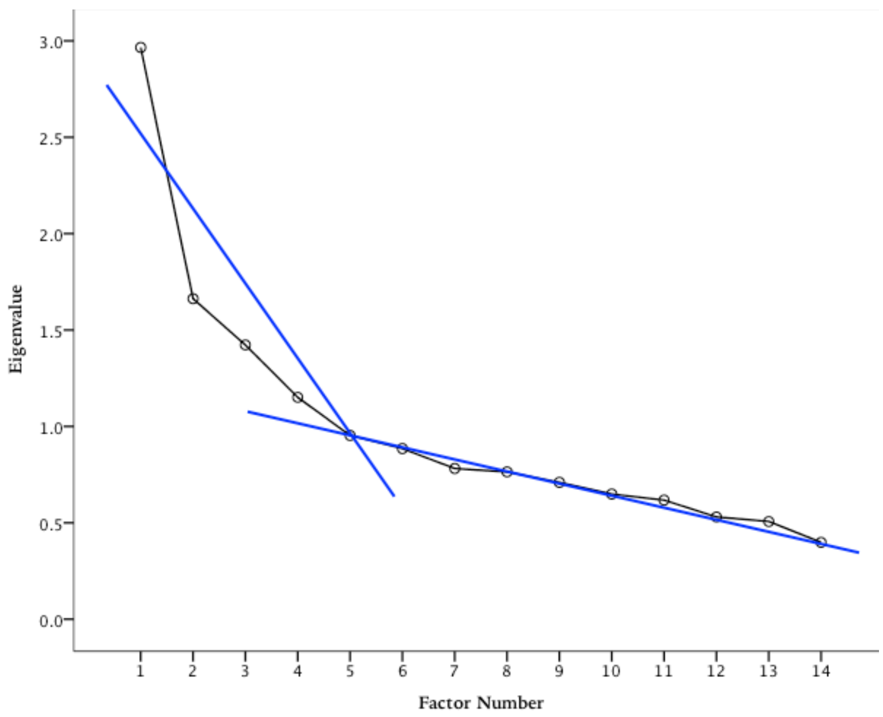


Figure 5.7: Scree plot for the first EFA indicating the presence of 4 Factors.

[34] Students' own written lecture notes

[35] Recommend textbooks/HELM workbooks

[36] Pre-university notes

[37] Mathematics Learning Support Centre (MLSC)

Table 5.11: Anti-image Correlation Matrix for the first EFA.

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Anti-image Correlation	(1) Notes	**.78**[a]	-.01	.00	.05	-.06	.04	-.06	.05	.00	-.08	-.05	-.07	-.08	.00
	(2) Online videos	-.01	**.77**[a]	-.12	.02	-.05	-.18	-.07	-.06	-.15	.01	-.05	.00	.01	-.12
	(3) Textbooks	.00	-.12	**.49**[a]	-.07	.15	.07	.17	-.23	.09	-.10	-.01	.05	-.12	.03
	(4) Social Media	.05	.02	-.07	**.75**[a]	-.08	-.04	-.34	.05	.00	-.03	-.11	-.01	-.07	-.02
	(5) Learn website	-.06	-.05	.15	-.08	**.77**[a]	-.15	.07	-.01	-.10	-.02	-.15	-.12	-.01	-.02
	(6) Online Encycl.	.04	-.18	.07	-.04	-.15	**.67**[a]	-.14	-.07	-.19	.07	.06	-.10	.09	.06
	(7) Instant messaging	-.06	-.07	.17	-.34	.07	-.14	**.65**[a]	-.07	.06	-.03	-.40	.03	-.02	.01
	(8) Other textbooks	.05	-.06	-.23	.05	-.01	-.07	-.07	**.69**[a]	-.04	-.17	.06	-.15	.06	-.17
	(9) Wolfram Alpha	.00	-.15	.09	.00	-.10	-.19	.06	-.04	**.76**[a]	-.09	-.04	-.02	.01	-.08
	(10) Pre-univ. notes	-.08	.01	-.10	-.03	-.02	.07	-.03	-.17	-.09	**.79**[a]	-.14	-.07	-.01	-.07
	(11) Other students	-.05	-.05	-.01	-.11	-.15	.06	-.40	.06	-.04	-.14	**.73**[a]	-.06	-.13	.04
	(12) Lecturers	-.07	.00	.05	-.01	-.12	-.10	.03	-.15	-.02	-.07	-.06	**.77**[a]	-.24	-.30
	(13) Staff at tutorials	-.08	.01	-.12	-.07	-.01	.09	-.02	.06	.01	-.01	-.13	-.24	**.75**[a]	-.18
	(14) MLSC	.00	-.12	.03	-.02	-.02	.06	.01	-.17	-.08	-.07	.04	-.30	-.18	**.76**[a]

Note. Individual KMO values (a) are in boldface (main diagonal of the Anti-image correlation matrix). Off diagonal elements represent partial correlations.

Table 5.12: Rotated Factor Matrix for the first EFA (Factor loadings for EFA with Varimax rotation).

	Factors			
	1	2	3	4
Instant messaging	**.77**	.05	.16	-.03
Other students	**.64**	.25	.10	-.01
Social Media	**.53**	.10	.10	.02
Lecturers	.05	**.65**	.26	.10
MLSC	-.01	**.55**	.22	.21
Staff at tutorials	.18	**.53**	-.05	.10
Notes	.14	.23	.00	-.03
Online Encyclopaedias	.12	-.07	**.60**	-.04
Wolfram Alpha	.03	.12	**.47**	.01
Online videos	.12	.09	**.40**	.19
Learn website	.15	.24	**.38**	-.15
Textbooks	-.06	.01	-.16	**.56**
Other textbooks	-.01	.21	.24	**.51**
Pre-university notes	.19	.28	.09	.28

Note. Factor loadings >.35 are in boldface.

Final Analysis

A final EFA was performed on the remaining 12 variables (removed variables: notes and pre-university notes) on a sample of 612 cases[38]. Factorability of **R** was examined by performing the same screening procedures as previously: determinant's value was found greater than the suggested limit of .00001 (.159); the Kaiser-Mayer-Olkin measure verified the sampling adequacy for the analysis (KMO=.7) and Bartlett's test

[38] Because variables were treated in listwise manner, a different number of cases was available in each analysis.

of Sphericity was found to be significant ($\chi^2(66)=1114.5$, $p<.001$); all but one individual KMO values were found to be well above .5 (Table 5.13); and nonredundant residuals were 4% (well below the 50% cut off value). Again the individual KMO value for the variable "recommended textbooks/HELM workbooks" was found to be slightly below the suggested limit of .5 (.47) but the variable was decided to be kept in the analysis because: (1)the value was close to .5; (2) individual KMO statistics are particularly useful for identifying problematic variables *if* the overall KMO statistic is unsatisfactory (Field, 2013); (3) the overall KMO statistic value was greater than the .5 cut-off value; (4) the factor solution (described later) was meaningful and logical; (5) the factor loading for this variable was high enough (see Table 5.14). Because of the sample size (N=612) the scree plot was chosen as the criterion for identifying the number of factors in the data; an inspection of the scree plot suggested the presence of 4 factors (Figure 5.8).

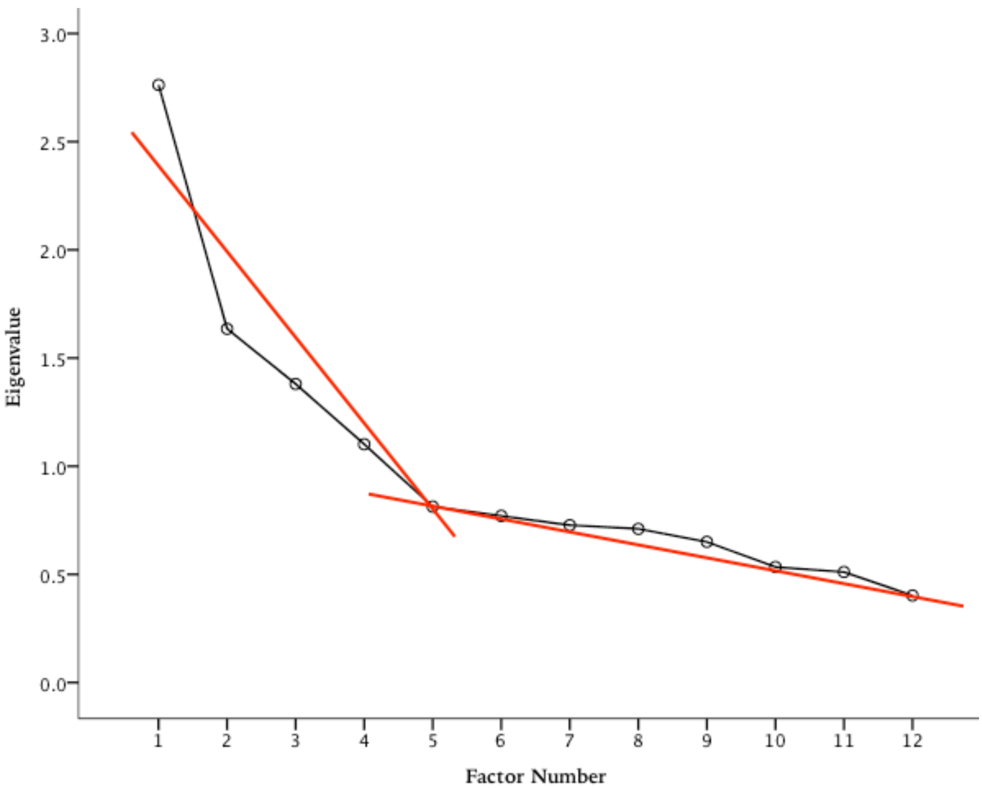


Figure 5.8: Scree plot for the second EFA indicating the presence of 4 Factors.

Table 5.13: Anti-image Correlation Matrix for the final EFA.

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Anti-image Correlation	(1) Textbooks	**.47**[a]	-.12	-.08	.14	.06	.17	-.26	.07	-.03	.05	-.13	.02
	(2) Online videos	-.12	**.77**[a]	.02	-.05	-.17	-.07	-.05	-.15	-.05	.00	.01	-.12
	(3) Social Media	-.08	.02	**.75**[a]	-.08	-.04	-.34	.04	-.01	-.11	-.01	-.07	-.02
	(4) Learn website	.14	-.05	-.08	**.76**[a]	-.15	.07	-.01	-.11	-.16	-.13	-.01	-.02
	(5) Online Encycl.	.06	-.17	-.04	-.15	**.69**[a]	-.14	-.05	-.18	.07	-.09	.09	.06
	(6) Instant messaging	.17	-.07	-.34	.07	-.14	**.64**[a]	-.07	.05	-.41	.02	-.02	.01
	(7) Other textbooks	-.26	-.05	.04	-.01	-.05	-.07	**.66**[a]	-.05	.04	-.16	.05	-.19
	(8) Wolfram Alpha	.07	-.15	-.01	-.11	-.18	.05	-.05	**.76**[a]	-.05	-.03	.01	-.08
	(9) Other students	-.03	-.05	-.11	-.16	.07	-.41	.04	-.05	**.71**[a]	-.08	-.14	.03
	(10) Lecturers	.05	.00	-.01	-.13	-.09	.02	-.16	-.03	-.08	**.74**[a]	-.24	-.30
	(11) Staff at tutorials	-.13	.01	-.07	-.01	.09	-.02	.05	.01	-.14	-.24	**.72**[a]	-.19
	(12) MLSC	.02	-.12	-.02	-.02	.06	.01	-.19	-.08	.03	-.30	-.19	**.73**[a]

Note. Individual KMO values (a) are in boldface (main diagonal of the Anti-image correlation matrix). Off diagonal elements represent partial correlations.

Table 5.14: : Rotated Factor Matrix for the final EFA (Factor loadings for EFA with Varimax rotation).

	Factors			
	1	2	3	4
Instant messaging	**.77**	.02	.15	-.06
Other students	**.63**	.19	.11	-.05
Social Media	**.55**	.08	.09	.01
Lecturers	.10	**.67**	.22	.00
MLSC	.02	**.61**	.18	.11
Staff at tutorials	.22	**.52**	-.08	.09
Online Encyclopaedias	.12	-.03	**.58**	-.05
Wolfram Alpha	.03	.14	**.48**	-.04
Online videos	.12	.12	**.43**	.18
Learn website	.16	.21	**.36**	-.19
Textbooks	-.05	.06	-.12	**.68**
Other textbooks	-.01	.29	.22	**.35**

Note. Factor loadings >.30 are in boldface.

Examination of the Rotated Factor Matrix (Table 5.14) revealed a clear and meaningful structure of the factors. The 4 extracted factors had eigenvalues of 2.76, 1.63, 1.38 and 1.10 respectively, and in combination they accounted for 57.33% of variance (Table 5.15). Each of the four extracted factors included the following variables:

- **Factor 1**: instant messaging, other students, social media
- **Factor 2**: lecturers, MLSC, staff at tutorials
- **Factor 3**: online encyclopaedias, Wolfram Alpha, online videos, Learn website
- **Factor 4**: textbooks, other textbooks

Table 5.15: A summary of the final EFA results (Factors, eigenvalues and variance explained)

	Factor 1	Factor 2	Factor 3	Factor 4
Instant messaging	**.77**	.02	.15	-.06
Other students	**.63**	.19	.11	-.05
Social Media	**.55**	.08	.09	.01
Lecturers	.10	**.67**	.22	.00
MLSC	.02	**.61**	.18	.11
Staff at tutorials	.22	**.52**	-.08	.09
Online Encyclopaedias	.12	-.03	**.58**	-.05
Wolfram Alpha	.03	.14	**.48**	-.04
Online videos	.12	.12	**.43**	.18
Learn website	.16	.21	**.36**	-.19
Textbooks	-.05	.06	-.12	**.68**
Other textbooks	-.01	.29	.22	**.35**
Eigenvalues	2.76	1.63	1.38	1.10
Variance explained	23.02%	13.63%	11.50%	9.18%
Total variance explained		**57.33%**		

5.2.2.3 Interpretation of Factors

Naming the Factors

Rummel (1970) notes that after a factor solution has been achieved, Factors can be named in three ways: descriptively, causally or symbolically. In the descriptive approach, factors are treated as descriptors of the interrelationships in the data. In this sense the factor structure offers ***a typology of the variables analysed*** and factors themselves are classifications to which descriptive names are assigned. When named causally, Factors are thought to reflect a common underlying influence causing the identified interrelationships between variables. Finally, in the symbolic approach Factors are labelled with symbolic tags (e.g. A, B or F_1, F_2) but they don't communicate any further meaning as in the previous two approaches. When naming factors, Rummel (1970) suggests that each Factor's name should reflect:

- what is a Factor (variables with high loadings) and what isn't (variables with zero, near-zero loadings)
- the relative contribution of each variable to the Factor belonging to. This can be calculated by squaring the Factor loadings for each variable. For example, a variable with a .57 loading on a Factor has a 0.3249 relative weight or a 32.49% overlap with the Factor

For the purposes of this section (producing a typology of resources) I will follow the descriptive approach: I will therefore choose names for each Factor in a way that best reflect the tools included in each Factor. As we can see at Table 5.15, Factor 1 includes three tools (instant messaging, other students, social media) with the first two contributing more to the Factor; thus an appropriate name for this Factor is ***Messaging Apps and Peers***. In Factor 2 lecturers and the MLSC contribute more to this Factor, thus the chosen name is ***Teaching and Support staff*** because it includes both lecturers who have a teaching capacity and also staff not having a "direct" teaching capacity but rather their role is supporting students when needed (MLSC). Factor 3 includes only online resources, with online encyclopaedias and Wolfram Alpha scoring higher, whereas online videos and the Learn website have lower loadings. However, because the Learn website contributes less than the rest of the variables, this Factor reflects mostly online resources that are chosen by students but are not provided by the university. Thus, Factor 3 was named as ***external online* resources**. Finally, Factor 4 includes variables related to mathematical textbooks with the ones recommended/provided by the university scoring much higher than textbooks chosen by students (other textbooks): thus this Factor was named as ***the official textbook***.

5.2.2.4 Discussion and Summary

As we saw earlier, the basic rationale of doing an Exploratory Factor Analysis on the questionnaire data, was to propose an empirically-based typology of the tools that undergraduates use when studying mathematics. Consequently, one might ask "why do Factors represent different types of tools that undergraduates use?". My main argument in answering the above question, is that since the variables upon which the EFA was performed are related to using a tool[39] and the EFA as a procedure allows us to identify latent constructs in our data, then the Factors found here represent ***types of tools*** that undergraduates use when studying mathematics.

Before proceeding into proposing a typology, I would like here to discuss an interesting finding from the previously described EFA. As you may recall, the variables that had to be removed from the final analysis (own written lecture notes, pre-university notes) were similar in nature. If we carefully examine Table 5.12 (Rotated Factor Matrix), we can observe that albeit the variables "own written lecture notes" and "pre-university notes" have low factor loadings (and thus they should be excluded from the analysis), they are associated with Factors 2 (Teaching and support staff) and 4 (Textbooks). In particular, "own written lecture notes" have a .23 loading on Factor 2 and pre-university notes have a .28 loading on both factors 2 and 4. This is interesting for two main reasons: (1) both "types" of notes seem to be related to the "Teaching and Support staff" Factor because they can be primarily conceived as a result of student-teacher interactions; (2) since pre-university notes (e.g. A-level notes) are also related to "Textbooks" (Factor 4) and they most likely reflect student-teacher interactions that took place in the past, it is possible that pre-university notes serve a similar to Textbooks function e.g. they are used as a reference.

The above discussion suggests that besides the four identified Factors, there is another major type of tools that students use, that is their ***notes***. I acknowledge that from a statistical point of view, this is not a typical interpretation of EFA results and as such it has its limitations. However, because notes as a tool (either own written lecture notes or pre-university notes) are to some extent fundamentally different than the rest of the tools included in the EFA, I assume that this interpretation has a

[39] Students were asked how often they use a list of resources when studying for their mathematics modules.

certain degree of validity. Thus, I propose that the major types of tools that students reported using when studying mathematics are: ***peers*** (Factor 1: the purpose of using a messaging app is for communicating with a peer, thus in either case the "eventual" tool here is a peer); ***teachers*** (Factor 2: both teaching and support staff act as instructors to students either on an occasional basis -lecturers, staff at tutorials- or on a demand basis –MLSC-, thus this type of tool has a teaching capacity); ***external online*** **tools** (Factor 3); ***the official textbook*** (Factor 4); and ***students' notes*** (own written lecture notes, pre-university notes i.e. variables that were removed from the final EFA).

In sum, based on the EFA results and the discussion above, the tools that students in the sample (N=612) reported using can be classified into 5 categories: ***peers***, ***teachers***, ***external online tools***, ***textbooks*** and ***notes***. As we saw earlier in section 3.3.1, among the little theoretical accounts in the literature proposing a typology of tools is Wartofsky's hierarchy of artefacts. From a Wartofskian point of view, all the tools used by undergraduates when examined separately are primary. This is because (1) in a broad sense, these tools contribute to "the production of the means of existence and in the reproduction of the species" (Wartofsky, 1973, p.202) and indeed tertiary education (as any form of formal education) offers the means for the species to exist and reproduce; and (2) when examined in a more narrow sense, the activity of learning mathematics can be considered as a subset of what Wartofsky calls existence and reproduction of the species.

The second level of Wartofsky's hierarchy consists of secondary artefacts which are "representations of primary artefacts and of modes of action using primary artefacts" (Cole, 1996, p.121). This means that the proposed typology of tools here corresponds to the different *secondary artefacts* that undergraduates use when studying mathematics. Since secondary artefacts "synthesise the ways and procedures of using instruments and materials" (Miettinen, 1999, p.189) each type of tool acts as an exemplar of interacting with other people (the case of ***peers*** and ***teachers***), taking notes (the case of students' ***notes***), reading the official mathematical textbook (the case of ***textbooks***) or using online tools (***external online tools***).

The use of verbs above in justifying why the proposed typology corresponds to Wartofsky's secondary artefacts is intentional, because the typology of tools when examined from an Activity Theory (AT) perspective corresponds to ***thematically related actions*** that students undertake when studying mathematics. This is due to the fact that in AT as actions are accounted the "...specific interactions that people have with artefacts and other people..." (González, Nardi, & Mark, 2009) i.e. actions are the processes of *using* a physical tool (notes, textbooks, online tools) and/or *interacting* with other subjects (peers, teachers). The link between Wartofsky's hierarchy of artefacts and Leontiev's hierarchy of human activities has been already proposed by Engestrøm (1987) who notes that primary artefacts correspond to the level of operations/conditions, secondary artefacts correspond to the level of actions/goals and tertiary artefacts correspond to the level of activity/motive.

Table 5.16 summarises the above discussion: the left column corresponds to the typology of tools and the right column represents the interpretation of this typology as secondary artefacts from a Wartofskian perspective or as thematically related actions from an AT point of view. It is worth noting here that prior to my engagement with Wartofsky's theory, I wasn't able to establish a link between the typology of tools and AT; it was Wartofsky's hierarchy of artefacts and its interpretation by various scholars (e.g. Cole) that enabled me to create this link; in this sense Wartofsky's hierarchy had also a methodological contribution to my study.

Table 5.16: The proposed typology of tools (left) and its equivalence with secondary artefacts and actions (right).

Typology of Tools	**Secondary Artefacts (Wartofsky) - Actions (AT)**
(1) Peers	Interacting with peers
(2) Teachers	Interacting with teaching and support staff
(3) External online tools	Searching for additional/alternative sources of information
(4) The official textbook	Studying the official mathematical textbook
(5) Students' notes	Taking notes during a lecture

5.2.3 How can students be profiled according to their tool-use?

In order to identify the existence (or not) of different profiles of tool-use in the sample, a cluster analysis on the variables for the tools was performed. Cluster analysis is an umbrella term used for describing a family of statistical procedures designed to arrange objects into relatively homogeneous groups based on multivariate observations (Gore, 2000).

Overall, the analysis for identifying tool-use profiles consisted of two main stages and was adopted from Mindrila (2016). First, a hierarchical cluster analysis using Ward's method with a squared Euclidean distance metric was performed as an initial estimation of the number of clusters. Results (number of clusters) were then used as an input for performing a K-means cluster analysis (this method assumes that the number of clusters is known). The main reason for following the above procedure is due to the fact that with Ward's method once a case is assigned to a cluster it cannot be reassigned to another one at a later stage (when for example, a case is less representative for a particular cluster), something that the K-means method is able to do.

5.2.3.1 Initial analysis: hierarchical cluster analysis

A hierarchical cluster analysis with Ward's method and squared Euclidean distance for a total of 606 cases (listwise) was initially performed on all 14 variables for tools. The number of clusters was determined by following the approach described by Yim and Ramdeen (2015) and included examination of the Agglomeration Schedule and dendrogram. By using the Agglomeration Schedule, a scree plot of the Agglomeration coefficients against the cluster analysis stages was plotted for determining at which stage the clusters become heterogeneous (indicated by a large difference between two consequent coefficients) and thus when the analysis should be stopped. A visual examination of the scree plot indicated a large difference between two points representing stages 603 (red "x" marker in the scree plot, Figure 5.9) and 604. This suggested terminating the analysis after stage 603, i.e. excluding the last 4 stages (607, 606, 605, 604) and thus obtaining a 5 cluster solution (indicated by a dashed red line in the dendrogram, Figure 5.10). Similarly, a visual examination of the dendrogram (Figure 5.10) suggested that the most appropriate number of clusters is 5 (number of times that the red line intersects with the dendrogram's horizontal lines). This was because the horizontal lines in the dendrogram are a measure of the dissimilarity between clusters and thus an indication whether merging of two clusters should take place. For example, if at stage 606 the two cluster are merged this would result a heterogeneous new cluster because the length of the horizontal lines is relatively large.

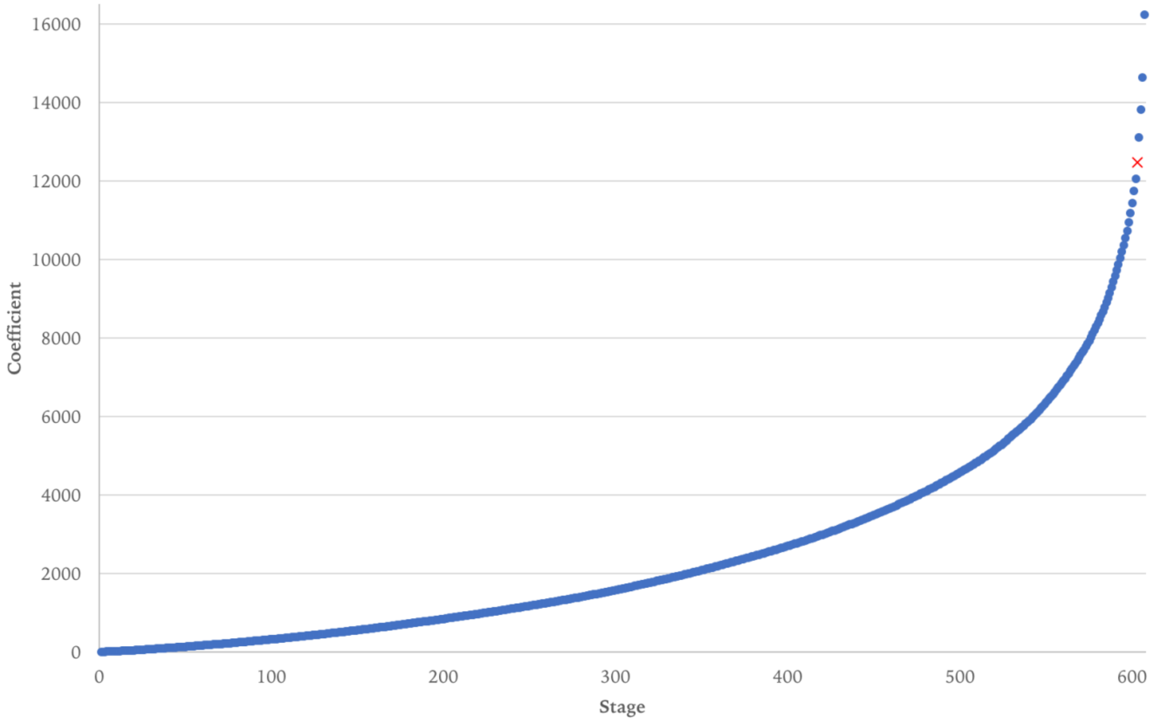


Figure 5.9: Plot of Agglomeration coefficients versus the stages of cluster analyisis.

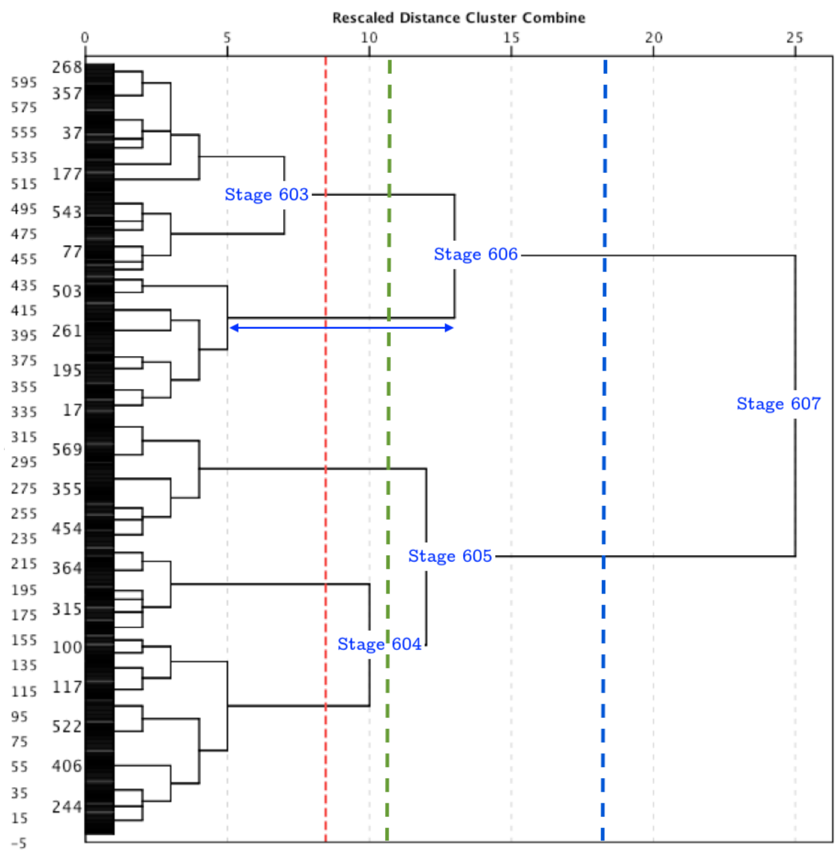


Figure 5.10: Dendrogram for the hierarchical cluster analysis. The vertical dashed lines indicate the suggested cluster solutions (blue: 2; green: 4; red: 5). The length of the horizontal lines (e.g. the blue horizontal line with arrows) indicate how heterogeneous clusters become after being merged.

5.2.3.2 *Main analysis: K-means*

The K-means cluster analysis was performed on the 14 variables for tools by requesting a 5 cluster solution (k=5). Descriptive statistics for each cluster are presented at Table 5.17 and Figure 5.11.

Table 5.17: Descriptive statisitcs (mean) for the five cluster profiles. Values in bold indicate the highest mean among clusters

Tool	C1 (N=107)	C2 (N=128)	C3 (N=107)	C4=(137)	C5 (N=127)
Notes	4.91	4.45	**5.27**	4.54	4.87
Pre-university notes	2.60	1.99	**3.71**	2.12	2.72
Textbooks	3.51	2.77	4.36	4.69	**5.12**
Other textbooks	1.97	1.71	**3.55**	2.14	2.95
Online videos	3.38	3.69	**4.27**	2.37	3.96
Online Encyclopaedias	2.26	2.62	**2.91**	1.64	2.09
Wolfram Alpha	1.90	3.95	**5.00**	1.74	2.00
Learn website	4.88	5.09	**5.21**	3.75	4.79
Instant messaging	**4.77**	2.15	3.77	1.61	2.43
Other students	**5.20**	3.79	4.88	3.07	4.24
Social Media	**3.37**	1.84	2.55	1.38	2.20
Lecturers	2.36	2.30	**3.74**	1.80	3.50
Staff at tutorials	3.64	2.88	4.12	3.04	**4.17**
MLSC	1.66	1.73	**3.07**	1.40	3.04

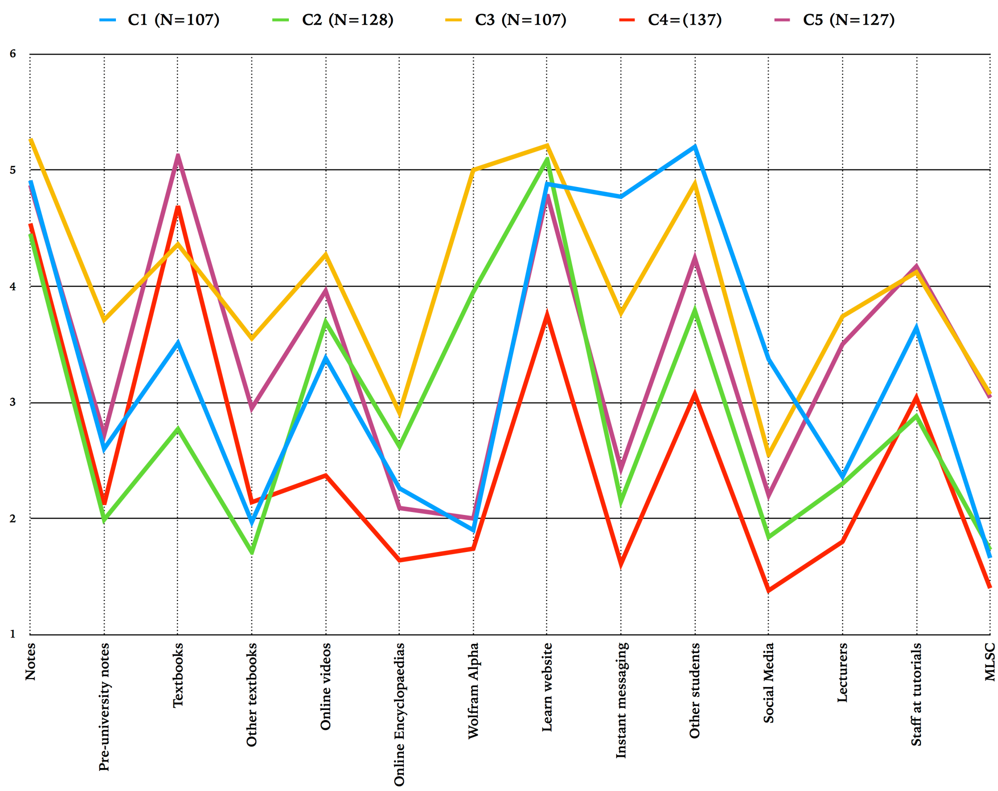


Figure 5.11: Line graphs for the identified cluster which allow a graphical comparison of the differences between clusters for each tool. Note that there is no natural order to the x axis; the graph is purely used for interpreting results.

5.2.3.3 *Description of clusters in terms of tool-use*

In describing the typical tool-use of students within each cluster, variables for tools were first arranged according to the typology presented at section 5.2.2 (notes, textbooks, online tools, peers and teachers). Then for each tool and cluster the difference from the sample's total mean (descriptive statistics, section 2.2.1, Table 5) was calculated; this reflected whether students in a cluster were having a mean above (positive) or below (negative) the sample's total mean for each tool, i.e. mean's difference = cluster's mean – total mean. For example, for cluster 1 and the tool online videos, the calculated value for the mean's difference was 3.38-3.50=-0.12, which meant that this cluster's use of online videos was slightly below the total mean. Results for each cluster and tool are presented at Table 5.18 below. The final step included the visual inspection and interpretation of a bar-chart created from Table 5.18 (Figure 5.12) which resulted the identification of each cluster's tool-use characteristics.

Table 5.18: Descriptive statistics for the five cluster profiles based on the difference between each cluster's mean and the sample's total mean (for each tool).

	C1 (N=107)	C2 (N=128)	C3 (N=107)	C4 (N=137)	C5 (N=127)
Notes	0.13	-0.33	0.49	-0.24	0.09
Pre-university notes	0.02	-0.59	1.13	-0.46	0.14
Textbooks	-0.60	-1.34	0.25	0.58	1.01
Other textbooks	-0.47	-0.73	1.11	-0.30	0.51
Online videos	-0.12	0.19	0.77	-1.13	0.46
Online Encyclopaedias	-0.02	0.34	0.63	-0.64	-0.19
Wolfram Alpha	-0.97	1.08	2.13	-1.13	-0.87
Learn website	0.17	0.38	0.50	-0.96	0.08
Instant messaging	1.94	-0.68	0.94	-1.22	-0.40
Other students	1.04	-0.37	0.72	-1.09	0.08
Social Media	1.17	-0.36	0.35	-0.82	0.00
Lecturers	-0.34	-0.40	1.04	-0.90	0.80
Staff at tutorials	0.10	-0.66	0.58	-0.50	0.63
MLSC	-0.49	-0.42	0.92	-0.75	0.89

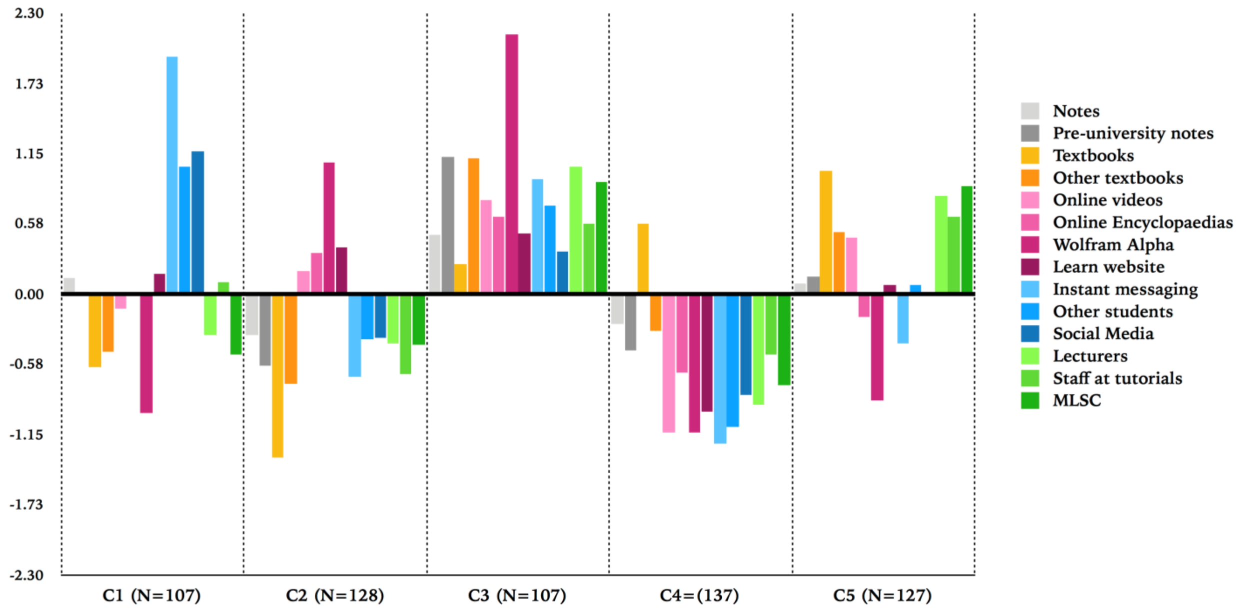


Figure 5.12: Deviations from the total average for each cluster and tool. Tools are organised into groups: notes (grey shaded), textbooks (orange shaded), online tools (magenta shaded), peers (blue shaded) and teachers (green shaded).

Cluster 1 (N=107) groups those undergraduates who reported using above average the tools instant messaging, other students and social media. Moreover, they had the highest tool-use across all clusters for these tools (instant messaging: M=4.77, other students: M=5.20, social media: M=3.37). For all the other tools, they reported using them below/slightly below average (textbooks, other textbooks, online videos, online encyclopaedias, lecturers, MLSC) or slightly above average (notes, pre-university notes, Learn website, staff at tutorials). Thus, cluster 1 represents students who preferred supporting their learning by using mostly tools related to interacting with their peers and consequently, this cluster was interpreted as the ***peer-learning group***.

In cluster 2 (N=128) are found the students who reported using above average online tools (online videos, online encyclopaedias, Wolfram Alpha, Learn website). This cluster's use of online tools was not particularly high when compared to other clusters (in particular with Cluster 3 who had the highest means across clusters for online tools) but the use above average of only online tools is what differentiates this cluster from the rest. Hence, cluster 2 represents the students who chose to use mostly online tools when studying mathematics and it was interpreted as the ***online-learning group***.

Cluster 3 (N=107) groups students who reported using above average all the tools they had at their disposal. When compared to the other clusters, students in this group were found having the highest mean for notes (M=5.27), pre-university notes (M=3.71), other textbooks (M=3.55), online videos (M=4.27), online encyclopaedias (M=2.91), Wolfram Alpha (M=5.00), the Learn website (M=5.21), lecturers (M=3.74), staff at tutorials (M=4.12), and the MLSC (M=3.07). Because these students reported using a variety of different resources, cluster 3 was interpreted as the ***blended-learning group***.

Cluster 4 (N=137) represents students who used only one tool above average, that is textbooks. Students in this cluster had the lowest mean for online tools (online videos, online encyclopaedias, Wolfram Alpha, the Learn website), peers (instant messaging, other students, social media), lecturers and the MLSC. This suggests that these students were not interacting frequently with their peers or the university's teaching and support staff (lecturers, MLSC) and they had the lowest online presence when compared to the other clusters. Hence, cluster 4 was named as the ***predominantly textbooks-learning group***.

Finally, cluster 5 (N=127) groups students who used above average textbooks and other textbooks, online videos and teaching and support staff (lecturers, staff at tutorials, MLSC). For the rest of the tools, their use was average (social media), slightly above average (notes, pre-university notes, Learn website, other students), slightly below average (online encyclopaedias) or well below average (Wolfram Alpha, instant messaging). Hence, Cluster 5 was interpreted as the ***selective-learning group (textbooks, online videos and lecturers)***.

5.2.3.4 The composition of clusters: degree and year of studies

The make-up of the 5 clusters was explored in terms of students' degree (engineering, mathematics) and year of studies (first, second). Because in both cases the group sizes differed (N_{Maths}=179, N_{Eng}= 420; N_{first}=348, N_{second}= 258), the composition of each cluster was investigated according to the total number of students (engineering/mathematics, first/second year) found in the sample and not within each Cluster. To be more specific, the percentage of engineering/mathematics students found in each cluster was calculated by dividing the number of engineering/mathematics students in a cluster with the total number of engineering/mathematics students found in the sample. For example, in cluster 1 were found 55 engineering and 52 mathematics students which resulted a $(55/420)\times100=13.1\%$ percentage for engineers and a $(52/179)\times100\approx29.0\%$ percentage for mathematicians. Similarly, the percentage of first/second year students was calculated by dividing the number of first/second year students in a cluster with the total number of first/second year students found in the sample. For example, in Cluster 1 were found 78 first year and 29 second year students; this resulted a $(78/348)\times100\approx22.4\%$ percentage for first year students and a $(29/258)\text{x}100\approx11.2\%$ percentage for second year students. The make-up of each cluster in terms of students' degree is presented at Table 5.19 and Figure 5.13, and in terms of the year of studies at Table 5.20 and Figure 5.14.

Table 5.19: The make-up of clusters in terms of students' degree (engineering or mathematics).

	Engineering students	Mathematics students
Cluster 1 (Peers)	13.1%	29.0%
Cluster 2 (Online)	13.6%	38.2%
Cluster 3 (Blended)	16.9%	19.3%
Cluster 4 (Textbooks)	30.2%	5.4%
Cluster 5 (Selective)	26.2%	9.1%

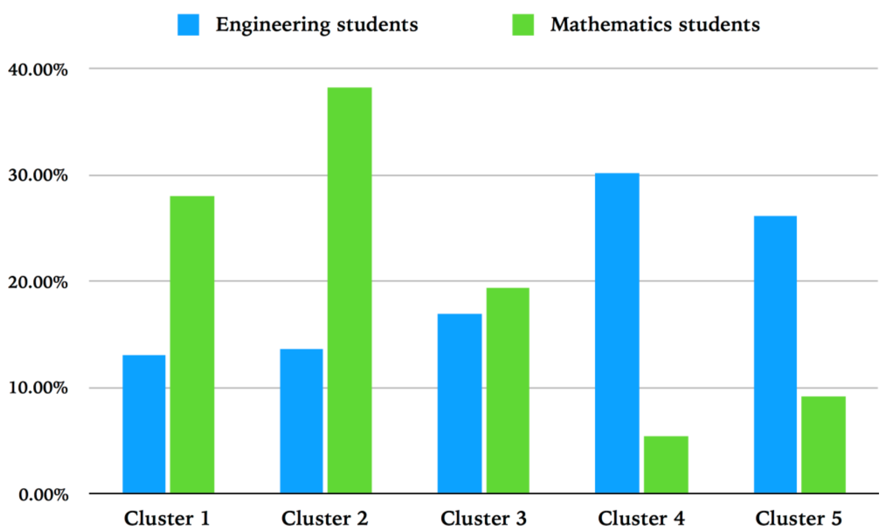


Figure 5.13: The make-up of clusters in terms of students' degree (engineering or mathematics).

Table 5.20: The make-up of clusters in terms of students' year of study (first or second).

	1st year students	2nd year students
Cluster 1 (Peers)	22.4%	11.2%
Cluster 2 (Online)	18.1%	25.2%
Cluster 3 (Blended)	13.2%	23.6%
Cluster 4 (Textbooks)	23.8%	20.9%
Cluster 5 (Selective)	22.4%	19.0%

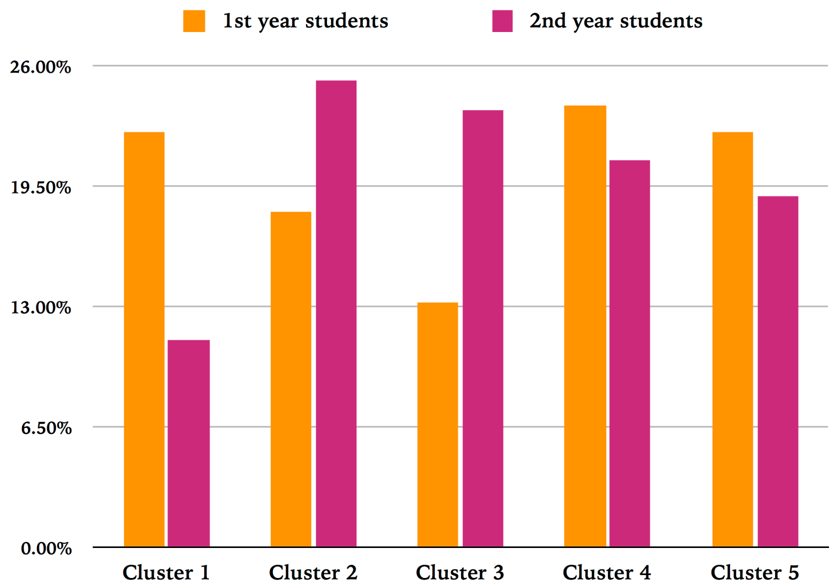


Figure 5.14: The make-up of clusters in therms of students' year of study (first or second).

A visual examination of Table 5.19 and Figure 5.13, showed that the majority of mathematics students (86.5%) were distributed across clusters 1, 2 and 3, whereas most of the engineering students (73.3%) were distributed in clusters 3, 4, and 5. A chi-squared test revealed a significant relationship between cluster membership and degree (engineering or mathematics), $\chi^2(4)=106.628$, $p<.001$.

In terms of the year of studies (Table 5.20, Figure 5.14), although a similar number of first and second year students was found in clusters 4 and 5, this was not the case for the rest of the clusters. In cluster 1 were found 22.4% of first year students and in clusters 2 and 3 25.2% and 23.6% of second year students respectively. A chi-squared test revealed a significant relationship between cluster membership and year of study (first or second), $\chi^2(4)=24.508$, $p<.001$.

5.2.3.5 Summary and Discussion

In answering my third research question (how can students be profiled according to their tool-use?), a Cluster analysis on the survey data was performed. This revealed 5 groups of students who combine different tools when studying mathematics: the ***peer-learning*** group (students using above average peers, instant messaging apps and social media); the ***online-learning*** group (students using above average online videos and encyclopaedias, Wolfram Alpha and the Learn website); the ***blended-learning*** group (students using above average all the tools at their disposal); the ***predominantly textbooks-learning*** group (students using above average only textbooks); and the

selective-learning group (students using above average textbooks, online videos and lecturers). An examination of composition of the five clusters in terms of subject specialism (degree) and year of studies, revealed a significant relationship between cluster membership, degree and year of studies, suggesting that tool-use differences may be driven by discipline (degree) or year of studies.

5.2.4 What factors can account for undergraduates' tool choices?

5.2.4.1 Introduction to Multinomial Logistic Regression

Multiple regression is a statistical method (model) for testing whether a continuous outcome variable (Y) can be predicted by a linear combination of two or more predictor variables (X_1, X_2, … , X_n). Logistic regression is a version of multiple regression in which the outcome variable is categorical in nature; when the categorical variable has two categories (or groups) then the analysis is called *binary logistic regression*, whereas when the outcome has more than two categories (e.g. the 5 groups from cluster analysis) it is called *multinomial logistic regression* (Field, 2013). Multinomial logistic regression has similar assumptions to multiple regression, in particular (Field et al., 2012; Tabachnick and Fidell, 2013):

- **Linearity**: logistic regression assumes that there is a linear relationship between any continuous predictors (covariates) and the logit of the outcome variable. The assumption of linearity is tested by running a logistic regression with predictors and their logs and checking whether interactions between them are not significant.
- **Independence of errors**: logistic regression also assumes that the cases are not related; violation of this produces overdispersion, in which case the observed variance has bigger than expected values. This assumption is checked by calculating the dispersion parameter, φ (φ=*deviance/degrees of freedom*) which should be less than 1.
- **Multicollinearity**: this happens when two or more variables are very closely linearly related (correlated). In logistic regression, multicollinearity between predictors creates an undesirable situation because it makes it difficult to evaluate the individual importance of a predictor. This assumption is tested by performing a multiple regression (with outcome and predictor variables as in logistic regression) and checking whether *tolerance values* are greater than 0.1 and VIF values are less than 10.

After checking the assumptions of logistic regression, the researcher should specify the outcome and predictor variables; the method (algorithm) used for performing the analysis; and the reference category. In terms of the method, Field (2013) suggests using the *Forced Entry (Enter)* method because it relies on theoretical reasons for including the chosen predictors but without any preference about the order in which the predictors are entered into the model. Finally, choosing the reference category (the group against which all the rest of the groups of the outcome variable are compared with) is chosen according to the goals of the analysis; this is crucial since results are relative to this category (Kwak & Clayton-Matthews, 2002).

Results of a multinomial logistic regression are in general evaluated by **assessing the model itself** (testing whether having a model is significantly better than having no model and if the model is a good fit to the data) and **the contribution of predictors** (determining which predictors are significant in predicting the outcome variable. Finally, results are utilised in answering the research questions by interpreting mainly the odds ratio (exp(B)) which indicates the change in odds resulting from a unit change in the predictor (Field, 2013). In the case of a ***covariate*** (continuous) predictor, an **odds ratio greater than 1** indicates that for higher values of the predictor it is more likely belonging to the group compared with the reference category (for each unit of the predictor the odds of belonging to the group compared with the reference category increases by [exp(B)-1]x100%); an **odds ratio less than 1** indicates that for higher values of the predictor it is more likely belonging to the reference category (each unit of the predictor increases the odds of belonging to the reference category by [|exp(B)-1|]x100%). In the case of ***categorical*** predictors, an **odds ratio greater than 1** indicates that it is more likely for the first category of the predictor belonging to the group compared with the reference category (odds of belonging to the group compared with the reference category for the first category is exp(B) times that of the second category); an **odds ratio less than 1** indicates that it is more likely for the second category of the predictor belonging to the group compared with the reference category (odds of belonging to the group compared with the reference category for the second category is 1/exp(B) times that of the first category) (Kwak & Clayton-Matthews, 2002).

5.2.4.2 Results

In order to investigate whether tool-use differences among undergraduates (as identified by cluster analysis) can be explained by certain qualities of the students (degree, year of studies, conceptions of mathematics) and the goals they pursue when studying mathematics, a multinomial logistic regression analysis (forced entry method) was performed with Cluster 4 (predominantly textbooks-learning group) as a reference category. Cluster 4 was chosen as the reference group because it represented those students with below average use for all tools except textbooks. As outcome variable was chosen cluster membership and in total, 14 predictors were used in building the model; two categorical (degree, year of studies) and 12 covariates (cohesive score, fragmented score, 10 variables for students' goals). The assumptions of logistic regression were assessed as described in section 5.2.4.1. No serious violations of linearity were identified except for one variable which was excluded from the final analysis (to enjoy mathematics: $\chi^2(4) = 11.958$, $p<.001$). Independence of errors was assessed by checking whether overdispersion was present in the data: the dispersion parameter φ was found less than 1 ($\varphi=.72$), therefore independence of errors was inferred. Finally, multicollinearity was not present in the data, since all tolerance values were above .1 and VIF values were less than 10.

Analysis revealed a significant model, $\chi^2(52) = 226.091$, $p<.001$, suggesting that the 13 predictors as a set can explain the different tool-use patterns. The Pearson, $\chi^2(2304) = 2391.095$, $p=.101$ and deviance statistics, $\chi^2(2304) = 1666.388$, $p=1.000$ suggested a good fit of the model. The predictors that had a significant main effect on cluster membership were, degree $\chi^2\ (4) = 130.652$, $p<.001$; year of studies $\chi^2\ (4) = 26.509$, $p<.001$ and the goals "to pass" $\chi^2\ (4) = 13.034$, $p=.011$, "to open your mind" $\chi^2\ (4) = 12.023$, $p=.017$; and "to understand the theory of mathematics" $\chi^2\ (4) = 11.848$, $p=.019$. Influencing predictors explained approximately 30% of variance,

R^2=.32 (Cox & Snell), .33 (Nagelkerke).

Table 5.21 presents the significant pairwise comparisons between the reference group (Cluster 4: predominantly textbooks-learning group) and the rest of the clusters. With regards to students' goals, the multinomial logistic regression showed that:

- *Being more oriented towards passing a module, increases the likelihood of using peers as tools.* In particular, each additional unit of the variable "to pass the module" (agreeing more that passing a module is a desirable goal) increases the odds of belonging to cluster 1 (Peers) by 41%[40].
- *Being more oriented towards acquiring mathematical skills, increases the likelihood of blending different tools*. To be more specific, each additional unit of the variable "to acquire mathematical skills" (agreeing more that acquiring mathematical skills is a desirable goal) increases the odds of belonging to cluster 3 (Blending) by 69%[41].
- *Being more oriented towards opening your mind, increases the likelihood of being selective in tools*. In particular, each additional unit of the variable "to open your mind" (agreeing more that opening your mind is a desirable goal) increases the odds of belonging to cluster 5 (Selective) by 47%[42].
- *Being more oriented towards understanding the theory of mathematics, increases the likelihood of using predominantly textbooks*. In particular, each additional unit of the variable "to understand the theory of mathematics" (agreeing more that understanding the theory of mathematics is a desirable goal) increases the odds of belonging to cluster 1 by 33%[43].

Table 5.21: Pairwise comparisons between the reference category (cluster 4) and the other clusters.

Reference category		**Predictor**	**B(SE)**	**Wald**	**95% CI for Exp(B)**		
					Lower	Exp(B)	Upper
Cluster 4 (Textbooks)	Cluster 1 (Peers)	Pass maths module(s)	.34 (.12)**	8.41	1.12	1.41	1.77
		Degree	-2.66 (.40)***	44.04	.03	.07	.15
	Cluster 2 (Online)	Year of Studies	-.80 (.29)**	7.58	.25	.45	.79
		Degree	-3.17 (.40)***	62.81	.02	.04	.09
	Cluster 3 (Blended)	Acquire mathematical skills	.53 (.24)*	4.80	1.06	1.69	2.71
		Year of Studies	-.87 (.29)**	8.67	.24	.42	.75
		Degree	-2.10 (.41)***	25.69	.05	.12	.28
	Cluster 5 (Selective)	Open your mind	.39 (.17)*	4.91	1.05	1.47	2.07
		Understand the theory of mathematics	-.40 (.17)*	5.42	.48	.67	.94

Note. R^2=.32 (Cox & Snell), .33 (Nagelkerke). Model $\chi^2(52)$ = 226.091, p<.001. * p < .05, ** p < .01, *** p < .001. **Covariates** (pass maths module, acquire mathematical skills, open your mind, understand the theory of mathematics)**:** Exp(B) > 1 increases the likelihood of belonging to the group compared with cluster 4, Exp(B) < 1 increases the likelihood of belonging to cluster 4. **Categorical** (degree, year of studies)**:** Exp(B)>1 indicates that it is more likely for engineering or first year students belonging to the group compared with cluster 4, Exp(B)<1 indicates that it is more likely for mathematics or second year students belonging to the group compared with cluster 4. **Fist category for degree:** engineering students; **First category for year of studies:** first-year students

[40] (1.41-1)×100=41%

[41] (1.69-1)×100=69%

[42] (1.47-1)×100=47%

[43] (|0.67-1|)×100=33%

In terms of subject specialism (degree), results showed that *it is more likely for mathematics undergraduates to use peers* (1/0.07=14.28 times more), *online tools* (1/0.04=25 times more) *or blend different tools* (1/0.12=8.33 times more) than engineering students. Finally, with regards to undergraduates' year of study (first, second), results showed that *it is more likely for second year students to use online tools* (1/0.45=2.2 times more) or *blend different tools* (1/0.42=2.38 times) than first year students.

5.2.4.3 Summary and Discussion

In answering my fourth research question (what factors can account for undergraduates' tool choices?), a Multinomial Logistic Regression was performed for a sample of N=590 students. Results suggest that discipline (degree) and year of studies are factors influencing the choice of tools that undergraduates make: it is more likely for mathematics undergraduates to use peers, online tools or blend different tools than for engineering students and also for second year students to use online tools or blend different tools than for first year students. In addition, (some of) the goals that undergraduates pursue when studying mathematics influence the choice of tools they make (details in the following paragraphs). Interestingly, conceptions of mathematics did not predict cluster membership, thus cannot explain tool-use differences identified from cluster analysis.

As we saw earlier (Part III: goals, p. 72), the goals included in the questionnaire were based on 5 pilot interviews and the work of Wood, Reid and colleagues in tertiary mathematics (Reid, Wood, Smith, & Petocz, 2005; Wood et al., 2012). Based on 22 interviews with students majoring in the mathematical sciences, the authors proposed a three-level hierarchical structure of the goals that undergraduates aim to achieve when learning mathematics. At the narrowest level lies the ***techniques orientation*** containing goals related to "the extrinsic and practical features of learning mathematics" (Wood et al., 2012, p. 42); next we have the ***subject orientation*** including goals related to understanding "all aspects of the mathematics being studied, the practical and theoretical, the pure and the applied" (*Ibid*., p.44); and finally, we find the broadest of all level, the ***life orientation***, comprised of goals going beyond the discipline of mathematics, related in "the role of learning mathematics in [students'] personal and professional lives, and the way it changes their view of the world around them" (*Ibid*., p.46). Here, from the goals that were identified as significant predictors, *to pass the module* and *to acquire mathematical skills* fall into the techniques orientation; *to understand the theory of mathematics* falls into the subject orientation; and finally *to open your mind* falls into the life orientation level.

If we think of Wood and colleagues' hierarchy of goals as a continuum (techniques-subject-life) and arrange the goals identified as significant predictors from the narrowest to the broadest (to pass-acquire mathematical skills-understand the theory of mathematics-open your mind), we can observe an interesting pattern in terms of how these goals influence the tools that undergraduates use. First, by moving from the goal *to pass the module* to the more general goal *to acquire mathematical skills,* results a more rich tool-box: students that are more oriented in passing their module are more likely to use only their peers, while students aiming at acquiring mathematical skills are more likely to blend all the available tools to them. Second, students who aim to understand the theory of mathematics are more likely to use just their textbooks, while students wanting to open their mind are more likely to be selective when blending different tools.

Chapter 6 Analysis and Results of Qualitative Data

6.1 Introduction

In this chapter results from the qualitative strand of my mixed methods study are presented and discussed. In the remainder of this section, my strategy for analysing the qualitative data is presented (section 6.1.1) and a short introduction of the approach adopted in analysing diary and interview data is presented (qualitative content analysis, section 6.1.2). Results are presented throughout sections 6.2 for diary data and 6.3 for interview data. At the end of each of these sections, a summary of the main findings is presented and conclusions are drawn and discussed.

6.1.1 Analysis Strategy

The purpose of analysing the diary and interview data was answering RQ4 (what factors can account for undergraduates' tool choices?) from a qualitative perspective. In doing so, a quantitative content analysis (QCA, see section 6.1.2) approach was taken. Usually, the main result after performing a QCA analysis is the coding frame, a hierarchically structured set of codes which summarises and describes the data. In my case, the coding frame was constructed in a way that captured instances of factors affecting tool-use, all stemming from both Leontiev and Engestrøm's versions of AT. In total, two coding frames were built, one for analysing the interview data and one for the diary data. Details about the structure of the two coding frames, the way each coding frame was built and how RQ4 was answered, are presented at sections 6.2 (diary data analysis) and 6.3 (interview data analysis).

My main strategy for analysing diary and interview data consisted of two layers. First, factors shaping undergraduates' tool preferences were sought in the ways individuals act (unit of analysis is individual activities, Leontiev's version of AT). Second, the focus was widened by including factors influencing tool-use from the wider sociocultural context within which individuals act, i.e. their activity system (unit of analysis is the activity system, Engestrøm's version of AT). In doing this, I had to resolve an inconsistency arising from the main difference between the two versions of AT used here i.e. what Leontiev and Engestrøm describe account as the object of individual and collective activities respectively.

As we saw in chapter 2 (Theoretical framework) the two main differences between these two schools of thought are related to the unit of analysis and the notion of the object (section 2.4). Because these two frameworks were used in conjunction, I examine here whether these two differences are problematic in my study's context. Leontiev focused primarily on individual activities and thus the unit of analysis is individual activities, whereas Engestrøm is concerned about the collective nature of activities. In my view, the different units of analysis do not cause any issues since they provide different analytical foci and as such they are welcome. This approach strategy is similar to the analytical strategy that Radzihovsky (1983) and Wertsch

(1998) have adopted in bridging the individual versus social gap by identifying the "genetically inherent sociality within individual activities and actions" (Kaptelinin & Nardi, 2006, p. 191). Although Wertsch and Radzikhovsky's aim was to build one framework for assigning the sociality of individual activities to certain aspects of the activities themselves (Kaptelinin & Nardi, 2006), in my view the use of two frameworks (Leontiev and Engestrøm's) –and thus units of analysis- offered the same flexibility to this study.

Since the researcher her/himself has to a-priori define what is accounted as individual and collective activities according to the purposes of a study (Russell, 2002), the difference related to the notion of the object needed more thought. Leontiev considered objects to be "owned" by individuals whereas Engestrøm by communities (Kaptelinin & Nardi, 2006). Thus, when adopting Leontiev's version of AT, it seems reasonable to assume that undergraduates' object is obtaining their degree; indeed, all undergraduates prior to their involvement in their course actively searched and chose to study at a university level in order to obtain a mathematics or an engineering degree. When adopting Engestrøm's perspective, it is reasonable to consider as community (the social group sharing the same general objective) undergraduates themselves and their lecturers. Thus, the object shared by this community is again a university degree, therefore I think that defining the same object for both versions of AT, does not cause any issues either.

6.1.2 Introduction to Qualitative Content Analysis

Qualitative content analysis (QCA) is a method for describing in a systematic way the meaning of qualitative material (Schreier, 2014). Contemporary QCA is similar to thematic analysis but it has distinct features when compared to other qualitative approaches such as grounded theory (Drisko & Maschi, 2015). The three key features that differentiate QCA from other qualitative methods are its capacity for reducing the amount of material, its highly systematic procedures and its flexibility (Schreier, 2014).

At the core of QCA lies the **coding frame**, which aims at producing a systematic description of the material under investigation by classifying all data as instances of a set of aspects related to the research questions. The coding frame has a hierarchical structure and consists of at least two levels: the **main categories** (or dimensions) which are the aspects on which a researcher wants to focus his/her analysis and the **subcategories** which specify *what is said* about the main categories (Schreier, 2012). In this sense, the main categories behave like variables related to certain aspects of a phenomenon and subcategories are the values of these variables.

When building a coding frame, the following steps are required (Schreier, 2014):

1. **Select** the parts of the material that are relevant to the research questions
2. **Structure** the coding frame i.e. decide which main categories will be used to describe the data and **generate** the subcategories for each main category. Structuring and generating can be done in a *concept-driven way* (main categories and subcategories are based on prior research or theory), a *data-driven way*

(main categories and subcategories are created in an in-vivo fashion) or a combination of these approaches. When generating the coding frame in a data-driven way, the researcher can choose from a variety of strategies such as *subsumption* (scanning the material and creating a subcategory each time a new concept is found) or *successive summarising* (paraphrasing entire passages and summarising similar paraphrases).

3. **Define** the main categories. This includes a name, description, examples and decision rules for each main category.
4. **Revise** and **expand** the coding frame until it covers all the variation of the data.

Every coding frame must fulfil a number of requirements (Schreier, 2014):

1. **Unidimensionality**: each main category (dimension) should capture only one aspect of the material and not multiple features of the data.
2. **Mutual exclusiveness**: if we assign a coded segment to a main category, this segment cannot be assigned to *another* main category too i.e. each coded segment must be relevant to one main aspect only. This requirement does not mean that we can code one segment only once but that we can code a segment *only once under one main category*.
3. **Exhaustiveness**: all relevant material should be assigned to at least one subcategory of the coding frame.

6.2 Diary Data Analysis and Results

In the following sections, results from the diary data analysis are presented. First, I describe the overall structure of my coding frame (section 6.2.1), its main categories (section 6.2.2 Defining the main categories) and their subcategories (section 6.2.3) Finally, in section 6.2.4, I present a summary of the results and RQ4 (What factors can account for undergraduates' tool choices?) is answered by virtue of the coding frame's subcategories.

6.2.1 Description of the Coding Frame

The coding frame for analysing the diaries was created by adopting a Qualitative Content Analysis (QCA) approach (Schreier, 2014). It consisted of 6 main categories (dimensions) reflecting the aspects that the 6 diary questions were intended to capture. The names of the main categories and their correspondence with the diary questions are presented at Table 6.1.

Table 6.1: The correspondence between diary questions and the coding frame's main categories

Diary questions	Main categories	Main category short description
(1) What resource(s) if any did you use?	Tools	The resources that undergraduates reported using.
(2) What did you want to achieve?	Goals	Students' goals while studying.
(3) Describe how you used the most useful resource.	Actions	A short description of how the resources were used.
(4) Why did you choose this particular resource?	Reasons	Reasons for choosing to use a particular resource.
(5) Did you finally achieve your goal?	Evaluation	A self-evaluation of whether students achieved their goals.
(6) Did you encounter with any difficulties while using this resource?	Difficulties	Any difficulties that the students faced while using a resource.

Table 6.1 does not imply that passages found as answers to a specific diary question could fall into the corresponding main category only e.g. answers to question 6 were not necessarily coded as "difficulties" only. For example, while a student reported on the difficulties he faced while trying to achieve a goal, he mentioned using other tools to resolve this. This analytical decision reflects two things: first, that students' activity "studying mathematics" consists of several aspects (e.g. resolving successfully or not issues, feeling that a goal has been achieved or not) which should be included in the analysis; and second the fact that although each diary question was explicitly designed to elicit information about one specific Activity Theory concept, students did not report in that way (e.g. difficulties that students faced were also found as answers to question 5 –evaluation). Moreover, although students were instructed to create their diary in a specific format, one of them (SD2) gradually created a personal style of reporting her activities; this student's diary data were monitored for their richness and it was decided not to disturb her and request a different way of reporting. Examples of two diary entries are presented at Figure 6.1 and Figure 6.2.

> 1. Learn website - module notes.
> 2. Copy lecture notes to "gappy" notes (printed handouts with missing notes)
> 3. Read the learn notes and copied it down word for word but changed the layout and wrote key words in red and side notes in green.
> 4. Because the Learn notes are written by the lecture of that specific module; Numbers.
> 5. Yes.
> 6. Did not understand the meaning of a word used and there was no one to ask; had to use Google to look up definition.

Figure 6.1: Example of how a diary entry from SD1 usually looked. Each number on the left is written by the student and corresponds to a diary question.

> Today I had a very busy day completing my mechanics course-work and I managed it! Like before, the problem sheets are the biggest help when completing a course-work because it gives you an idea of the layout and what the lecturer will be looking for when marking it. I used my own notes quite a lot as well because a few questions were 'state the definition' so I like to write the version what he gave us, also one of the proofs in my notes helped too

Figure 6.2: Example of how a diary entry from SD2 usually looked. This student developed a personal style of reporting her everyday activities.

6.2.2 Defining the main categories

Since the main categories of the coding frame were related to the diary questions (decided in advance and based on Activity Theory concepts) my frame's main categories are all *concept-driven* in nature. As per usual in QCA, for each main category a definition was created which included (Schreier, 2014): the main category's name (indicating what the category refers to), its description (what is meant by this category and its characteristics), indicators (signs that point to the presence of a phenomenon), examples of the main category as found in the material and if necessary decision rules (e.g. if there is an overlap between two main categories). The definitions for the 6 main categories are presented at Table 6.2-Table 6.7.

Table 6.2: Definition for the main category "Tools"

Name	**Tools**
Description	This dimension captures all the tools that students reported using when studying for their mathematics modules. It includes traditional resources (e.g. textbooks, own written notes), digital/online resources (LEARN website, Wikipedia) and people that students interact with (e.g. a peer or a lecturer).
Indicators	Tools are usually (but not always) found at student's answer for diary question 1.
Examples	"a friend", "MLSC", "my notes", "lecturer's notes on LEARN", "problem sheets", "a past paper".
Decision rules	If a diary entry has multiple instances of the same tool, then code it only once (this is because code frequencies will be also used in the analysis).

Table 6.3: Definition for the main category "Goals"

Name	**Goals**
Description	This dimension captures what a student wants to achieve in a given situation while studying. From an Activity Theory perspective, goals are conscious and they behave like an action's object, i.e. they are the why of an action. Segments coded as goals should reveal an aim or intention.
Indicators	Goals are usually identified by the presence of a preposition (for, to, in) and they answer the question "why did you act like that?" or "what did you want to achieve?". Goals are usually (but not always) found at student's answer for diary question 2.
Examples	"to memorise a theorem", "to learn how to write a certain proof", "to complete my coursework", "preparing for the in-class test",
Decision rules	No decision rules were required.

Table 6.4: Definition for the main category "Actions"

Name	**Actions**
Description	Actions are processes subordinated to the idea of achieving a result. They are the specific interactions that people have with tools or other people.
Indicators	Actions answer the question "what did you do?" and they are identified when a participant explicitly or implicitly mentions using an artefact or interacts with a person. Actions are usually identified by the presence of a verb which accompanies an artefact or a person. Actions are usually (but not always) found at student's answer for diary question 3.
Examples	"read my notes", "watched a video on YouTube", "visited the MLSC to talk with a lecturer"
Decision rules	No decision rules were required.

Table 6.5: Definition for the main category "Reasons"

Name	**Reasons**
Description	Reasons include a student's justification of using a particular resource.
Indicators	Reasons answer to the question "why did you use this particular resource?" and they are usually (but not always) found at student's answer for diary question 4. Reasons are primarily used to gather information of a student's choice of tools that are not directly addressed by Activity Theory.
Example	"quickest way to talk to my friend" (why using WhatsApp to communicate with a peer)
Decision rules	If as a reason for using a tool the student expresses a goal (i.e. I used tool A because I wanted to do B) then code the segment as a goal and not as a reason. If a student's justification implies intention for achieving something then code the segment as a goal and not as a reason

Table 6.6: Definition for the main category "Evaluation"

Name	**Evaluation**
Description	A student's self-evaluation of achieving her/his goals. It usually has a binary nature and thus it is limited to a "yes" or "no" type of response.
Indicators	Evaluation is usually (but not always) found at student's answer for diary question 5.
Example	"Yes, I did the question I wanted in my coursework", "my condensed notes and practicing the questions have made me much quicker and confident with the module".
Decision rules	If a student's self-evaluation is elaborate and includes segments related to her/his goals or reveals intention, then these segments are coded under the main category goals.

Table 6.7: Definition for the main category "Difficulties"

Name	**Difficulties**
Description	This dimension captures the difficulties that a student faced while she/he was trying to achieve her/his goal(s), while using a resource or any other issues that occurred. Difficulties refer to either subjective or non-subjective issues that a participant had to solve while acting. They usually have a binary status (yes, no) but they can also be more elaborate.
Indicators	Evaluation is usually (but not always) found at student's answer for diary question 6.
Example	"Didn't understand a proof for a lemma so spoke with my friend about it."
Decision rules	If segments found at diary question 6 are elaborate (as the example above) and are related to any other main categories such as actions or goals, then code relevant segments as required.

Coding the diary material and adjusting the definitions for each main category occurred in two phases. First, students' answers for each diary question were coded with the corresponding main categories: for example, passages found on students' answers for question 1 were coded as ***Tools***, answers for question 2 were coded as ***Goals*** and so on. An example is presented at Figure 6.3.

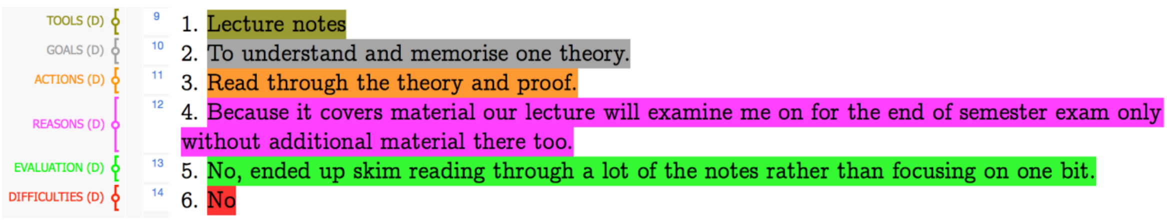
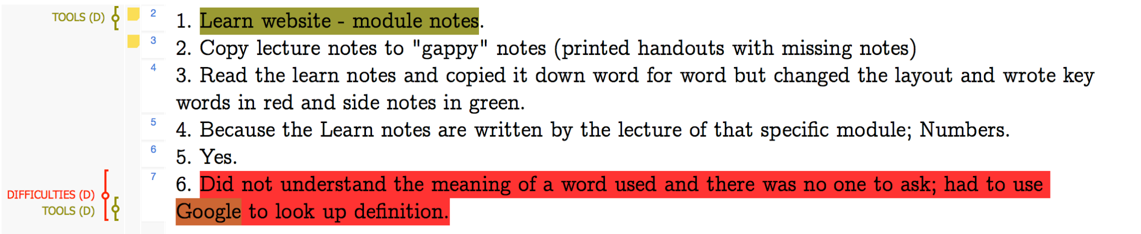


Figure 6.3: An example of a coded diary entry during the first phase of the coding process. Numbers on the left correspond to a diary question. Smaller numbers further left, correspond to the text lines of the data, related to how MAXQDA structures a manuscript. Each main category has been assigned a different colour and the coded text with each main category is highlighted accordingly.

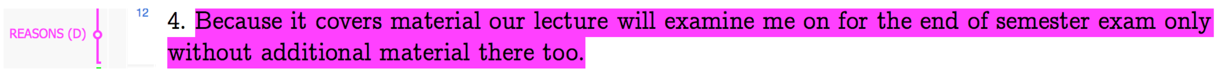
In the second phase, all the coded material was examined in order to determine whether (1) passages coded under one main category (e.g. ***Reasons***) included segments related to other main categories as well (e.g. ***Goals***) or whether (2) they should be labelled under another main category. In case (1), if a passage coded under one main category included also segments relevant to another category, then these segments were coded under another main categories too. For example, a passage coded as ***Difficulties*** contained also a segment related to ***Tools*** and thus it was coded as such (Figure 6.4).



1. Learn website - module notes.
2. Copy lecture notes to "gappy" notes (printed handouts with missing notes)
3. Read the learn notes and copied it down word for word but changed the layout and wrote key words in red and side notes in green.
4. Because the Learn notes are written by the lecture of that specific module; Numbers.
5. Yes.
6. Did not understand the meaning of a word used and there was no one to ask; had to use Google to look up definition.

Figure 6.4: In this diary entry, the student's answer for the difficulties she faced while studying (answer to question 6, red-highlighted text), contained also information about another resource she used (Google) not reported in her answer to question 1 (resources used, olive-highlighted text); thus this segment was coded as ***Tools***.

In case (2), if a passage coded under one main category could be considered as belonging to another main category, then the passage was coded under another main category. For example, a passage that was initially coded as ***Reasons*** (Figure 6.5) was decided to be coded as ***Goals*** instead because it contained statements related to intention and thus better described by this main category. The above rules have been incorporated into the definition for each main category (see Rules at Table 6.2-Table 6.7).



4. Because it covers material our lecture will examine me on for the end of semester exam only without additional material there too.

Figure 6.5: A passage that was initially coded as ***Reasons*** was decided to be assigned under the main category **Goals** because it revealed intention: the student used her lecture notes because there she could find all the necessary material that would enable her to achieve a goal, that is succeeding in exams.

The main categories and the total number of coded segments for each main category are presented at Figure 6.6 below.

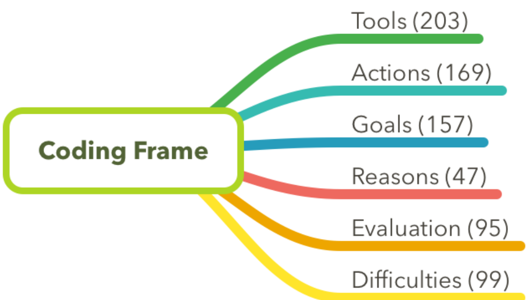


Figure 6.6: The six main categories of my coding frame and the total number of coded segments for each.

6.2.3 Generating the subcategories

After coding the diary data with the six main categories of my frame, I started creating subcategories for each dimension in a data-driven way. In answering my research questions, only the main category ***Goal*** and its subcategories were used. Results for the main categories ***Actions***, ***Reasons*** and ***Evaluation*** are not reported. The main category ***Actions*** served an auxiliary purpose i.e. to reassure that segments coded as ***Goals*** are indeed goals and not actions. Even though the diary protocol was structured with each question intentionally designed in order to help me distinguish tools, actions and goals during the analysis, the way the four diarists created their entries was not uniform and in many cases an action could misinterpreted as a goal. For example, "reading through the theory and proof" is an action since the student reported using the tool "lecture notes" in a previous line; however the goal of this action as stated by the student at a following sentence was "to understand and memorise one theory". Segments coded as ***Evaluation*** did not provide any useful insights, since in almost all of them, students simply reported in a positive or negative way (yes, I achieved my goal; no, I didn't achieve my goal). For ***Reasons***, things were a little bit more complicated so I will explain this here. The initial number of segments coded as ***Reasons*** was 88 however, after the second iteration of my coding frame 42 of them were subsumed as ***Goals*** because students stated as a reason for using a particular tool a goal[44] (which is interesting as a finding but I will touch upon it later). While I was working on creating subcategories for the remaining 44 segments, it was evident to me that the diary question relevant to ***Reasons*** ("why did you use this particular resource?") failed in gathering appropriate data: students' answers seemed to be more related to justifying why a particular resource was useful after it has been used (e.g. referring to useful features of a tool) rather than the actual reasons for choosing to use a particular tool at first. Results for the main categories ***Tools*** and ***Difficulties*** are presented but used in a complementary manner: the category ***Tools*** offered a fine-grained image of the tools that a much smaller sample of undergraduates reported using over a period of time and ***Difficulties*** contributed in highlighting some interesting aspects of undergraduates' activities.

6.2.3.1 Tools

Generating subcategories for the dimension ***Tools*** was a straightforward procedure: each resource that students reported using was treated as an instance of this main category. In total, 24 different tools were identified in the diary data which were grouped into 8 subcategories (Figure 6.7, Table 6.9): ***online tools***, ***teaching staff***, ***peers***, ***Learn website***, ***notes***, ***HELM workbooks***[45], ***R software*** and ***revision material***. Some of these tools were grouped according to the typology presented at section 5.2.2 whereas others that were mostly created by students (e.g. revision notes, mind maps, revision cards) and were not included in the survey, were grouped and named according to their reported use as ***revision material***. Tools accessed via the Learn website were also subsumed into one subcategory named ***Learn website*** (Table 6.10). R software was not subsumed into another subcategory. Finally, Table 6.8 presents how frequently each diarist reported using the above categories of tools and the overall reported use for each category of tools.

[44] This is why the definition for Reasons includes the rule that if a Reason is related to a goal/intention then it should be coded as Goal instead (see Table 6.5: Definition for the main category "Reasons")
[45] HELM workbooks were the only textbooks reported by the four diarists; this is why this subcategory was named as such and not as Textbooks.

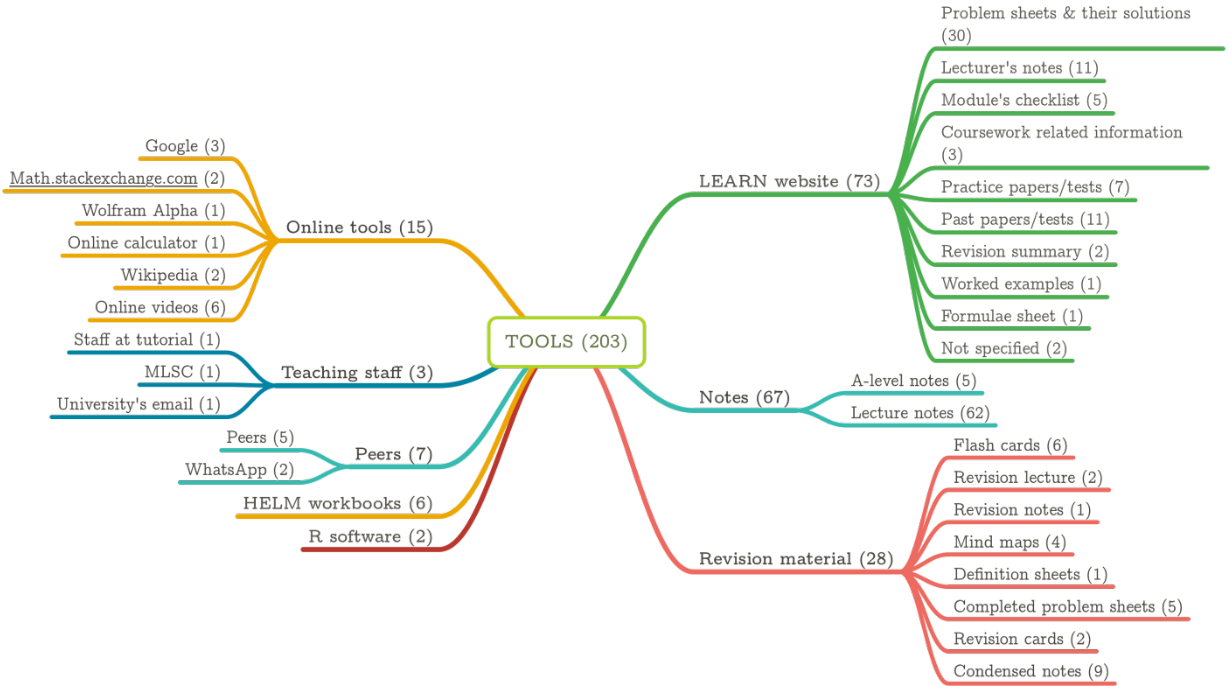


Figure 6.7: The main category “Tools” and its 8 subcategories. The figure includes also the 10 sub-subcategories for the subcategory LEARN website (the choice of colours, placement and order are random). Numbers in parentheses for each category reflect the coding frequency.

Table 6.8: Tool-use frequencies for each diarist (columns SD1, SD2, SD3, SD4) and overall use for each tool (column Total) as indicated by the coding frequency.

TOOL	SD1	SD2	SD3	SD4	TOTAL
LEARN website	12	31	27	3	73
Notes (lecture notes, A-level notes)	17	24	12	14	67
Revision material (condensed notes, flash cards, mind maps, revision cards, revision notes, solved problem sheets, definition sheets)		18	10		28
Online Tools (online videos, Wikipedia, Google, online calculator, W.A., Math.stackexchange.com)	9		3	3	15
HELM workbooks				6	6
Peers (peers, WhatsApp)	2	1	3	1	7
Teaching staff (email to contact lecturer, revision lecture, tutorial, MLSC)	1		3	1	5
R software			2		2
TOTAL	41	74	60	28	203

Table 6.9: Short description for each resource coded under the main category **Tools**.

SUBCATEGORY	SHORT DESCRIPTION
LEARN website	The university's virtual learning environment (VLE) which usually contains several resources that a module's lecturer uploads for her/his students.
Notes	
Lecture notes	Students' own written lecture notes.
A-level notes	Students' A-level notes.
Revision material	
Condensed Notes	Students' notes in a condensed form. They are based on their lecture notes.
Flash cards	Normal flash cards created by students.
Completed problem sheets	Problem sheets solved by the student.
Mind maps	Tabular-like summary of a topic created by the student.
Revision cards	Cards created by the student for revision purposes .
Revision lecture	A lecture provided by the module's lecturer for revision purposes.
Revision notes	Notes created for revision purposes by the student. Not specified further.
Definition sheets	Sheets containing definitions created by the student. Not specified further.
HELM workbooks	Mathematical textbooks designed especially for engineering students and available to them freely. For more information see http://helm.lboro.ac.uk/
Peers	
Peers	Other students on the same course.
WhatsApp	An instant messaging application used for communicating with peers. It can be used on a desktop or laptop computer, on a smartphone or on a tablet. For more information see www.whatsapp.com.
Online tools	
Online Videos	Online videos with mathematical content hosted either on YouTube (www.youtube.com) or at Exams Solutions site (www.examsolutions.net).
Google	Google's search engine (www.google.co.uk).
Wikipedia	A free online encyclopaedia that anyone can access and edit articles (www.wikipedia.org).
math.stackexchange.com	Mathematics Stack Exchange (https://math.stackexchange.com) is a mathematics related question and answer site were anyone (registered user) can post or answer a question.
Wolfram Alpha	An online computational knowledge engine that utilises its own knowledge base for doing computations instead of searching results on the web (www.wolframalpha.com).
Online calculator	An online version of a traditional calculator (not further specified by the student).
R software	R is a free, open source software environment for statistical computing and graphics (https://www.r-project.org).
Teaching staff	
MLSC	The Mathematics Support Centre responsible for providing mathematics and statistics support to all undergraduates.
Staff at tutorial	Lecturers or PhD students helping students solving their problem sheets during a session called tutorial.
University's email	Student's university email account.

Table 6.10: Short description for each resource coded under the subcategory **LEARN website**.

SUBCATEGORIES: LEARN website	SHORT DESCRIPTION
Problem sheets and their solutions	Sheets with problems for students' weekly tutorial sessions.
Lecturer's notes	These can be either a pdf version of their in-lecture presentation or separate notes.
Past papers	Past examination papers.
Practice paper/ test	Practice exam papers and test: this can be either in pdf format or computer based.
Module's checklist	Checklist written by the module's lecturer.
Coursework related information	Lecturer's posts or documents containing information about coursework.
Revision summary	Revision summary written by the module's lecturer.
Formulae sheet	A small booklet containing formulas that students are allowed to have with them during exams.
Worked examples	Solved problems by a lecturer.
Not specified	Instances where a student reported using the LEARN website without specified what he/she used.

6.2.3.2 Goals

For the main category ***Goals*** (Table 6.11), all its subcategories were created in a data-driven way by using a subsumption strategy i.e. by scanning segments coded as ***Goals*** and creating a subcategory each time a conceptually different type of goal was found. While I was doing this, I noticed that two major kinds of goals were present in the data: the first was goals that were instant in nature (e.g. "to understand and memorise a theory") and the second category was general and broad goals (e.g. "exam preparation"). This is consistent with Leontiev's version of AT since our activities are structured in a hierarchical way and in principle there exist goals which are higher in the hierarchy of a person's activity. Subsequently, I created and defined two main subcategories for ***Goals***, named ***Remote goals*** (Table 6.11) and ***Immediate goals*** (Table 6.12). In total, 89 segments were coded as ***Remote*** and 71 as ***Immediate goals***. The overall structure (subcategories and sub-subcategories) for the main category ***Goals*** is presented at Figure 6.8.

Table 6.11: Definition for the subcategory **Remote goals** (89 coded segments).

Name	**Remote goals**
Description	Remote goals are long-term, general in nature goals, that can be also distant in a temporary sense. They are interpreted as being higher in the hierarchy of a student's goals.
Indicators	Remote goals entail elements of scheduling ahead and they usually require a number of instant goals to be fulfilled.
Example	"today I prepared condensed notes in preparation of my final exams",
Decision rules	In principle, any number of remote goals can be found in each diary entry. However, if a diary entry has multiple instances of the same remote goal, then code it only once (this is because code frequencies will be also used in the analysis).

Table 6.12: Definition for the subcategory **Immediate goals** (71 coded segments).

Name	**Immediate goals**
Description	Immediate goals are simple and instant in nature goals. They are perceived to be lower in the hierarchy of a student's goals.
Indicators	Any goal that does not seem to constitute of other goals.
Example	"to memorise a theory", "to gain full understanding of the topic".
Decision rules	Any number of immediate goals is allowed for each diary entry.

The next step of the analysis included identifying the different types of remote and instant goals: after all goals were coded as either remote or instant, I worked again in a data-driven manner to generate the sub-subcategories for remote and instant goals. For ***Remote goals***, 4 sub-subcategories (sub-goals) were identified: three of them were related to assessment (***coursework***, ***test***, ***exams***) whereas the last one was goals related to preparing for an upcoming lecture or tutorial (***prepare***). Definitions for these sub-subcategories are presented at Table 6.13-Table 6.16. In total, 49 segments were coded as ***exams***, 19 as ***coursework***, 17 as ***test*** and 4 as ***prepare***.

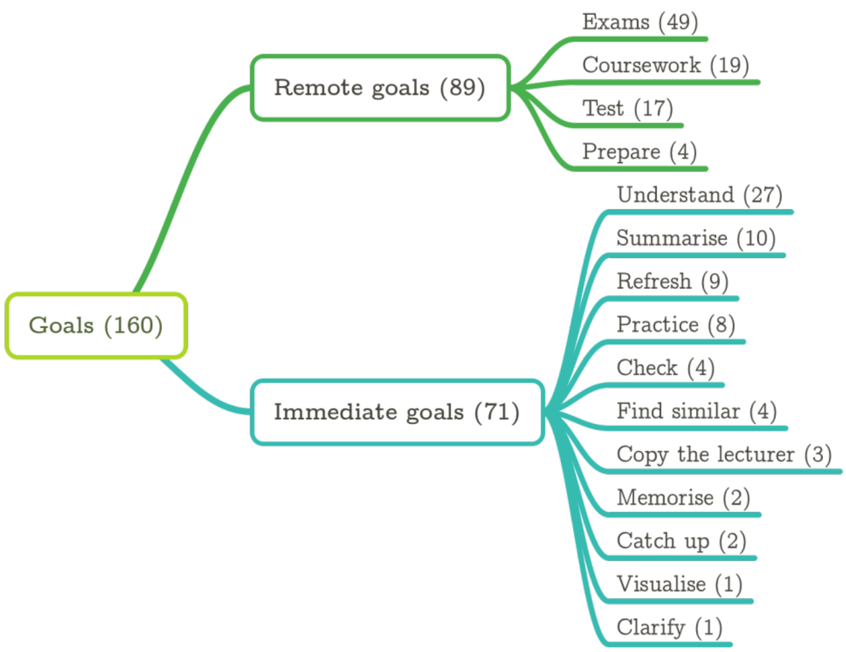


Figure 6.8: The structure of the main category Goals. Numbers in parentheses indicate the number of coded segments.

Table 6.13: Definition for the sub-subcategory **Coursework** (19 coded segments).

Name	**Coursework**
Description	A remote goal related to the submission of a coursework.
Indicators	Remote goals containing the word "coursework".
Example	"to get my coursework done", "big piece of coursework upcoming"
Decision rules	No decision rules were required.

Table 6.14: Definition for the sub-subcategory **Test** (17 coded segments).

Name	**Test**
Description	A remote goal related to an in-class test.
Indicators	Remote goals containing the words "test", "class test", "computer-test".
Example	"I have a probability class test on Friday"
Decision rules	No decision rules were required.

Table 6.15: Definition for the sub-subcategory **Exams** (49 coded segments).

Name	**Exams**
Description	A remote goal related to a module's final examination.
Indicators	Remote goals containing the word "exam".
Example	"Methods 2 and Mechanics exam"
Decision rules	No decision rules were required.

Table 6.16: Definition for the sub-subcategory **Prepare** (4 coded segments).

Name	**Prepare**
Description	A remote goal related to preparation prior a lecture or a tutorial.
Indicators	Remote goals containing the word "prepare" or similar.
Example	"I wanted to prepare myself for the next lecture".
Decision rules	No decision rules were required.

For ***Immediate goals***, 11 sub-subcategories (sub-goals) were identified: ***understand***, ***summarise***, ***remember***, ***practice***, ***check***, ***find similar***, ***memorise***, ***catch up***, ***copy the lecturer***, ***visualise*** and ***clarify***. Definitions for these sub-subcategories and the number of coded segments for each are presented at Table 6.17-Table 6.27.

Table 6.17: Definition for the sub-subcategory **Understand** (27 coded segments).

Name	**Understand**
Description	An immediate goal related to understanding a topic in mathematics.
Indicators	Immediate goals containing the word "understand" or similar.
Example	"understand the calculations in my notes better"
Decision rules	No decision rules were required.

Table 6.18: Definition for the sub-subcategory **Summarise** (10 coded segments).

Name	**Summarise**
Description	An immediate goal related to summarising a mathematical topic.
Indicators	Immediate goals containing the words "summarise", "condense" or similar.
Example	"create bullet points", "create condense notes"
Decision rules	No decision rules were required.

Table 6.19: Definition for the sub-subcategory **Refresh** (9 coded segments).

Name	**Refresh**
Description	An immediate goal related to remembering various topics of mathematics.
Indicators	Immediate goals containing the words "remember", "brush-up", "refresh".
Example	"refresh my memory", "remember things"
Decision rules	No decision rules were required.

Table 6.20: Definition for the sub-subcategory **Practice** (8 coded segments).

Name	**Practice**
Description	An immediate goal related to practising certain aspects of mathematics.
Indicators	Immediate goals containing the word "practice" or similar.
Example	"practice how to carry out certain calculations"
Decision rules	No decision rules were required.

Table 6.21: Definition for the sub-subcategory **Check** (4 coded segments).

Name	**Check**
Description	An immediate goal related to checking whether some work is correct or not.
Indicators	Immediate goals containing the word "check" or similar.
Example	"see if my answer was on the right lines", "checked my answers against the answers in the book"
Decision rules	No decision rules were required.

Table 6.22: Definition for the sub-subcategory **Find similar** (4 coded segments).

Name	**Find similar**
Description	An immediate goal related to finding something similar to a task the student is working on.
Indicators	Immediate goals containing the word "similar".
Example	"see the how to answer complex calculations through examples similar to my question"
Decision rules	No decision rules were required.

Table 6.23: Definition for the sub-subcategory **Memorise** (2 coded segments).

Name	**Memorise**
Description	An immediate goal related to learning by hard mathematical topics.
Indicators	Immediate goals containing the word "memorise".
Example	"memorise a theory"
Decision rules	No decision rules were required.

Table 6.24: Definition for the sub-subcategory **Catch up** (2 coded segments).

Name	**Catch up**
Description	An immediate goal related to catching up with the current status of a student's learning activities.
Indicators	Immediate goals containing the word "catch up".
Example	"catch up on the lectures I miss"
Decision rules	No decision rules were required.

Table 6.25: Definition for the sub-subcategory **Copy the lecturer** (3 coded segments).

Name	**Copy the lecturer**
Description	An immediate goal related to imitating the way a lecturer would perform a task.
Indicators	Immediate goals containing the words "lecturer" + "prefer"
Example	"see how the lecturer would prefer the layout of the proof"
Decision rules	No decision rules were required.

Table 6.26: Definition for the sub-subcategory **Visualise** (1 coded segment).

Name	**Visualise**
Description	An immediate goal related to visualising a mathematical object.
Indicators	Immediate goals containing the word "visualise".
Example	"plot functions to help visualise them"
Decision rules	No decision rules were required.

Table 6.27: Definition for the sub-subcategory **Clarify** (1 coded segment).

Name	**Clarify**
Description	An immediate goal related to seeking clarification for a situation.
Indicators	Immediate goals containing the word "clarify"
Example	"needed clarity on what was required for one question"
Decision rules	No decision rules were required.

Finally, the coding frequencies for ***Remote*** and ***Immediate Goals*** and their sub-subcategories per diarist were calculated (Table 6.28).

Table 6.28: Coding frequency for the main category ***Goals*** and its subcategories per diarist.

Goals	**SD1**	**SD2**	**SD3**	**SD4**	**Total**
Remote goals					***89***
Exams	13	9	17	10	49
Coursework	8	6	5		19
Test	1	5	5	6	17
Prepare		1		3	4
Immediate goals					***71***
Understand	8	10	5	4	27
Summarise	2	8			10
Refresh		4		5	9
Practice	1	2	2	3	8
Check	2			2	4
Find similar	3	1			4
Copy the lecturer	2	1			3
Memorise	2				2
Catch up		2			2
Visualise			1		1
Clarify	1				1

6.2.3.3 Difficulties

All the subcategories for the main category ***Difficulties***, were created in a concept-driven way, based on theoretical notions stemming from Activity Theory. Since the early phases of the coding process, it was clear to me that a concept-based approach for generating subcategories for ***Difficulties*** was a better approach instead of a data-driven approach since certain Activity Theory concepts could describe/summarise more efficiently the data.

In total, two main subcategories were created for difficulties: ***conditions*** and ***contradictions*** (Figure 6.9). Conditions is a concept deriving from Leontiev's writings and refers to the non-subjective factors affecting a person's activity (Roth & Lee, 2007) whereas contradictions are central to Engestrøm's version of Activity Theory and have roots in the philosophical writings of Marx. For the benefit of the reader, a short theoretical introduction has been included in each of the sections presenting results.

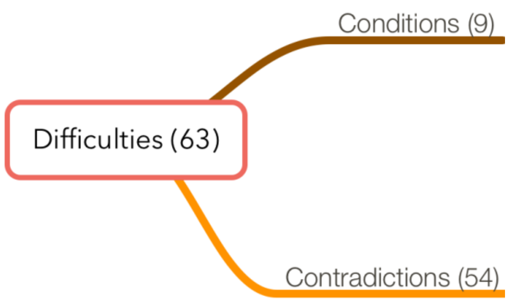


Figure 6.9: The two subcategories for the main category Difficulties and their sub-subcategories. Numbers in each parenthesis indicate the coding frequency.

Conditions

Although the notion of conditions has an important role in Leontiev's hierarchical structure of activities, it seems that its theoretical definition is not well articulated in relevant literature. For example, Leontiev himself notes that operations are not shaped "by the goal in itself but by the objective-object conditions of its achievement" (Leontiev, 1977, p. 102) and Kaptelinin and Nardi (2012; 2006) do not elaborate much on the notion; they just note that operations "are oriented toward the conditions under which the subject is trying to attain a goal" (Kaptelinin & Nardi, 2006, pp.62-63). Roth and Lee (2007) explain that "operations emerge in response to the relationship of goal and current state of the action and its material context" (p.202). In other words, conditions are qualities of the material, objective world in which praxis takes place and have the ability of shaping a subject's activity (at the levels of actions-goals and operations-conditions).

Although I have treated conditions as characteristics emerging from the material context and not the subject, it is worth noticing that some authors do not treat conditions in the same manner: for example, Roth (2007) counts emotional states also as conditions resulting from various somatic systems of the subject (e.g. neuromuscular, biochemical) and he notes that these emotional states must be understood as having a dual nature, both shaping activity (as conditions) and as outcomes of practical action (e.g. the result of an action produces a certain emotional state)[46].

For the purposes of my coding frame, conditions were defined as non-subjective characteristics of the objective world shaping a person's actions and goals (see definition at Table 6.29). In total, 9 segments were coded as conditions and 4 sub-subcategories were generated in a data-driven way (Figure 6.10, Table 6.30-Table 6.33).

Table 6.29: Definition for the subcategory Conditions

Name	**Conditions**
Description	Non-subjective characteristics of the objective world shaping a person's actions.
Indicators	Factors affecting the way a subject acts and usually have a negative effect.
Example	"I used the online HELM workbooks and they were slow to load up" (SD4)
Decision rules	No decision rules were required.

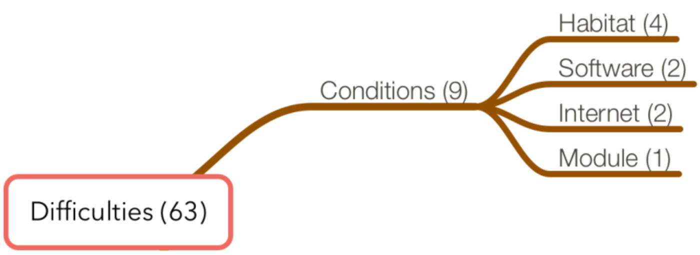


Figure 6.10: The sub-subcategories for Conditions and their coding frequency (numbers in parentheses).

Table 6.30: Definition for the sub-subcategory Habitat

Name	**Habitat**
Description	Conditions related to the aspects of the physical environment in which a student acts.
Indicators	References related to the surroundings of a student's environment
Examples	- "I don't have a desk in my room, so I can only use the communal kitchen which isn't a good working environment" (SD2) - "[PhD students] ... weren't always available on a 1-1 basis since there's about 20 students in the tutorial" (SD4)
Decision rules	No decision rules were required.

[46] This is part of Roth's attempt to incorporate –among others- emotion into third generation AT.

Table 6.31: Definition for the sub-subcategory Software

Name	**Software**
Description	Conditions related to how the environment of a software works.
Indicators	Any mentions of how a software or in general digital/online environment works.
Examples	- "The coding [in R] can be very specific, so a small mistake can make a big difference to the maths" (SD3) - "[A difficulties encountered was] getting used to the different coding commands [in R]" (SD3)
Decision rules	No decision rules were required.

Table 6.32: Definition for the sub-subcategory Internet

Name	**Internet**
Description	Conditions related to internet connectivity.
Indicators	References to internet connectivity.
Example	- "The Internet was a bit slow so videos took some time to load up" (SD4) - "I used the online HELM workbooks and they were slow to load up" (SD4)
Decision rules	No decision rules were required.

Table 6.33: Definition for the sub-subcategory Module

Name	**Module**
Description	Conditions related to a module's environment.
Indicators	Mentions of what is expected from students in a specific module and in general how things work in a module.
Example	"Complicated notation for the module [Statistical Modelling]"
Decision rules	No decision rules were required.

Contradictions

The important role of contradictions in Activity Theory is due to the fact that activity systems are considered to be under constant development and this development is understood in a dialectical sense as a process driven by contradictions (Kaptelinin & Nardi, 2012). Engestrøm (1987; 2015) recognises four types of contradictions depending on "where" they originate: primary (within the components of an activity system), secondary (between components of an activity system), tertiary (between the object of the dominant activity system and its culturally more advanced form) and quaternary (between neighbouring activity systems).

According to Engestrøm and Sannino (2011), contradictions are historical and systemic phenomena and thus cannot be observed directly. They note that in many studies, the notion of contradictions is not well defined and in most of the cases the term is misused. The authors argue that in empirical studies contradictions can be traced through their discursive manifestations and propose a framework for defining and identifying four types of contradictions: dilemmas, conflicts, critical conflicts, double binds. **Dilemmas** refer to "aspects of socially shared beliefs which give rise to the dilemmatic thinking of individuals" (Engestrøm and Sannino, 2011, p.373, citing Billing *et al.*, 1988). Common expressions of dilemmas in discourse take the form of hedges and hesitations such as "on the one hand... ...on the other hand" or "yes, but".

Conflicts refer to situations "when the actions of one person are interfering, obstructing or in some other way making another's behaviour less effective" (Engestrøm and Sannino, 2011, p.374, citing Tjosvold, 1997, p.24). Common expressions of conflicts in discourse take the form of resistance, disagreement, argument and criticism, and include linguistic ques such as "no", "I disagree" and "this is not true". **Critical conflicts** denote circumstances in which "people face inner doubts that paralyse them in front of contradictory motives unsolvable by the subject alone" (Engestrøm and Sannino, 2011, p.374). Critical conflicts involve "personal, emotionally and morally charged accounts that have narrative structure and frequently employ strong metaphors" (Engestrøm and Sannino, 2011, p.374). Engestrøm and Sannino (2011) in their analysis describe critical conflicts as contradictions between different roles that a subject has e.g. the role of a person in helping patients versus the role of a person in containing costs of health care. **Double binds** are "processes in which actors repeatedly face pressing and equally unacceptable alternatives in their activity system, with seemingly no way out" (Engestrøm and Sannino, 2011, p.374). Common discourse expressions include rhetorical questions (such as "what can we do?") indicating both the need to act and expressions of helplessness.

Based on the discussion above, contradictions in the coding frame were defined as problematic situations that subjects encounter with when acting (see definition at Table 6.34). Contradictions were not identified by using the linguistic cues that Engestrøm and Sannino (2011) propose because (1) the diary data did not have a conversational structure (as the data that Engestrøm and Sannino used to develop their framework) thus they don't lend themselves in identifying cues such as rhetorical questions; and (2) as the authors themselves note, linguistic cues may differ in different social contexts. In total, 54 segments were coded as Contradictions (Table 6.34) and 5 sub-subcategories were generated (Figure 6.11): ***goal binds***, ***conflicts***, ***self-conflicts***, ***double binds*** and ***critical conflicts***. Of them, 3 were based on the types of contradictions suggested by Engestrøm and Sannino (2011) (conflicts: Table 6.36, critical conflicts: Table 6.39, double binds: Table 6.38), whereas the rest emerged from the data (goal binds, self-conflicts)[47]. Since the last two types of contradictions are results of the diary data analysis, it would be worthy discussing them here more.

Goal binds (Table 6.35) refer to problematic situations where the subject is not able to achieve or efficiently achieve his/her goals. Goal binds refer to conflicts not related to previous/current actions of the subject (self-conflicts), other people's actions (conflicts), the different roles that a subject has (critical conflicts), undesirable alternatives (double binds) or dilemmas. Due to the nature of the diary data, the source of goal binds was not always clear/present. In some of the goal binds identified in the diary data, the source of conflict is the nature of the goal that the subject pursues. For example, in a diary entry SD1 describes that she was trying to

[47] Engestrøm and Sannino (2011) note that their list of contradictions is not exhaustive.

complete her coursework for a module by using her lecture notes and problem sheets solution found on the Learn website. She writes that “the lecture notes included worked examples similar to the questions I was set, so I based my answer around it and used a similar method”. At the diary question related to the difficulties encountered, she writes: “not all types of question in my coursework had similar worked examples so I could only to use the notes for these”. This means that (1) the student fulfilled her goal partially/less effectively and (2) she faced difficulties because she wanted to find similar to her coursework questions i.e. the contradiction is caused by the nature of her goal. If the student had decided for a different approach (i.e. a different series of goals) and under different conditions she wouldn’t face that difficulty.

Self-conflicts (Table 6.37) is another type of contradiction identified in the data and are similar to **conflicts** but in this case it is the actions of the subject itself that make his/her own behaviour less effective and not those of another person’s (as in the case of conflicts). For example, in a diary entry SD2 describes how she studies mechanics by going through her notes and making sure she has understood everything. In the same diary entry, she writes: “I should have done this earlier on in the semester, leaving it this late wasn’t a good idea”. This excerpt indicates that the student criticises her decision to study mechanics at a later stage of the semester, which in turn created a problematic situation; thus, her own actions (or the absence of them) made her to be less effective.

In total, 54 passages in the diary data were coded as contradictions. Of them, 29 were related to the goals that a subject wanted to achieve (goal binds); 13 were related to issues emerging from the actions of another person (conflicts); 5 were related to issues arising from the subject itself (self-conflicts); 4 were related to situations were the subject was faced with pressing and equally unacceptable alternatives (double binds); and finally, 3 of them were related to problems rising from the different simultaneous roles that a subject has (critical conflicts).

Table 6.34: Definition for the subcategory Contradictions

Name	**(discursive manifestations of) Contradictions**
Description	Problematic situations that subjects encounter with when acting. In principle, they can be primary, secondary, tertiary or quaternary.
Indicators	Situations expressing dissatisfaction, disappointment, criticism and in general emotionally charged accounts indicating the presence of a problem.
Example	“I have a lecturer who I don’t quite understand visually or verbally”
Decision rules	No decision rules were required.

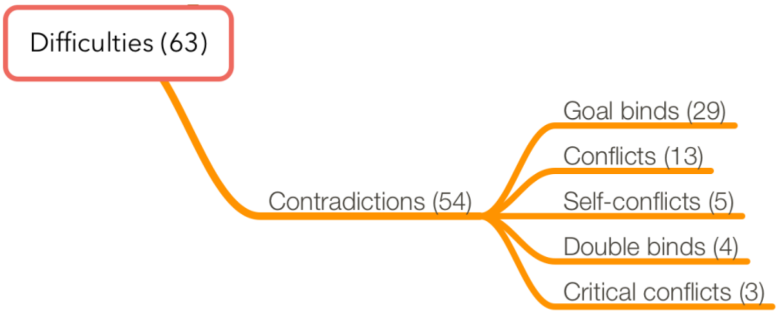


Figure 6.11: The sub-subcategories for Contradictions and their coding frequency (numbers in parentheses).

Table 6.35: Definition for the sub-subcategory Goal binds

Name	**Goal binds**
Description	A problematic situation emerging because a goal has not been attained. This can be caused by the nature of the goal itself.
Indicators	Expressions of facing difficulties in achieving a certain goal.
Examples	“Had to look through the other problem sheet to find out where a similar question would be” (SD1) “Couldn’t answer some of the proof questions using my lecture notes so had to check solutions so understand how to answer” (SD3) “The questions only give you an answer, no worked solutions, so when I got stuck I couldn't complete the questions there and then” (SD4)
Decision rules	No decision rules were required.

Table 6.36: Definition for the sub-subcategory Conflicts

Name	**Conflicts**
Description	The actions of one person are making the behavior of another person less effective.
Indicators	Expressions of resistance, disagreement, argument and criticism related to another person’s actions that make a subject’s behaviour less effective.
Examples	“Mechanics lecture notes [provided by the lecturer] are not very clear. They're mainly bullet point of random things without a concise structure to the notes.” (SD1) “the lecture is refusing to put the solutions to any past papers on Learn so that’s a huge difficulty” (SD2)
Decision rules	No decision rules were required.

Table 6.37: Definition for the sub-subcategory Self-conflicts

Name	**Self-conflicts**
Description	A person's current/past actions make his/her own behavior less effective.
Indicators	Expressions of guilty feelings and acknowledgement that a subject's own actions are causing problematic situations.
Examples	"My only difficulty was being short on time but that's my own fault for presuming it would be easy again." (SD2) "The coursework was really hard so I had kept putting off doing it. I (stupidly) ended up trying to complete it last minute." (SD2)
Decision rules	No decision rules were required.

Table 6.38: Definition for the sub-subcategory Double binds

Name	**Double binds**
Description	Situations in which subjects face pressing and equally unacceptable alternatives.
Indicators	Expressions of both the need to act but also a perceived impossibility of action.
Examples	"A big problem was the fact that I'd left it so late and I kept having panics mid-work and it wasn't the best and it made me very stressed" (SD2) "I don't enjoy working with proofs and definitions so find it difficult to revise this module" (SD3)
Decision rules	No decision rules were required.

Table 6.39: Definition for the sub-subcategory Critical conflicts

Name	**Critical conflicts**
Description	Contradictions between a person's multiple roles or motives.
Indicators	When subjects express doubts in front of contradictory motives/roles.
Examples	"I am back home now [for the Easter break] so I am wanting to meet people I haven't seen for a while." (SD2) "a slight difficulty was the weather, it was way too nice to stay indoors so we found a bench outside [with my friend to study]" (SD2)
Decision rules	No decision rules were required.

6.2.4 Summary and Discussion

In answering RQ4 (What factors can account for undergraduates' tool choices?) diary data from 4 undergraduates were analysed by using a Qualitative Content Analysis (QCA) approach. The main result of QCA was the construction of a coding frame which summarises and describes the data. In total, 5 main categories were created but only one of them (***Goals***) was used in answering RQ4. Results for the main categories ***Tools*** and ***Difficulties*** were also reported but their purpose was supplementary i.e. to complement the survey data results for the tools that undergraduates use and to offer an enhanced image of students' activities respectively.

In terms of the tools that the 4 diarists reported using during the data collection period (Table 6.8, Figure 6.12), we can notice that the most popular choices include the Learn website, students' notes and revision material created by students themselves, with the latter not identified with the survey and interview data. These resources are followed in popularity by various online tools, the HELM workbooks, peers and teaching/support staff. The last tool, R was reported by only one student (SD3) and its use was mandatory for a module (Statistical Modelling).

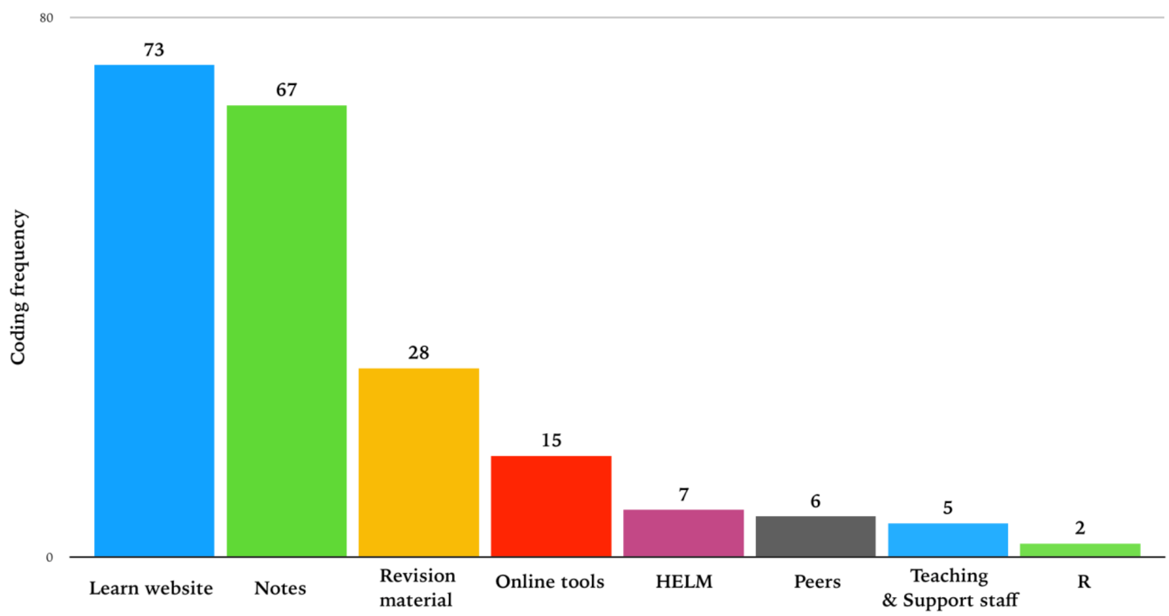


Figure 6.12: The popularity of the tools that the 4 diarists reported using as identified from each tool's coding frequency (presented at Table 6.8).

These findings match with the survey data results (section 5.2.1.1 All students Figure 5.1, p.89), where among the most popular tools identified were the Learn website and students' lecture notes. However, because the first three students (SD1, SD2, SD3) were mathematics undergraduates, they didn't report using textbooks as the fourth student did who was an engineering undergraduate and as we saw at section 5.2.1.2 Engineering and mathematics students, mathematics and engineering students' use of textbooks differs significantly. Moreover, the three mathematics undergraduates were assigned to the online-learning group whereas the fourth in the predominantly textbooks-learning group (see section 5.2.3.3 Description of clusters in terms of tool-use); this explains why their use of peers as a tool was found low in relation to the overall descriptive statistics (see Figure 6.13).

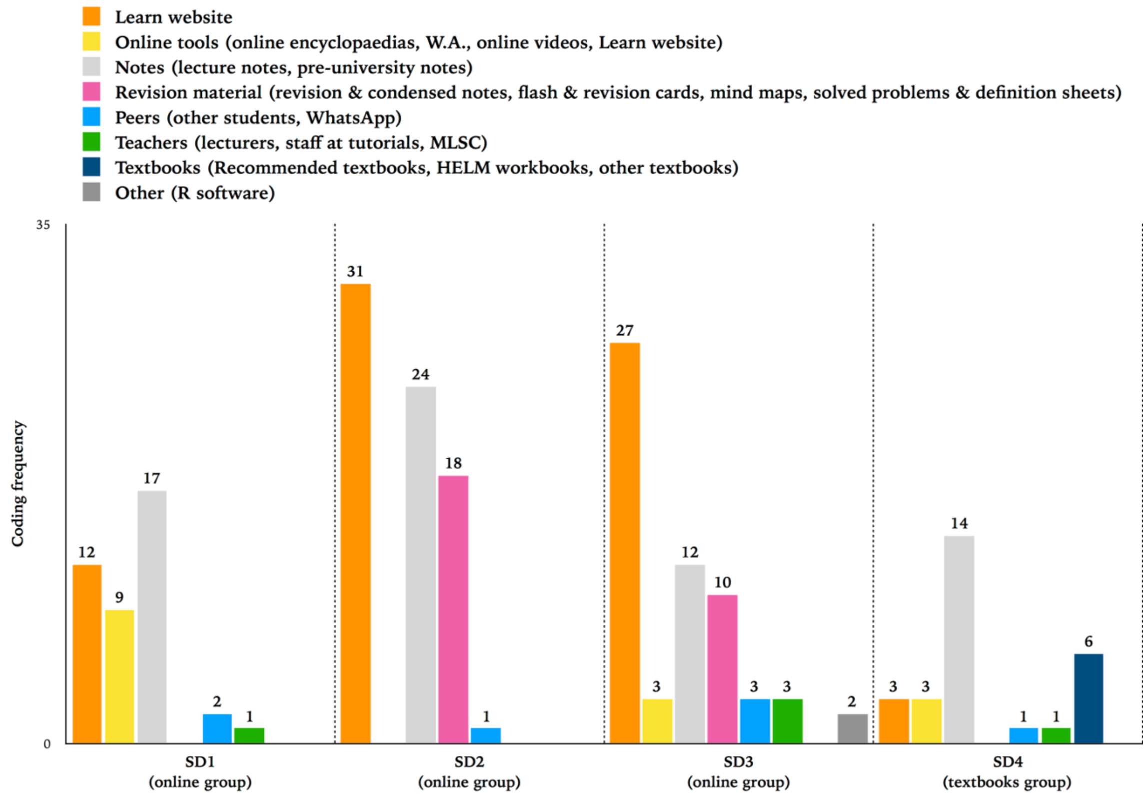


Figure 6.13: Tool-use frequencies per diarist.

With regards to the difficulties that students reported facing while studying mathematics, these were classified into two main categories: conditions (non-subjective factors shaping a person's actions) and contradictions (problematic situations within or between components or between activity systems). In total 4 types of conditions were identified in the data: those related to the physical environment (habitat), those related to the digital environment a student was acting in (software, internet) and those associated with a module's environment (module). Finally, 5 different discursive manifestations of contradictions were found in the diary data: issues related to the achievement or not of a goal (goal binds), problematic situations caused by the actions of another person (conflicts) or the subject itself (self-conflicts), problems when a subject faces pressing and equally unacceptable alternatives (double binds) and issues arising from the different roles or motives that a subject has (critical conflicts). Of the 54 identified contradictions, students reported resolving 20 of them (that does not necessarily mean that the rest were unresolved, students just didn't provide further information). An interesting finding though is that in 15 of the resolved contradictions, students reported using a tool in order to overcome them (see Table 6.40 for some examples).

Table 6.40: Examples how students resolved a contradiction (italic) with the use of a tool (bold).

Resolving a contradiction with the use of a tool.	Participant
"*Did not understand the meaning of a word used* and there was no one to ask; had to use **Google** to look up definition."	(SD1)
"*I have a lecturer who I don't quite understand visually or verbally,* so I catch up ok his lectures through **his notes on Learn** but because *his handwriting isn't the best* I borrow **my friends notes**"	(SD2)
"*..but I think a few of the symbols she'd [friend] copied down were wrong because his [lecturer] hand-writing is so bad* so I had to use **my A-level notes** as well just to double check the symbols.	(SD2)
"*Couldn't answer some of the proof questions using my lecture notes* so had to check **solutions** [problem sheet solutions hosted on the Learn website] to understand how to answer"	(SD3)
"*Wasn't quite sure what some of the terms meant in my lecture notes* so had to use **Google** to get a better understanding."	(SD3)
"*I encountered some difficulties with understanding my notes on some parts* but **my friend** explained it"	(SD4)

In respect of students' goals when studying mathematics, two major types were identified: goals that are simple and instant in nature and can be conceptualised as being lower in the hierarchy of a student's activity (immediate goals) and those which are more broad/general and can be thought as higher in the hierarchy (remote goals). The most commonly identified immediate goals (higher coding frequency) were related to a student's intention in understanding, summarising, refreshing or practicing on a mathematical topic/procedure. Remote goals were mostly related to assessment (exams, coursework, test) whereas only one was related to preparation prior a lecture or a tutorial. If we examine the goals identified in the data without acknowledging the (interpreted) place of goals in students' hierarchical activities, the most frequently coded goals are exams, understand, coursework and test (Figure 6.14).

In principle, any number of different layers within each level of an activity may exist (for example, we can distinguish between general goals, less general goals, narrow goals and so on) but as we saw at chapter 2, Gonzalez, Nardi and Mark (2009) based on empirical research proposed the addition of a fourth level between the top (activity/object) and the middle levels (actions/goals) of Leontiev's hierarchy, named ensembles/purposes. In this sense, the identified in the diary data remote goals are *purposes*, broad goals that help students to "make actions meaningful beyond the scope of short-term goals" (*Ibid.*, p.117), to "map actions onto higher-level practical purposes" (*Ibid.*, p.117) or to "envision and define workloads" (*Ibid.*, p.118) and indeed the diary data do support this interpretation. In many situations, remote goals were found *framing* an immediate goal or in other words they were *the why of an immediate goal*. To be more specific, when a remote goal was present it usually was appearing after an immediate goal followed by a preposition with a causal effect (e.g. *to*, *for*, *in*) or a conjunction word (e.g. because). For example, SD1 wrote that she "wanted to learn how to write a certain proof [immediate goal] for a question given in [her] Numbers coursework [remote goal]. Table 6.41 presents some other examples of remote goals directly framing immediate goals (in the same sentence). In other cases, the broader context of a single diary entry was providing evidence supporting the framing nature of remote goals. For example, SD1 stated as her goals "to understand and memorise one theory [immediate goals]" and within the same diary entry she justified her choice of using her lecture notes to achieve that goal as "Because it covers material our lecture will examine me on for the end of semester exam [remote goal]". Table 6.42 presents some more examples of this type of indirect framing of remote goals (not in the same sentence).

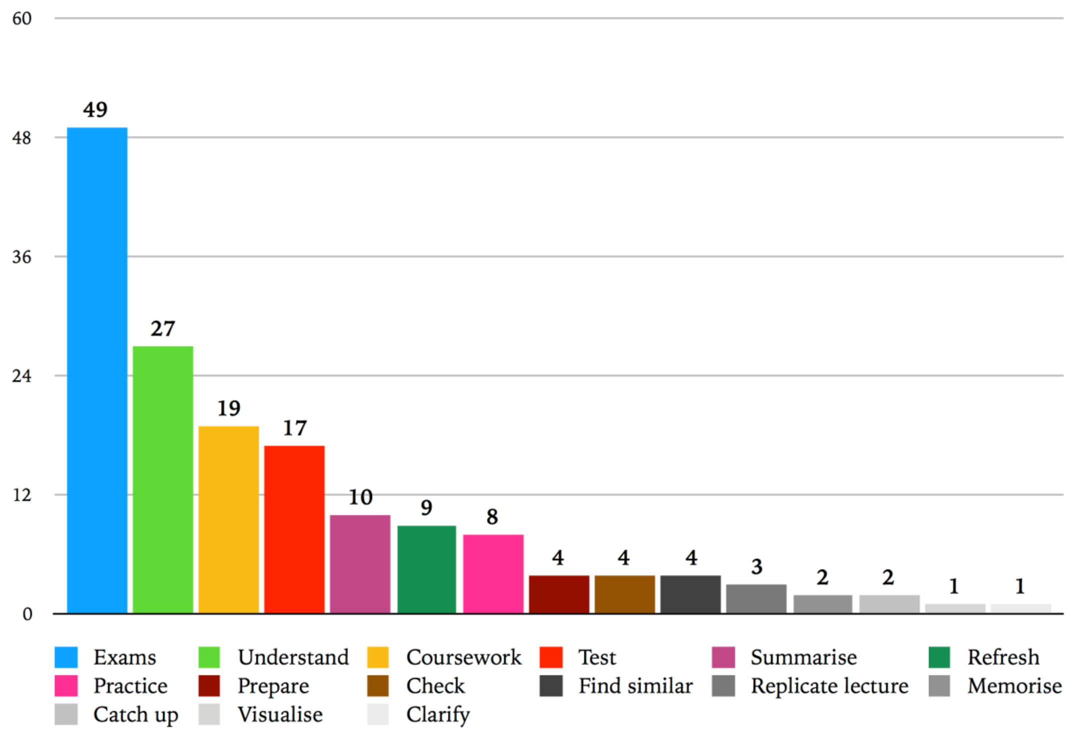


Figure 6.14: Frequency of goals without taking into account their place in the hierarchy of students' activity.

Table 6.41: Direct framing of an immediate goal (italic) by a remote goal (bold) identified in the same sentence.

Immediate and remote goal(s)	Participant
"*Understand* a question **in** the **coursework**"	SD1
"There's a question asking you to carry out calculations to find "properties" of a matrix and this seems likely to come up in the ***exam***. So I wanted to *know how to do this* in general for any matrices.	SD1
"...to refresh myself and make sure I'm confident in preparation for my exam"	SD2
We tried to *help each other* [learn to solve problems for Geometry and Groups module] because we had the **tutorial** for this problem sheet later that day and thought it was best to try and do them on our own first.	SD2
"I wanted to *go over the content from the lecture* with my notes and using my A-level notes I wanted **to prepare myself for the next lecture**"	SD4

Table 6.42: Indirect framing of an immediate goal (left column, italic) by a remote goal (right column, italic) found elsewhere but in the same diary entry.

Immediate goal(s)	Remote goal	Participant
"Needed *clarity on what was required for one question*".	Complete *my Numbers coursework*.	SD1
"Wanted to see the *how to answer complex calculations* through examples similar to my question"	"Because the lecturer sets *the coursework* and does the worked solutions too so I would have my answer as he wanted it hopefully."	SD1
"Today I used my notes to *create condense flash cards*. I went through the whole of my probability work so far *picking out important theorems and equations* and putting them on a piece of paper"	"I did this because I have a probability *class test* on Friday and through experience I know this helps me a lot."	SD2
"I wanted to practice questions to gain *full understanding of the topic*"	"I chose this [HELM workbooks] because it's one of few resources with *relevant questions to the upcoming test*"	SD4
"*understand* the calculations in my notes better"	"Revise for my Geometry and Groups *exam*"	SD1
"Needed to *practice* how to carry out certain calculations"	"Revise for Methods 2 *exam*"	SD1
"Used the problem sheets as I wasn't quite sure how to *answer the questions* and we don't get examples in the lecture notes. Used google for terms and topics I didn't quite *understand*."	"[I did this because of the] *Coursework*"	SD3

Note that not all students reported about their activities in the same way: for example, the first diarist's (SD1) way of answering yielded more framing examples whereas the third student (SD3) was consistently justifying his actions, goals and choice of tools by referring to a remote goal related to assessment. Also, not all immediate or remote goals were coupled e.g. accompanied by a remote or immediate goal respectively as in many instances students reported either only a remote or an immediate goal.

The above discussion demonstrates that students *structure their activity* around higher level goals (purposes) related to assessment which in turn suggests that *undergraduates choose to use certain tools because they enable them to pursue their exam-driven goals*. Indeed in many instances students justified their tool choices by citing the goal they wanted to achieve: as mentioned earlier (section 6.2.3 Generating the subcategories), although the diary question "Why did you choose this particular resource" failed to provide meaningful data, almost half of students' responses to this question was related to a goal (42 out of the 88 segments initially coded as ***Reasons*** were recoded as ***Goals***). However, this is not to say that the only reasons for students choosing certain tools are their assessment related goals. As we saw in the short analysis of contradictions, in some cases undergraduates use tools to resolve issues associated with their activity too. There might exist other factors influencing the choice of tools but the instrument used, the nature of collected data, as well as the choice of the theoretical framework, used in this study highlights the role of students' goals in relation to their tool use.

If we accept that undergraduates' exam-driven goals are among the factors influencing their tool choices, what/who influences their goals, i.e. why students pursue such goals (and thus make certain tool choices)? The nature of the identified purposes is central in answering this question: all but one of the identified remote goals are related to assessment i.e. they reflect *the rules of the activity system that undergraduates act within*. If we conceptualise students' object as "to obtain a mathematics degree" (mathematics undergraduates) or "to pass a mathematics module" (engineering undergraduates), then any form of assessment is among the rules that govern their activity systems. In other words, "artefacts are not only evoked and employed according to the nature of the subject and the action to be performed on it. Their selection and formation is simultaneously moulded by the rules and the division of labour characteristic to the activity system in which the actions take place. Rules and division of labour are relatively constant, systemic features of the activity" (Engestrøm, 1990b).

6.3 Interview Data Analysis and Results

In the following sections, results from the interview data analysis are presented. First, I describe the overall structure of my coding frame (section 6.3.1), its main categories (section 6.3.2) and their subcategories (section 6.3.3) and finally, in section 6.3.4 I present a summary of the results and RQ4 (what factors can account for undergraduates' tool choices?) is answered by virtue of the coding frame's categories and subcategories.

6.3.1 Description of the Coding Frame

The coding frame for analysing interview data was created by adopting a Qualitative Content Analysis (QCA) approach (Schreier, 2014). Interviews were not fully transcribed and instead, sections mainly related to how undergraduates use each tool from their top-5 list (covering on average over 70% of interview time) and their reasons for choosing these specific tools were transcribed and used for building the coding frame[48]. Each interview's transcribed sections correspond to the interview protocol's questions 5, 6, 7, 10 and 11 (see Appendix C). An example of a fully transcribed interview is provided at Appendix E.

During the early stages of my analysis, it was evident that interview data could be best described/summarised by a coding frame consisting of main categories stemming from both Leontiev and Engestrøm's versions of Activity Theory. In particular, the notions of ***purposes***, ***goals*** and ***conditions*** (Leontiev); ***subject***, ***tools***, ***object***, ***community***, ***rules*** and ***division of labour*** (Engestrøm) were utilised as means for capturing the factors accounting for undergraduates' tool choices (Figure 6.15). In this way, data were analysed at two different planes, the ***individual*** (Leontiev) and the ***collective*** (Engestrøm); thus, factors related to undergraduates' tool choices were treated as either mostly related to an undergraduate's praxis (individual) or to the wider sociocultural context within which an undergraduate acts (collective).

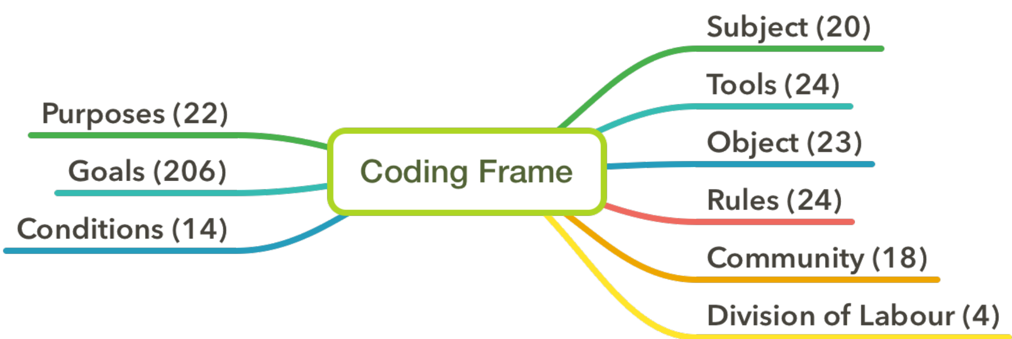


Figure 6.15: My coding frame's main categories for analysing the interview data. On the left are placed the dimensions related to Leontiev's version of AT and on the right the ones related to Engestrøm's version of AT. Coding frequencies are provided within each parenthesis.

In order for this blend of AT approaches to work best, I adopted Kuutti's (1996) approach which also combines the two versions of AT. In particular, Kuutti (1996)

[48] Still, approximately 80% of each interview was needed to be transcribed.

by combining Leontiev and Engestrøm's versions of AT, suggested a classification of how technology can potentially support activities (Table 6.43). For example, technology can help subjects to manipulate and transform an object (action level support) or can enable an entity to become a common object (activity level support). In a similar way, Ritva Engestrøm (1995) conceptualised social talk by adding levels to an activity system: she suggested that an individual subject's activity level (Leontiev) is actually the activity system (Engestrøm) which exists outside the subject and "reveals itself as external collective activity rather than as individual consciousness" (*Ibid.* p.201). By doing so, I was able to differentiate between levels of the same instance in the interview data, i.e. how subjects experience their activity system (Engestrøm) at the different levels of their individual activity (Leontiev).

Table 6.43: Examples of how technology can support components of an activity system at different levels. Adapted from (Kuutti, 1996, p. 36).

	Operation level support	**Action level support**	**Activity level support**
Tools	Automating routines	Making tools and procedures visible and comprehensible	Enabling the automation of a new routine or construction of a tool
Object	Providing data about an object	Making an object manipulable	Enabling something to become a common object
Subject	Triggering predetermined responses	Supporting sense-making actions within an activity	Supporting learning and reflection with respect to the whole object and activity
Rules	Embedding and imposing a certain set of rules	Making a set of rules visible and comprehensible	Enabling the negotiation of new rules
Community	Creating an implicit community by linking work tasks of several people together	Supporting communicative actions	Enabling the formation of a new community
Division of labour	Embedding and imposing a certain division of labour	Making the work organisation visible and comprehensible	Enabling the reorganisation of the division of labour

As already mentioned, combining Leontiev and Engestrøm's frameworks for analysing the interviews was supported by the data themselves and this analytical decision enabled me to identify factors affecting undergraduates' tool choices in a more inclusive way. To be more specific, when students were describing how they choose and use online videos, in many cases they referred to the mathematical content as playing a crucial role in choosing a certain online video or not using online videos at all (and thus choosing another tool). For instance, SI11 said:

> There are some topics where I can't find a video… And that happens a lot with university… During A-levels and GCSE there's so much more material like more videos… Whereas at university it's quite limited…

As we shall see in the following sections, an online video's relevance to university mathematics was one of the factors identified as playing a role in choosing to use or not an online video. Since undergraduates' object is related to obtaining a mathematics or engineering degree, mathematical content is an integral aspect of their object (to a greater extent for mathematics students and to a less degree for engineering students). Thus, the most appropriate way of describing this factor in AT terms, was to conceptualise an online video's mathematical content as an undergraduate's object at the actions/goals level for example. In sum, by conceptualising undergraduates' individual activities as embedded within their activity system, allowed me to identify how students' activity is placed within the wider sociocultural environment and how certain aspects of this environment affect different levels of the activity.

6.3.2 Defining the Main Categories

The main categories of the coding frame for analysing the interview data were all based on concepts stemming from Leontiev's and Engestrøm's versions of AT (concept-driven categories) and in total 9 were created: ***purposes***, ***goals***, ***conditions***, ***subject***, ***tools***, ***object***, ***community***, ***rules*** and ***division of labour*** (Figure 6.15). The main categories were treated as ***aggregators of factors affecting tool choices*** at both the individual (purposes, goals, conditions) and the collective planes (subject, tools, object, community, rules, division of labour) of a subject's activity. As per usual in QCA approaches (Schreier, 2014), for each main category a definition was created and included: the main category's name (indicating what the category refers to), its description (what is meant by this category and its characteristics), indicators (signs that point to the presence of a phenomenon), examples of the main category as found in the material and if necessary decision rules (e.g. if there is an overlap between two main categories). The definitions for the 9 main categories are presented at

Table 6.44-Table 6.52.

Each definition here and in the following sections contains examples taken from the interviews of what each main category and its subcategory captures, however, not all excerpts are equal i.e. there are examples demonstrating very well the content of a main category whereas others do not. This could be solved by assigning a weight to each coded segment but in keeping things simple, I avoided this approach.

Table 6.44: Definition for the main category ***purposes***.

Name	**Purposes**
Description	Purposes frame thematically related actions i.e. they are the "why" of ensembles. The goals of these actions accumulate towards achieving a purpose (González et al., 2009). Purposes appear as higher level goals that justify a series of actions and can be conceptualised as placed high in the hierarchy of an individual's activity. This main category captures higher level goals that allow students to have a long-term perspective of their workload.
Indicators	Instances of higher level goals allowing students to plan in a long-term perspective their activity.
Example	"So yeah, that's usually the method that I use on Learn.. I think I do this because.. obviously problem sheets are usually **similar style questions to what the exam is going to ask** hum.. And obviously if I do the problem sheets **I'll probably be better prepared for the actual examination..**" (SI7)
Decision rules	If a segment can be best described as a lower in the hierarchy goal, then code it as a goal and not purpose.

Table 6.45: Definition for the main category ***goals.***

Name	**Goals**
Description	This dimension captures what a student wants to achieve in a given situation while studying. From an Activity Theory perspective, goals are conscious and they behave like an action's object, i.e. they are the why of an action. Segments coded as goals should reveal an aim or intention.
Indicators	Goals are usually identified by the presence of a preposition (for, to, in) and they answer the question "why did you act like that?" or "what did you want to achieve?"
Example	"I think.. when it comes to videos I try and.. because it's someone I don't know or someone different to [my lecturer] or who ever teaches me.., it's.. what I am hoping is that they sort of **explain it in a slightly different way**.." (SI12)
Decision rules	No decision rules were required.

Table 6.46: Definition for the main category ***conditions.***

Name	**Conditions**
Description	Conditions refer to non-subjective characteristics of the objective world shaping a person's actions (Roth & Lee, 2007). The dimensions capture non-subjective factors affecting a subject's tool choices.
Indicators	References to characteristics of the material world shaping a subject's tool choices.
Example	"In the day time, I will obviously ask them to their face because they are like sat next to me or something but I don't live with anybody that does maths so I can't just pop and ask them… (SI9)
Decision rules	No decision rules were required.

Table 6.47: Definition for the main category ***subject.***

Name	**Subject**
Description	The "individual or sub-group whose agency is chosen as the point of view in the analysis" (Engestrøm, 1990a, p.79). In contexts related to using technologies the subject refers to points of view of users (Nardi, 1996). This category captures students' opinions in relation to using a tool or a subject's characteristics that affect choosing (or not) a tool.
Indicators	A subject's opinion or characteristics that appear having an impact on his/her tool choices.
Example	"I like using my notes because… **they're a personalised resource**, so when I'm/ so I use them in the revision, they're good for me because I've made them myself…" (SI1) "Because, actually quite clearly here… I also have dyslexia as well so… sometimes I can't always read his [the lecturer's] handwriting…" (SI10)
Decision rules	No decision rules were required.

Table 6.48: Definition for the main category ***tools.***

Name	**Tools**
Description	Tools are aspects of the material world that have been modified over time and have been incorporated into goal directed action (Cole, 1996). They mediate the relationship between subjects and their object (Bellamy, 1996). This dimension captures factors affecting undergraduates' choices related to a tool's characteristics.
Indicators	Instances of a tool's properties or features.
Examples	"So, I think it's easier for us to communicate on that... Because I can **just take my phone and just take a picture of the problem**…" (SI7)
Decision rules	No decision rules were required.

Table 6.49: Definition for the main category ***object.***

Name	**Object**
Description	"The 'raw material' or 'problem space' at which the activity is directed and which is moulded or transformed into outcomes with the help of... tools" (Engestrøm, 1993 p.67). What gives activities "attention, motivation, effort, and meaning" (Engestrøm, 2009, p.304). Due to the nature of students' activity, this dimension captures how the mathematical content influences students' tool choices.
Indicators	References related to how mathematical content affects tool-use.
Examples	"There are some topics where I can't find a video… And that happens a lot with **university** [mathematics]… During A-levels and GCSE there's so much more material like more videos… Whereas **at university it's quite limited**…" (SI11)
Decision rules	No decision rules were required.

Table 6.50: Definition for the main category ***community.***

Name	**Community**
Description	Community consists of "the social group that the subject belongs to while engaged in an activity" (Yamagata-Lynch, 2010, p.2) or more specifically to "multiple individuals and/or sub-groups who share the same general object and who construct themselves as distinct from other communities" (Murphy & Rodríguez-Manzanares, 2013, p.38). This dimension captures how members of a subject's community influence his/her tool choices.
Indicators	References to other students and lecturers related to using or not a tool.
Examples	"Wolfram Alpha… I started using [it] when I came to University maybe, I think we… **one of my lecturers used it in a lecture**... maybe like in the second week of term in first year and I was like wow that's quite cool..."
Decision rules	No decision rules were required.

Table 6.51: Definition for the main category ***rules.***

Name	**Rules**
Description	Rules are a set of "explicit and implicit regulations, norms and conventions" (Engestrøm, 1990a, p.79) that "constrain activity... [and] inherently guide (at least to some degree) ... the activities acceptable by the community" (Jonassen, 2000 p.103 cited in Murphy & Rodríguez-Manzanares, 2013). In other words, rules constitute the formal or informal mechanisms controlling the operation of an activity system (Cowan & Butler, 2013). This category captures how the rules of students' activity system shape their tool choices.
Indicators	References to formal and informal rules that influence undergraduates' tool choices.
Example	"I don't know **it might sound a bit cheeky** if I just ask someone I don't really speak to everyday, "how you do this?" and then just not speak to them.." (SI7)
Decision rules	No decision rules were required.

Table 6.52: Definition for the main category ***division of labour.***

Name	**Division of Labour**
Description	Division of labour describes "how the activity is distributed among the members of the community, that is, the role each individual in the community plays in the activity, the power each wields, and the tasks each is held responsible for" (Bellamy, 1996, p.125). This main category captures how the division of labour in a university setting affects students' tool choices.
Indicators	References to the different roles that undergraduates and lecturers have and may affect tool-use.
Examples	"Maybe if there's something you don't quite understand, **you are more comfortable stopping your friend** and explain it **than maybe stopping a lecturer**…" (SI7)
Decision rules	No decision rules were required.

6.3.3 Generating the Subcategories

After coding all interviews with the six main categories of my frame, I started creating subcategories for each dimension. Almost all subcategories were generated in a data-driven way, except the subcategories for ***goals*** where a mixed approach was used (both data and concept driven).

6.3.3.1 Purposes

In total 22 segments were coded as ***purposes***. As already described in the definition for ***purposes*** (

Table 6.44), this main category captures goals that seemed to be higher in the hierarchy of students' goals because they appear to guide and structure students' whole activity, in the sense that lower level goals accumulate in achieving a higher-level goal i.e. a purpose. The examples provided at Table 6.53, demonstrate this and they also show that all but one segments coded as ***purposes*** are related to exams. Thus, the subcategories created for ***purposes*** (Figure 6.16) were ***exams*** (Table 6.54) and ***prepare*** (Table 6.55). The tools associated with each example at Table 6.53 demonstrate that tools not directly related to exams are also used for such purposes and this offers an additional validity to my analysis because these tools are not only directly related to exams e.g. as in the case of past papers.

Figure 6.16: The two subcategories for purposes and their coding frequencies (numbers in parentheses).

Of course, not all students were able to express themselves in a way allowing the identification of ***purposes*** but there were also numerous examples of lower level goals pointing towards exams (see section 6.3.3.2). What distinguishes ***purposes*** from lower level goals is that the latter, when expressed, they are not directly related to a specific action as in the case of goals related to exams but appearing to be limited in scope. In this sense, although there were examples of lower level goals related to exams, these seemed to have local power rather than universal as in the case of ***purposes***. Despite that, I recognise the possibility that these lower goals could also be ***purposes*** but students didn't express them as such.

Table 6.53: Examples demonstrating the exam-driven nature of students' ***purposes*** as identified in the interview data.

Participant	Segment coded as ***Purpose***	Associated tool(s)
SI10	"I will only use the notes really to help me with the exercises in the HELM workbook because I know… ***the aim of this… module is to pass the exam you know…*** that's really why I am doing the module… well that's not quite right but.. You know the.. Basically, I have to/ ***I'm learning the maths.. basically just so I can sort of pass the exam you know…*** Of course I enjoy the maths and I like understanding it but.. you know that's what obviously the university is set up/ before you.. you have to learn the maths so, you pass the exam.. so I have to look at the HELM workbooks, see the exercises/ see what might be in the exam and then use my own notes to help.. understand the exercises and.. help me with the exercises.. that's how I'd use my own notes if that makes sense…"	Notes, HELM workbooks
SI2	"I went.. this time.. I went through back over all the tutorial sheets and I liked to do as many past papers as I can as well.. ***cause then I know what to expect.. And like if you're looking at past papers it's, it's kind of a realistic expectation of what the exam's gonna be*** so that's why I like to do them, I literally just do as many things as I can and… if I'm stuck on a certain question, I'll like flip back through my own notes and work through it that way but I just work through as many questions as I can.."	Tutorial problem sheets, past exam papers, notes
SI13	"..and again what I hope to achieve from that.. I suppose.. ***to be able to answer the questions in the exams*** because.. they are similar… they are going to be similar to those.."	HELM workbooks
SI5	"Well.. I probably filter all the derivations and stuff that.. I like knowing how they working stuff but ***often we don't need actually know them for the exam..*** So I'll just look for example questions maybe, sometimes write those down and just like the other key bits of information.."	Notes
SI3	"I use them as.. sort of the.. ***what I need to know basically in order to get through the exams…*** and actually what I supposed to be learning…"	HELM workbooks
SI4	"It's because… I actually/ I don't want to just have the answer, I want to learn the method… I want to see what the answer would be and I would use online resources like that to learn the method… So therefore, I teach myself how to apply that knowledge to.. not just that question but if it comes up in the future/ ***it prepares me for exam…*** It comes in two parts, one preparing you for doing it in the real world and one ***preparing you for the exams so you can just do it straight off…*** "	Online tools in general
SI12	"…the first time he said for example, next week or on Monday I'll finish of this topic and I'll start differential equations.. So at that point I think to myself over the weekend.. I'll sort of find my books and just have a quick../ ***retro quick flick of what is differential equations, how to do them, just sort of.. so I am prepared for the next lecture…*** so I sort of think… Ok, this is how we did them, whether it's similar or different to the method Joe will use, I will sort of be prepared of what to do… So.. have a look a t first and then after a lecture again, I'll probably go back to my notes, my old notes and have a look, do they work, is it the same.. if it's the same or the same level I'll sort of keep the notes somewhere near.. and then just come back to them if I need to…	Pre-university notes

Table 6.54: Definition for the subcategory ***exams.***

Name	**Exams**
Description	A purpose related to a module's final examination.
Indicators	Purposes containing the word "exam".
Example	"..and again what I hope to achieve from that.. I suppose.. to be able to answer the questions in the exams because.. they are similar… they are going to be similar to those.." (SI13)
Decision rules	No decision rules were required.

Table 6.55: Definition for the subcategory ***prepare.***

Name	**Prepare**
Description	A purpose related to preparation prior a lecture or a tutorial.
Indicators	Purposes containing the word "prepare" or similar.
Example	"So at that point I think to myself over the weekend.. I'll sort of find my books and just have a quick../ retro quick flick of what is differential equations, how to do them, just sort of.. so I am prepared for the next lecture…" (SI12)
Decision rules	No decision rules were required.

6.3.3.2 Goals

In total, 206 segments were coded as ***goals***. The generation of subcategories for ***goals*** took place in two phases. Firstly, all ***goals*** were coded in an in-vivo fashion and based on each goal's surrounding context (what the interviewee was saying in the interview transcript), they were organised into subcategories (in a data-driven manner). To be more specific, the process of generating subcategories for ***goals*** during the first phase, was based on identifying whether the under-examination goal was ***framed*** by another goal that could be thought as being higher in the hierarchy of a student's activity. In order to make this process clear, two examples are provided in the following.

While student SI1 was describing how he uses various resources hosted on the Learn website, he mentioned accessing worked solutions of problems uploaded by his lecturer. He said:

> "So, then I can go on to the worked solutions for that particular topic... hum... and then compare, ***compare what the lecturer sees as a model solution to my solution***, so this is, this is, this is an example of why I think Learn's great because ***this is the exact kind of questions which I'm going to be asked in the exam***, so I can see a direct example and also a direct example of what the lecturer believes is the model answer..."

In the above excerpt, the student's goal coded as ***copy lecturer*** ("…compare what the lecturer sees as a model solution…") is ***framed*** by a goal coded as ***assessment*** ("…this is the exact kind of questions which I'm going to be asked in the exam…"). Thus, the goal ***copy the lecturer*** is related to exams and thus should be classified as the subcategory ***assessment***.

In a similar manner, while student SI14 was describing how he constructs and uses his notes, he was asked about his aims and replied:

> "…in terms of what I want to achieve, I want to ***condense*** it down as much as I can, so.. lots of steps, lots of colour, just to condense it… and if there's something I am not sure of, then I will use one of the other resources to kind of back it up and make sure I am writing the right thing…"

When asked why he condenses his notes, SI14 replied:

> "Um.. I think.. Why am I condense them? It is just neater and it's just/ you think/ because I use them as a ***referral*** for when I am doing questions../ So if I am ***doing a question paper*** and I get to something I don't quite know, I'll go to my notes and then see/ok this is the process and I'll just see it straight away/ I'll just think much quicker instead of not having to read through "Probability is the…" So that's why I want to condense them."

In the above, the goal ***condense*** is framed by another goal, that is using condense notes as a reference source when ***practising*** i.e. when trying to solve problems (usually found on tutorial problem sheets). Thus, the goal ***condense*** was treated as a subcategory of the goal ***practice*** (which was also identified several times as a "standalone" goal).

The second phase entailed the generation of subcategories for goals that could not be subsumed further by applying the above technique. This concerned goals related to understanding and for that reason, Sierpinska's (1990) conceptualisation of understanding was used (meaning that these subcategories were created in a data-driven way). Sierpinska (1990; 1994) based on the ideas of Locke[49] (1690), Dewey[50] (1910) and Hoyles (1986) about understanding, proposed four types of understanding or as she calls them "acts of understanding":

1. ***Identification***: related to discovering or recognising the object of understanding which belongs to the concept in question. The act of identification involves the introduction of a hierarchy into what the subject conceives as important.
2. ***Discrimination***: related to distinguishing between two objects, properties or ideas that were confused before.
3. ***Generalisation***: related to becoming aware of non-essential characteristics of

[49] Sierpinska (1990) mentions that Locke distinguishes four types of understanding: (1) identifying ideas and discriminating between ideas; (2) finding relations between ideas; (3) discovering properties of a complex idea and; (4) finding relations to reality

[50] Sierpinska (1990) summarises Dewey's ideas about understanding as: (1) identifying an object; (2) experiencing the object (3) generalising from the experience gained on other objects; (4) discriminating between properties of an object; (5) applying in order to explain new cases of objects and; (6) synthesising

an assumption or of the possibility of extending the range of applications. In other words, generalisation relates to recognising that the object of understanding is a special case of another object.

4. ***Synthesis***: related to grasping relations between two or more facts or objects and organise them in a consistent whole. It means searching for a common link or a unifying principle between several generalisations and view them as a whole.

Sierpinska notes that the required condition for the above acts to take place, is what Dewey (1910) mentions as ***applying*** (explaining new cases with the help of an already discovered case) or in Hoyles' (1986) words ***using*** (using a concept as a tool to achieve a particular goal) which in our case are of course concepts related to ***practising mathematics***. Sierpinska uses her conceptualisation of understanding for analysing students' learning of mathematics mostly at a micro level and speaks mainly about acts of understanding that have a local character e.g. *identifying* the crucial role a geometric figure has in a proof or grasping the idea of a mathematical proof by *synthesising* its steps; she does however mentions examples of acts of understanding that have a more global character e.g. *synthesising* vast domains of mathematical knowledge. Finally, Sierpinska notes that acts of understanding are difficult to be organised into a hierarchy but recognises that there do exist different degrees within each act of understanding, e.g. different degrees of identification or discrimination for example.

Due to the low level of details captured by the interview data, it was not possible to create subcategories covering all types of understanding as discussed by Sierpinska and in fact, the most frequently identified goal was ***understanding*** itself (which of course did not allow discriminating further this goal since students were simply referring to understanding as one of their goals without providing further details). Nevertheless, Sierpinska's framework helped me to better distinguish between goals and generate subcategories in a more consistent way.

For ***goals*** (Table 6.56), two subcategories were generated (Figure 6.17): ***assessment*** and ***understanding***. The subcategory ***assessment*** includes goals related to identifying the structure of exams, practising for exams (e.g. working with past papers and timing the effort), getting good grades, knowing the exam content, coursework and copying the lecturer's way of solving exam questions. Tables Table 6.57 and Table 6.58 provide the definition for ***assessment*** and examples demonstrating the nature of this subcategory.

Table 6.56: Definition for the main category ***goals***.

Name	**Goals**
Description	This dimension captures what a student wants to achieve in a given situation while studying. From an Activity Theory perspective, goals are conscious and they behave like an action's object, i.e. they are the why of an action. Segments coded as goals should reveal an aim or intention.
Indicators	Goals are usually identified by the presence of a preposition (for, to, in) and they answer the question "why did you act like that?" or "what did you want to achieve?"
Example	"I think.. when it comes to videos I try and.. because it's someone I don't know or someone different to [my lecturer] or who ever teaches me.., it's.. what I am hoping is that they sort of **explain it in a slightly different way**.." (SI12)
Decision rules	No decision rules were required.

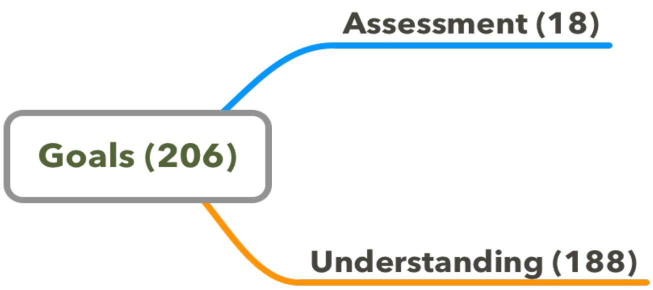


Figure 6.17: The two subcategories for goals and their coding frequencies (numbers in parentheses)

Table 6.57: Definition for the subcategory ***assessment***.

Name	**Assessment**
Description	A goal related to any type of assessment.
Indicators	Any goal related to exams, coursework or in-class test.
Example	"Notes… are sort of have a look… what I need to know… At least for the exams, just have a look" (SI12)
Decision rules	No decision rules were required.

Table 6.58: Examples demonstrating the nature of the subcategory ***assessment***.

Participant	Segment coded as ***assessment***	In vivo code
SI3	"…the biggest aim is to ***get used to the structure in which then people ask questions*** um.. because that's something that always you have to get used to.. So from GCSC to IB to uni the way they structure their questions is all different.. um.. and it's just getting used to being able to sit down on that chair in the hall and know exactly where to start so…"	Exam structure
SI5	"Um.. I'll often ***try and time myself*** because time is always an issue for me, cause quite often I know I can get there it just takes me (laughing).. So that's the main reason for…"	Time myself
SI7	"For the final exam so.. That's something that ***I'd do before the exam*** um.. Just ***work through it as if it was the exam***.. I also use the past exam papers…"	Practice for exams
SI4	"I found it very helpful… [practice papers found on Learn] it helps you ***get good marks*** for the class test and also it is very nice to review closer the exams"	Good marks
SI12	"Notes… are sort of have a look… ***what I need to know… At least for the exams***…"	Exam content
SI11	"Then there's ***guidelines for the coursework***… [on the Learn website] I.. I always like to know how it's ***structured*** but I put it on my phone so… I'll write that… these are the deadlines I have so I make sure I know it…"	Coursework structure
SI1	"I can see a direct example and also a direct example of what ***the lecturer believes is the model answer***…"	Copy the lecturer

For ***understanding*** (Table 6.59) 4 sub-subcategories were generated: ***understand, practice***, ***identification***, ***reality*** and ***alternative views***. The sub-subcategory ***understand*** contains goals related to ***understanding*** but since these goals were not discriminated further by the students, it was not feasible to classify them further. In this sense, it is a pseudo sub-category and thus no definition is provided since it is covered by the definition of ***understanding***.

Table 6.59: Definition for the subcategory ***understanding***.

Name	**Understanding**
Description	Goals related to students' understanding of mathematics.
Indicators	Goals containing the words "understand", "learn", "knowledge".
Example	"…with that.. [online videos] what I am achieving is thorough understanding.." (SI11)
Decision rules	No decision rules were required.

The sub-subcategory ***practice*** captures goals related to Dewey's notion of ***applying*** or Hoyles' notion of ***using*** and are thus related to ***practicing mathematics***. Goals in this sub-subcategory are related to students' intentions of solving problems i.e. practising mathematics. In many instances students simply referred to their aim as being solving a problem given to them (e.g. with tutorial problem sheet) but in others lower level goals were framed by their intention to practice mathematics. These goals were related to verifying a mathematical result when working on a problem (e.g. by using Wolfram Alpha), learning a method for solving a particular problem (for example as demonstrated in HELM workbooks), making and using a tool as a reference when solving a problem (e.g. condensing lecture notes) or even memorising a proof as part of practicing mathematics. The definition for ***practice*** and some examples are provided at Table 6.60 and Table 6.61.

Table 6.60: Definition for the sub-subcategory ***practice***.

Name	**Practice**
Description	Goals related to the practical aspect of understanding mathematics.
Indicators	References to solving problems containing the words "practice", "problems" and "working".
Example	"…each week, during the weekend, I tried to tackle the problems in the subjects [topics] he gave us, in order to keep up to date and…" (SI8)
Decision rules	No decision rules were required.

Table 6.61: Examples demonstrating the nature of the sub-subcategory ***practice***.

Participant	Segment coded as ***practice***	In vivo code
SI9	"I usually use Wolfram Alpha if I had to draw a graph and I just want ***to double check that I've done it right***…"	Verify
SI10	"Generally to just.. I guess… understanding the question, I feel a lot of the time is actually.. understanding what I need to be looking at for a label to recognise and.. using that to solve it.. you know.. ***the steps basically.. learning the steps, the process in which I need to go through*** in order to solve the exercises…" [referring to using the HELM workbooks]	Learn the method
SI14	"..in terms of what I want to achieve, I want to ***condense it*** [the notes] down as much as I can, so.. lots of steps, lots of colour, just to condense it.. and if there's something I am not sure of, then I will use one of the other resources to kind of back it up and make sure I am writing the right thing.."	Condense
SI4	"[Why condense your notes?] …because I use them as a ***referral for when I am doing questions***../ So if I am doing a question paper and I get to something I don't quite know, I'll go to my notes and then see/ok this is the process and I'll just see it straight away/ I'll just think much quicker instead of not having to read through "Probability is the…" So that's why I want to condense them.."	Reference
SI5	"So I'll just turn up to the tutorial with my [HELM] workbook, quite often now we are actually covering content in the tutorial as well, like they'll do an ***extra example that you sort of really need*** and if you are not going to the tutorial and like miss out on that…"	Example you need
SI13	"Basically because I like loads of different examples they give you and.. like.. yeah like little tests you could do throughout the [HELM] workbooks.. so I suppose I ***just try to go through all of them***…"	Practice
SI11	"I will keep either reading that [notes], ***memorising*** it or I will write it out… so if there's a proof I'll keep writing out on a scrap paper and then I'll throw it away and then I'll rewrite it, throw it away and rewrite it until I memorise and then understand it as well…"	Memorise

Identification (Table 6.62) refers to Sierpinska's first type of understanding and contains goals related to students' intentions in recognising the "object" of their understanding i.e. identifying what is to be understood. None of the goals in this sub-subcategory were coded as such but they were rather subsumed after examining their content. Table 6.63 provides some examples demonstrating the nature of these goals.

Table 6.62: Definition for the sub-subcategory ***identification***.

Name	**Identification**
Description	A goal related to identifying the "object" of understanding.
Indicators	References related to students' efforts in recognising the "object" of their understanding e.g. when being introduced to a new topic for the first time or identifying what is important for them to understand.
Example	- "If he's going on to a new topic, I use his lecture as a source of opening an introduction to whatever this topic is, write down, hear what he's saying or what he's written…" (SI4)
Decision rules	No decision rules were required.

Table 6.63: Examples demonstrating the nature of the sub-subcategory ***identification***.

Participant	Segment coded as ***identification***	In vivo code
SI2	"…what I'll do kind of.. to check it works or it's what I'm looking for [the online video].. I'll kind of have a quick look here… Sometimes.. I just like to look.. I wanna ***check it's got what I wanna learn about on*** it as opposed to too much detail or too little so it saves a little bit of time if I looked down I find like actually there's too much information..	Identify important
SI11	at the start of the year, I read these "module structure" [information about the module in pdf format] and.. I.. either print it out or I make my own version… So.. I know how that module is structured and ***what we are going to be taught***…"	Module structure
SI14	"If he's going on to a ***new topic***, I use his lecture as a source of ***opening an introduction*** to whatever this topic is, write down, hear what he's saying or what he's written…"	Introduction
SI10	"My own written notes.. I probably tend to use those… Sort of towards.. I don't know.. probably just before I'm started to revise for exams.. So I use them more to just get a.. ***general overview of what's going on***…"	Overview

Reality (Table 6.64) derives from Locke's writings and refers to identifying relations between the "object" of knowledge and reality (not incorporated by Sierpinska into her acts of understanding but still different to identifying relations between objects as in ***synthesis*** for example).

Table 6.64: Definition for the sub-subcategory ***reality***.

Name	**Reality**
Description	Identifying connections between the "object" of knowledge and reality.
Indicators	References to how mathematics is connected or applied in real life situations.
Example	"Also context.. they provide a lot of context as well.. [the HELM workbooks] So if I think, how on earth in the real world am I going to use equation that we've learned.. then they have really good practical examples on that…" (SI14)
Decision rules	No decision rules were required.

Finally, the sub-subcategory ***alternative views*** (Table 6.65) was created in data driven way and does not correspond to any of Sierpinska's acts of learning. The goals included in this sub-subcategory are related to students' intentions of finding different or multiple explanations of a mathematical topic. The analytical decision to include this as a standalone sub-subcategory was due to the fact that ***alternative views*** seemed not to fit within any of Sierpinska's types of understanding. Table 6.66 provides some examples demonstrating the nature of these goals.

Table 6.65: Definition for the sub-subcategory ***alternative views***.

Name	**Alternative views**
Description	Finding for alternative perspectives i.e. different explanations of a mathematical topic.
Indicators	References to students' goals related to finding alternative explanations.
Examples	"...but in terms of actually learning and gaining understanding I think you need different perspectives so that's talking to my fellow students, talking to lecturers, talking to../ or you know watching an online video which explains it." (SI14)
Decision rules	No decision rules were required.

Table 6.66: Examples demonstrating the nature of the sub-subcategory ***alternative views***.

Participant	Segment coded as *alternative views*	In vivo code
SI14	"…but in terms of actually learning and gaining understanding I think you need ***different perspectives*** so that's talking to my fellow students, talking to lecturers, talking to../ or you know watching an online video which explains it."	Different explanation
SI12	"I think.. when it comes to [online] videos I try and.. because it's someone I don't know or someone different to [my lecturer] or who ever teaches me.., it's.. what I am hoping is that they sort of ***explain it in a slightly different way***.. or maybe/ even if they write the same thing, maybe something they say will just click and I think.. oh I get this now.. or even if they just write something or make a little note somewhere, then I think oh, I now understand this.. So just usually trying to get someone else explaining it hopefully in a different way…"	Different explanation
SI6	"…mostly my goal is to see their opinion as well.. Because as I've told you it's really good to see what others.. like you know people with you, went through the same process of learning I have in mind or they're trying to see.. what their work is going to be on or how they approach a problem.."	What others do
SI11	"So I like to see if a student has asked a question because… Something they want to know it might be something that I want to know…"	What others do

An overview of the subcategories and sub-subcategories for ***goals*** is presented at Figure 6.18.

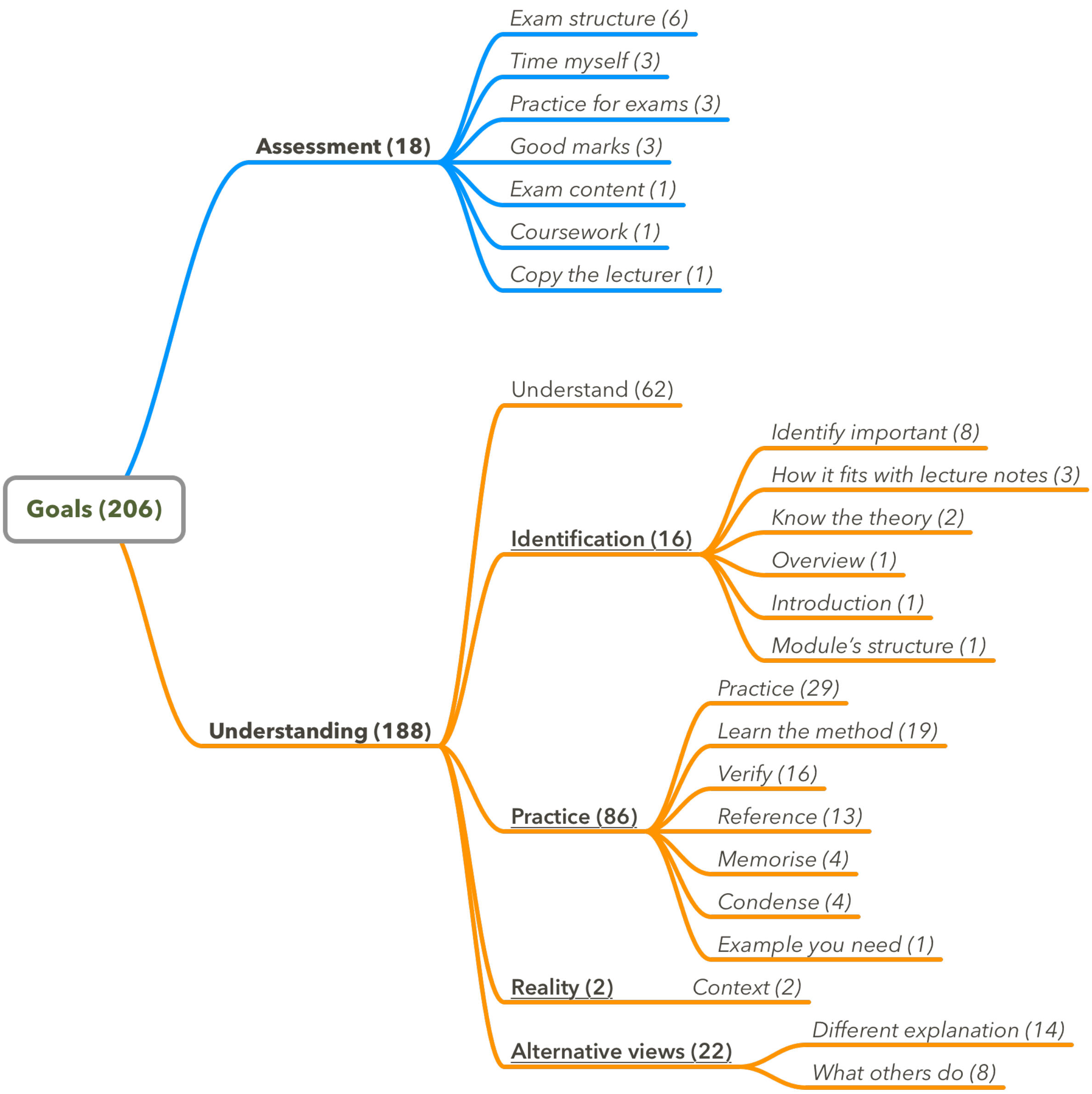


Figure 6.18: An overview of the sub- and sub-subcategories for the dimension ***goals***. Subcategories are in boldface, sub-subcategories are underlined and in-vivo codes are in italics. Coding frequencies are found in each parenthesis.

6.3.3.3 Conditions

As we saw at the diary data analysis section, conditions are non-subjective factors affecting a person's activity. In total, 14 segments were coded as ***conditions*** (Table 6.67). By using a data driven approach, 3 subcategories were generated (Figure 6.19): ***habitat*** (Table 6.68), ***biology*** (Table 6.69) and ***internet*** (Table 6.70).

Table 6.67: Definition for the category ***conditions***.

Name	**Conditions**
Description	Non-subjective characteristics of the objective world shaping a person's actions.
Indicators	Factors affecting the way a subject acts, in a positive or negative way.
Example	"So, not so much this year because I've had like other ways of researching things, so like at Christmas I was away but I was staying with a friend who's actually got a maths degree, so as opposed to like looking for a video, I was just like "can you help me please?" (SI2)
Decision rules	No decision rules were required.

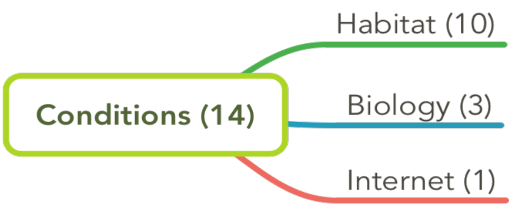


Figure 6.19: The three subcategories for conditions and their coding frequencies (numbers in parentheses).

Table 6.68: Definition for the subcategory ***habitat***.

Name	**Habitat**
Description	Conditions related to the aspects of the physical environment in which a student acts. It can be also related to the proximity of a tool.
Indicators	References related to the surroundings of a student's environment or how far a tool is.
Examples	"In the day time I will obviously ask them to their face 'cause they are like sat next to me or something but I don't live with anybody that does maths so I can't just pop and ask them… So I have to… [use Messenger]" (SI9) "Um.. probably speak to people that I'm in the halls with… It's probably about 4 or 5 maths students spread out… So there's always someone to talk to…" (SI7) "..there's walking to the library and then there's walking to the MLSC, compared to where everyone lives is quite distant, you have to walk to it…" (SI4)
Decision rules	No decision rules were required.

Table 6.69: Definition for the subcategory ***biology***.

Name	**Biology**
Description	Conditions concerning a subject's biological aspects that affect his/her activity.
Indicators	References related to a person's physical condition.
Examples	"Because, actually quite clearly here.. I also have dyslexia as well so.. sometimes I can't always read his [lecturer's] handwriting…" (SI10)
Decision rules	No decision rules were required.

Table 6.70: Definition for the subcategory ***internet***.

Name	**Internet**
Description	Conditions related to internet connectivity.
Indicators	References to internet connectivity.
Example	"Because of my flat.. I don't have very good internet so.. this is something that is actually applicable [not having access to a resource] It is quite irritating…" (SI10)
Decision rules	No decision rules were required.

6.3.3.4 Subject

For the category ***subject*** (Table 6.71) 20 segments were coded and in total, 3 subcategories were created in a data driven way. These are (Figure 6.20): ***learning preferences*** (Table 6.72), ***beliefs about learning or learning environment*** (Table 6.73) and ***beliefs about a tool*** (Table 6.74).

Table 6.71: Definition for the category ***subject***.

Name	**Subject**
Description	The "individual or sub-group whose agency is chosen as the point of view in the analysis" (Engeström, 1990a, p.79). In contexts related to using technologies the subject refers to points of view of users (Nardi, 1996). This category captures students' opinions in relation to using a tool or a subject's characteristics that affect choosing (or not) a tool.
Indicators	A subject's opinion or characteristics that appear having an impact on his/her tool choices.
Example	"I like using my notes because… **they're a personalised resource**, so when I'm/ so I use them in the revision, they're good for me because I've made them myself…" (SI1) "Because, actually quite clearly here… I also have dyslexia as well so… sometimes I can't always read his [the lecturer's] handwriting…" (SI10)
Decision rules	No decision rules were required.

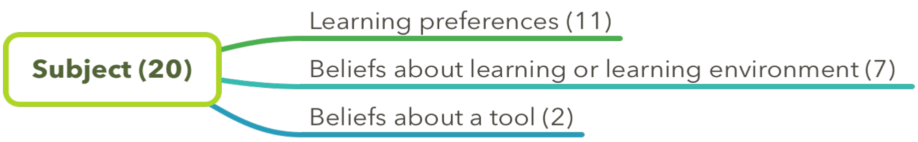


Figure 6.20: The three subcategories for ***subject*** and their coding frequencies (numbers in parentheses).

Table 6.72: Definition for the subcategory ***learning preferences***.

Name	**Learning preferences**
Description	This subcategory captures students' learning preferences i.e. their conceptions about what works best for them as learners.
Indicators	References related to the way a student prefers to learn.
Examples	"I think it's how I learn… I find that I am.. a quite sort of visual learner.. I tend to be so that's why maybe I use more online videos rather than textbooks or anything like that… I just think it's just… what works for me…" (SI10) "Well basically I think that the best way to go in like a university life and the way you're trying to learn something from a lecturer, trying to take some other sources let's say from external sources like the internet in general, something like that, they teach the material in a different way that the lecturer does it, so that confuses me a lot more than trying to understand new methods…Because when you go to a lecture and you have like the lecturer going through something, they do it like a specific way like where they think it's better, although they won't like cut a grade or whatever or you won't lose a mark if you do it in a different method and still is correct but I find it a lot more difficult to try to adapt to a new method than the one I was originally introduced.. So I think that going through an online video and trying or… going to another source which my lecturer didn't approve or he didn't go through it, I find it like a lot harder to understand it.." (SI6) "I suppose it just depends on what kind of learner you are… because like some people are visual learners and other people just like listening.. so if you are a person… like me.. for me I really like doing the examples…" (SD13) "I think it's because I'm actually quite old fashioned when it comes to technology like, I much prefer printing everything of../ like I print all my worksheets of Learn and I find if I've got the computer there like, I sometimes get distracted and stuff, like at school I always used to just have textbooks, like nothing was online and that's just what I am used to.." (SI5)
Decision rules	No decision rules were required.

Table 6.73: Definition for the subcategory ***beliefs about learning/learning environment***.

Name	**Beliefs about learning/learning environment**
Description	This subcategory refers to students' beliefs about what works best for learning in general (not necessarily related to them) and their opinion about their learning environment. This subcategory is related to learning preferences but it is more inclusive since it is not limited to the subject only.
Indicators	References to how "things" work best for learning in general.
Examples	"…which I guess I've never been to the Maths Learning Centre, I guess you can go and do it there as well, it's just like, **sometimes when people are teaching stuff, they kind of explain it one way** and.. even if you asked them to kind of go over it, sometimes they are like, stuck in that way of explaining it. So I just use videos as a different way…" (SI2) "…other students… it's great because… for one it's a break from personal like study on your own, it's nice to have interaction, hum.. and also **I think when you learn maths is always great to have different inputs** hum, they've might say something that you've not considered, you might say something they've might not considered.." (SI1) "Lectures would work if combined with tutorials: 10 minutes lecturing - 20 minutes tutorial. **I don't think any engineering student can say that they learn by listening to maths, they learn by doing maths, that's what an engineering student is an applied learner…** they learn by doing things. So i don't think listening and just sort of.. going by a theory is the best way/ an engineering student would just get bored.." (SI3) "I don't really use the problem sheets as much as I should… [Why?] So… We learn a section and then they'll hand out problem sheets… And these questions are only on the problem sheets… But **it's kind of like in college when you are given homework and you had to do it…**" (SI11)
Decision rules	No decision rules were required.

Table 6.74: Definition for the subcategory ***beliefs about a tool***.

Name	**Beliefs about a tool**
Description	This subcategory corresponds to students' beliefs about whether a specific tool is good or appropriate for learning mathematics.
Indicators	Students' opinion about a tool (positive or negative).
Examples	"I believe that maybe Facebook wouldn't have reliable or worthy resources that would be helpful enough, I just assume that you probably can get more reliable and trustworthy resources just by Googling or look videos at YouTube/ YouTube is quite a big part in helping me, maybe other people but… **I don't just see Facebook as a way to help yourself in the academic way**…" (SI4) "Khan Academy **I just think it's like a really good.. He's just a very good teacher**, he likes explaining it step by step, he's very clear… he gives examples as well which I really like../ And he has all the different parts of the module which I also like.. Like he goes through a different like.. sections, and in each section there's a different categories.. like going from like really easy, like basics to harder.. and he has different names so you know what kind of section he's talking about…" (SI13)
Decision rules	No decision rules were required.

6.3.3.5 Tools

For the category ***tools*** (Table 6.75) 24 segments were coded and in total, 4 subcategories were created in a data driven way (Figure 6.21). These are ***usability*** (Table 6.76), ***accessibility*** (Table 6.77), ***availability*** (Table 6.77) and ***other tools*** (Table 6.79).

Table 6.75: Definition for the category ***tools***.

Name	**Tools**
Description	Tools are aspects of the material world that have been modified over time and have been incorporated into goal directed action (Cole, 1996). They mediate the relationship between subjects and their object (Bellamy, 1996). This dimension captures factors affecting undergraduates' choices related to a tool and can include a tool's characteristics, its availability or even the presence of other tools.
Indicators	Instances of a tool's properties or features.
Examples	"So I think it's easier for us to communicate on that.. Because I can **just take my phone and just take a picture of the problem**…" (SI7)
Decision rules	No decision rules were required.

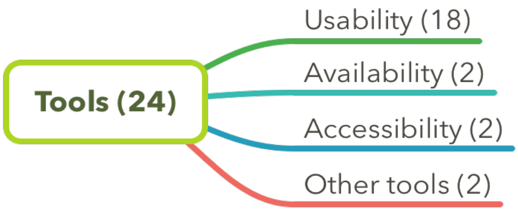


Figure 6.21: The four subcategories for ***tools*** and their coding frequencies (numbers in parentheses).

Table 6.76: Definition for the subcategory ***usability***.

Name	**Usability**
Description	Related to features of a tool that make it easy (or not) to be used. Usability relates also to whether a tool's features can be aligned with a subject's intentions i.e. whether a student can achieve his/her goals by using a particular tool.
Indicators	References of a tool's properties, characteristics that make its use uncomplicated or enable students to achieve their goals.
Examples	"…it's a lot quicker just to type into Wolfram Alpha's some terms.. [in comparison to Mat Lab] (SI5) "As to why I use it [Wolfram Alpha], it's just very quick, gives answers, saves you a lot of time… and it just helps to explain how you'd actually work a question out, how to do it mathematically correct…" (SI4) "So I think it's easier for us to communicate on that [Facebook's Messenger]… Cause I can just take my phone and just take a picture of the problem…" (SI7) "I do both [using a text-based online tool vs a video-based], I just like videos because they're simpler to sort of go through them as opposed to like a really large bunch of text…" (SI2) "I also like the fact that he's organised… [founder of Khan Academy] like his notes are organised, they have different colours and stuff.. I don't know why but it makes it easier for me to understand…" (SI13) "I prefer shorter.. not too short.. I prefer videos [YouTube] around 15 minutes because normally if it's like this, 48 minutes, it's like a whole lecture and he's trying to put so much into one video… whereas I want something brief that's on one topic and like… 15 minutes generally covers something and there's room for examples…" (SI11)
Decision rules	No decision rules were required.

Table 6.77: Definition for the subcategory ***availability***.

Name	**Availability**
Description	This subcategory relates to whether a tool is available or not to a student.
Indicators	References to using a tool because is available.
Examples	"Recommended textbooks/HELM… yeah these.. you know, the university advices you.. you always… So yeah I mean.. If the recourses are there you use them." (SI14)
Decision rules	No decision rules were required.

Table 6.78: Definition for the subcategory ***accessibility***.

Name	**Accessibility**
Description	Relate to how easy or not is to access a tool.
Indicators	References to accessing a tool easily.
Example	"it's so much not easier.. convenient to use these resources, the online stuff on Learn and the notes because there are right there at my disposal, only two clicks from actually looking at them.." (SI8)
Decision rules	No decision rules were required.

Table 6.79: Definition for the subcategory ***other tools***.

Name	**Other tools**
Description	This subcategory refers to how the presence of other tools affects or not undergraduates' tool choices.
Indicators	References to situations where a student does not use tool B because of the presence of tool A.
Examples	"Although interesting enough I don't use the MLSC, nearly as much as maybe.. I could or should… (why's that?) It's an incredible resource but.. yeah I just haven't been… I think… from the tutorials sessions you can kind of answer all of your questions… But yeah… I'm not sure…" (SI14) "I know the… a lot of especially engineering mechanics and maths they say to go to the MLSC but I've never been to it, I don't know why I just never used it… (why?) I don't know… I think that would be the last resort if no one can help me because usually.. someone at the tutorial or a friend or a video can explain it… so… It could be the fact that my notes, the videos and a friend is usually sort of close by, so even if it's a phone call, a Skype, a text or a look in the book.." (SI12)
Decision rules	No decision rules were required.

6.3.3.6 Object

For the category ***object*** (Table 6.80) 23 segments were coded and in total, 3 subcategories were created in a data driven way (Figure 6.22): ***content level*** (Table 39), ***familiarity*** (Table 6.81) and ***availability*** (Table 6.82) and ***mathematics vs other modules*** (Table 6.83).

Table 6.80: Definition for the category ***object***.

Name	**Object**
Description	"The 'raw material' or 'problem space' at which the activity is directed and which is moulded or transformed into outcomes with the help of... tools" (Engestrøm, 1993, p.67). What gives activities "attention, motivation, effort, and meaning" (Engestrøm, 2009, p.304). Due to the nature of students' activity, this dimension captures how the mathematical content influences students' tool choices.
Indicators	References related to how mathematical content affects tool-use.
Examples	"There are some topics where I can't find a video… And that happens a lot with **university** [mathematics]… During A-levels and GCSE there's so much more material like more videos… Whereas **at university it's quite limited**…" (SI11)
Decision rules	No decision rules were required.

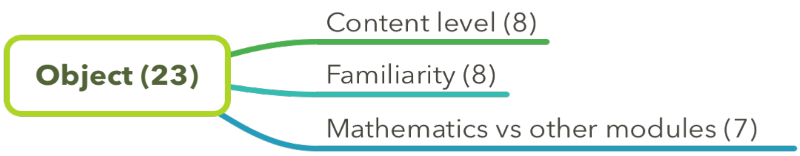


Figure 6.22: The three subcategories for ***object*** and their coding frequencies (numbers in parentheses)

Table 6.81: Definition for the subcategory ***content level***.

Name	**Content level**
Description	This subcategory captures instances of how the content of mathematics at a university level affects undergraduates' tool choices.
Indicators	References to how the content of mathematics at university level affects students' tool choices.
Examples	"I would be using it [www.examsolutions.net] if he actually went up to.. University level but here it goes up to A-level maths…" (SI4) "There's getting less and less resources the higher into education I get… Like I remember in GCSC there was plenty of like BBC Bitesize… [www.bbc.co.uk/education] and then the higher I've got there's less to choose from… less available…" (SI9) "There are some topics where I can't find a video… And that happens a lot with university… During A-levels and GCSE there's so much more material like more videos… Whereas at university it's quite limited…" (SI11) "if it's.. sort of a common topic like differential equations that a lot of people use, they're easier to find [online videos].. whereas as looking for videos on the Fourier transformation.. and I don't know whether it's because I've not done it before or something I just was a bit.. like I wasn't quite sure what I was looking for or what was too much or too little information…" (SI2) "[So on www.examsolutions.net you couldn't find Laplace transformations?] Yes, I couldn't find it, so I went to YouTube…" (SI12)
Decision rules	No decision rules were required.

Table 6.82: Definition for the subcategory ***familiarity***.

Name	**Familiarity**
Description	This subcategory summarises how a student's familiarity with a certain topic/level of mathematics affects his/her tool choices.
Indicators	References to a student's familiarity with a mathematical topic in relation to tools.
Examples	"…so.. if I… so we have a test next week on Laplace transform and.. that's very new to me.. because I haven't done it before so… I would definitely have a look at… read over my notes… videos and as much as possible.." (SI12) "But for maths not really, I think for maths it's… I think for most people../ because maths is something they've done it before.. most people sort of.. understand it or.. understand it more than other modules [that are totally new to them?] that are totally new to them, yeah… so I think at the moment not many people use it [Facebook groups] because.. it is sort of familiar to them, so the know how to sort of work… if that makes sense.. So I don't really use them at the moment.." (SI12) "HELM [workbooks].. I actually../ at the beginning of the year I didn't really used HELM that much.. I think because it was some kind of a repetition from what I've learned before.. at A-levels.. So because of that I didn't feel like I needed the extra support of.. yeah doing other examples.. So I only started using that probably on January, when I started learning new things that I haven't learned before…" (SI13) "I found the topics this year, cause like Fourier series and Fourier transformations I've not done before, so when you look for videos and stuff, like you need to find one that's in context, like, and if you've not really done this subject like that area before, you don't really know what you are looking for as well, in a video or if there's too much information or not enough information, so that's why this time I kind of like asked my friend for help…" (SI2)
Decision rules	No decision rules were required.

Table 6.83: Definition for the subcategory ***mathematics vs other modules***.

Name	**Mathematics vs other modules**
Description	This subcategory reflects the differences between mathematics and other modules as experienced by students. This relates to the nature of mathematics or the way mathematics is translated to teaching practices versus other modules.
Indicators	References to mathematics as driving a student's practice or comparisons with other modules.
Examples	"Um.. Yeah.. I'd probably say with my accounting modules that I purely use just my written notes I think.. Obviously there would be times where I'd speak to people, text people and things/ that they are on that side of my course.. But I think it's a lot different to Maths in the sense that basically last semester I had a law module which I needed to do/ for part of my accounting accreditation.. Basically I just used the notes, cause as long as you learn the cases.. and learn that there's not much more you can do…" (SI7) "And.. to be honest with you, only for mathematics modules, the exercises are so clear between them.. For example, this is eigenvalues, eigenvectors.. In other modules, various subjects are mixed in various exercises, so it's not that easy to actually divide… For mathematics that was very clear.. Bam this is that! And I was mostly using them [past papers] for mathematics/ after that…" (SI8) "I believe in other modules I definitely have to do the tutorials to understand the subject however.. I feel that, for maths once you understand the method, the core staple method, um.. once up there, there might be some tricks that might change it but once you manage to convert that to.. a way where you understand it, so you can apply it through the sort of step, this main method that you've learned, then it's alright../ Cause in maths is sort of logical way where.. Well.. They give you the question and you just have to go for that pattern, that method to break it down and get the answer.. Even though I know there's more intuitive times, sometimes when it comes to exams, it's better to../ It's kind of constrictive, you just want to get the answer.. but you know the method but sometimes it would be nice to actually understand more about what's going on…" (SI4)
Decision rules	No decision rules were required.

6.3.3.7 Community

For the category ***community*** (Table 6.84) 18 segments were coded and in total 3 subcategories were created in a data driven way (Figure 6.23): ***lecturers*** (Table 6.85), ***students*** (Table 6.86) and ***past members*** (Table 6.87).

Table 6.84: Definition for the main category ***community***.

Name	**Community**
Description	Community consists of "the social group that the subject belongs to while engaged in an activity" (Yamagata-Lynch, 2010, p.2) or more specifically to "multiple individuals and/or sub-groups who share the same general object and who construct themselves as distinct from other communities" (Murphy & Rodríguez-Manzanares, 2013, p.38). This dimension captures how members of a subject's community influence his/her tool choices.
Indicators	References to subjects that can be considered as part of students' community such as other students or lecturers that can affect students' tool choices.
Examples	"Wolfram Alpha… I started using [it] when I came to University maybe, I think we… **one of my lecturers used it in a lecture**.. maybe like in the second week of term in first year and I was like wow that's quite cool.."
Decision rules	No decision rules were required.

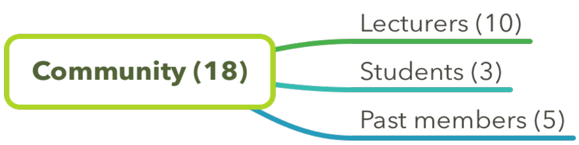


Figure 6.23: The three subcategories for ***community*** and its coding frequencies (numbers in parentheses).

Table 6.85: Definition for the subcategory ***lecturers***.

Name	**Lecturers**
Description	This subcategory refers to the lecturers participating in undergraduates' wider activity.
Indicators	References to lecturers affecting one way or another students' tool choices.
Examples	"I suppose Lecture Capture… [recorded lectures hosted on Learn] the lecturer did say at the end of each lecture if you want to go over this lecture, please go on Learn and you can see the lecture again…" (SI13) "We have seen Wolfram Alpha but actually haven't actually used it, my lecturer this year showed us a couple of examples on, during our lectures and I found it interesting but I will not go to the measure of using it myself unless I have to, see that I actually need its help to actually to understand something…" (SI8) "Wolfram Alpha… Wolfram Alpha I started using when I came to University maybe, I think we… one of my lecturers used it in a lecture in maybe like in the second week of term in first year and I was like wow that's quite cool… […] I mean he wasn't, he wasn't showing to us in terms of you should go and use this, he was just, he just used it to quickly in a lecture and I was like, wow that's quite a good tool" (SI1) "Now.. for mathematics what was happening, last year is that/ because we had two.. two different lecturers for two semesters last year. One had complete lecture notes, you didn't need to write anything, what you written down would be your own stuff.. but he actually did examples during class that you had to write down your shelf… […] The other lecturer actually employed the tactics of gappy notes but he had everything on the notes, even examples and everything.. And that's the difference.. And this year.. every note was handwritten, it was a Greek style of learning, he would write on the board and you'd have to copy everything exactly how he had written, like 5 or something.. And that's how notes were constructed throughout each semester…" (SI8)
Decision rules	No decision rules were required.

Table 6.86: Definition for the subcategory ***students***.

Name	**Students**
Description	This subcategory refers to other students participating in undergraduates' wider activity.
Indicators	References to other students affecting their peers' tool choices.
Examples	"Um.. there's like one or two occasions and then that's when I talk to people on my module again and they'll kind of suggest a video they found helpful and things like that…" (SI2) [Why using other students?] Other students… because we are doing the same thing they understand what questions I'm asking…" (SI9)
Decision rules	No decision rules were required.

Table 6.87: Definition for the subcategory ***past members***.

Name	**Past members**
Description	This subcategory captures community members that have affected a student's tool choices in a previous activity system.
Indicators	References to subjects not part of students' current community that have affected their tool choices.
Examples	"Yeah, well.. I'd say I started with online videos during my.. mechanics module/um exam in A-level… So my.. mechanics teacher in school was um.. a big fan of.. whichever resource it was, I can't properly remember the name so.. [www.examsolutions.net] That's when I started watching maths videos online…" (SI7) "Wolfram Alpha.. that's from my A-level.. A-level maths teacher.. he recommended it.. so that's why I use that…" (SI14) "Yeah, used that [Wolfram Alpha] a lot in high school as well um.. My mom is a maths teacher herself so she introduced me to that.. um when I was doing my A-levels so.. I found that really useful too.." (SI7)
Decision rules	No decision rules were required.

6.3.3.8 Rules

For the category ***rules*** (Table 6.88) 24 segments were coded and in total two subcategories were created in a data driven way (Figure 6.24). These are ***institutional rules*** (Table 6.89) and ***community rules*** (Table 6.90).

Table 6.88: Definition for the main category ***rules***.

Name	**Rules**
Description	Rules are a set of "explicit and implicit regulations, norms and conventions" (Engestrøm, 1990a, p.79) that "constrain activity… [and] inherently guide (at least to some degree) … the activities acceptable by the community" (Jonassen, 2000 p.103 cited in (Murphy & Rodríguez-Manzanares, 2013). In other words, rules constitute the formal or informal mechanisms controlling the operation of an activity system (Cowan & Butler, 2013). This category captures how the rules of students' activity system shape their tool choices.
Indicators	References to formal and informal rules that influence undergraduates' tool choices.
Example	"I don't know **it might sound a bit cheeky** if I just ask someone I don't really speak to everyday, "how you do this?" and then just not speak to them.." (SI7)
Decision rules	No decision rules were required.

Figure 6.24: The two subcategories for ***rules*** and their coding frequencies (numbers in parentheses).

Table 6.89: Definition for the subcategory ***institutional rules***.

Name	**Institutional rules**
Description	Formal rules set by the university.
Indicators	References to formal rules set by the university that regulate undergraduates' behaviour in relation to their tool choices.
Examples	"…because obviously during coursework you are not allowed help, you are not allowed to ask the lecturers or anything…" (SI11) "I just sort of packed away my A-level calculators because they are not allowed for uni… it was a problem at first because in certain… like for Stats I've really heavily relied on like… I forgot what is called… Standard deviation, so I've had to actually memorise the equation… which I didn't have to do for A-level…" (SI9). "In maths, in the whole course we have something like 4 or 5 different topics… and after each topic we have a test… So I would say… they definitely peak [use the top-5 list of tools], sort of towards the end of the topic close to the tests… and then definitely before the exam.. or so… they definitely peak at the end of the topics…" (SI12) "…if I don't get it still I'll go back to the HELM book, I'd try to reduce the amount I am using, until I get to just the.. the.. the little book that you are allowed in.. (the yellow formula book?) the yellow one… [a booklet containing mathematical formulas allowed to be used by students during exams] And then I'll reduce it until I am just on the yellow book as my sort of help guide for questions…" (SI3) "And this [pointing to an external link provided by the lecturer] the "Problem of points" an article on Math Forum, was actually other sources from other websites in order for us to look at.. But it was all additional, even if you didn't look at that it didn't matter, it wasn't/ it wouldn't be included in the class test…" (SI8)
Decision rules	No decision rules were required.

Table 6.90: Definition for the main category ***community rules***.

Name	**Community rules**
Description	Informal rules not explicitly set by the university which shape the social interactions among the members of the community.
Indicators	References to informal rules shaping the social interactions between students or between students and lecturers.
Example	"[Do you prefer communicating with other students that you live together?] Definitely with people that I live with because… I am closest to them in general.. I don't know it might sound a bit cheeky if I just ask someone I don't really speak to everyday, "how you do this?" and then just not speak to them…" (SI7)
Decision rules	No decision rules were required.

6.3.3.9 Division of Labour

For the category ***division of labour*** (Table 6.91) only 4 segments were coded. Segments coded under this main category reflected how the different roles and status that lecturers and undergraduates have affect tool choices for the letter.

Table 6.91: Definition for the category ***division of labour***.

Name	**Division of Labour**
Description	Division of labour describes "how the activity is distributed among the members of the community, that is, the role each individual in the community plays in the activity, the power each wields, and the tasks each is held responsible for" (Bellamy, 1996, p.125). This main category captures how the division of labour in a university setting affects students' tool choices.
Indicators	References to the different roles that undergraduates and lecturers have and may affect tool-use.
Examples	"Maybe if there's something you don't quite understand, **you are more comfortable stopping your friend** and explain it **than maybe stopping a lecturer**…" (SI7) "Um.. So say I was to go to the MLSC with a problem/ … or I was to go to a friend with the same problem.. **With my friend** I think I'd be **more.. comfortable** to like.. **interrogating them a little bit more and ask more questions..** Cause I think that's just human nature, you **feel more comfortable with people you are around more** um, you are around more.. These are the people that I eat with, do sports with… so I suppose doing maths is… [natural?] Yeah, well I think it's easiest to communicate because.. I don't know, it's hard to be explained really um.." (SI7) "I like using other students because they are often in **a similar situation to me**…" (SI1)
Decision rules	No decision rules were required.

In my view, the above quoted excerpts demonstrate how the different roles that students have (acting as learners) and lecturers (acting as instructors) affect tool-use. This is because although both parties work towards the same object (undergraduate degree) the division of tasks, power and status among them are different (Kuutti, 1996). This is well demonstrated by the students who reported preferring to work with their peers (rather than their lecturers) since they feel being in a similar situation (SI1) and more comfortable asking a fellow student when needed (SI7).

6.3.4 Summary and Discussion

In answering RQ4 (what factors can account for undergraduates' tool choices?) interview data from 14 undergraduates were analysed by using a Qualitative Content Analysis (QCA) approach. The main result of QCA was the construction of a coding frame which summarises and describes the data. In total, nine main categories were created with three of them stemming from Leontiev's version of AT and the remaining six from Engestrøm's (Figure 6.25). The incorporation of both Leontiev's and Engestrøm's frameworks in analysing the interview data, provided two different lenses of analysis enabling me to identify factors affecting undergraduates' tool choices at both the ***individual*** (Leontiev) and ***collective planes*** (Engestrøm). In the following, first a summary of the findings as identified from each perspective is presented, followed by a discussion involving both approaches.

By using Leontiev's version of AT, passages related to undergraduates' aims (goals) while studying mathematics were identified and in total 228 segments were coded. In addition, 14 segments related to the notion of conditions (non-subjective factors affecting undergraduates' activities) were found and coded. By applying the second principle of Leontiev's framework (hierarchical structure of activities) the segments categorised as aims were organised into two major groups: ***goals*** and ***purposes***, with the latter containing aims seemingly higher in students' hierarchy. This process was followed by the generation of subcategories for these two major groups. For ***goals*** two subcategories were created, ***understanding*** containing goals related to understanding mathematics and ***assessment*** including goals related to exams. For ***purposes***, two subcategories were created, ***exams*** and ***prepare*** with the former containing almost all the coded segments, demonstrating that the higher ranks of students' activities are dominated by exam-driven goals (

Table 6.92). Thus, at the ***individual plane***, higher level goals related to exams, shape and structure undergraduates' activities and can therefore account for their tool choices.

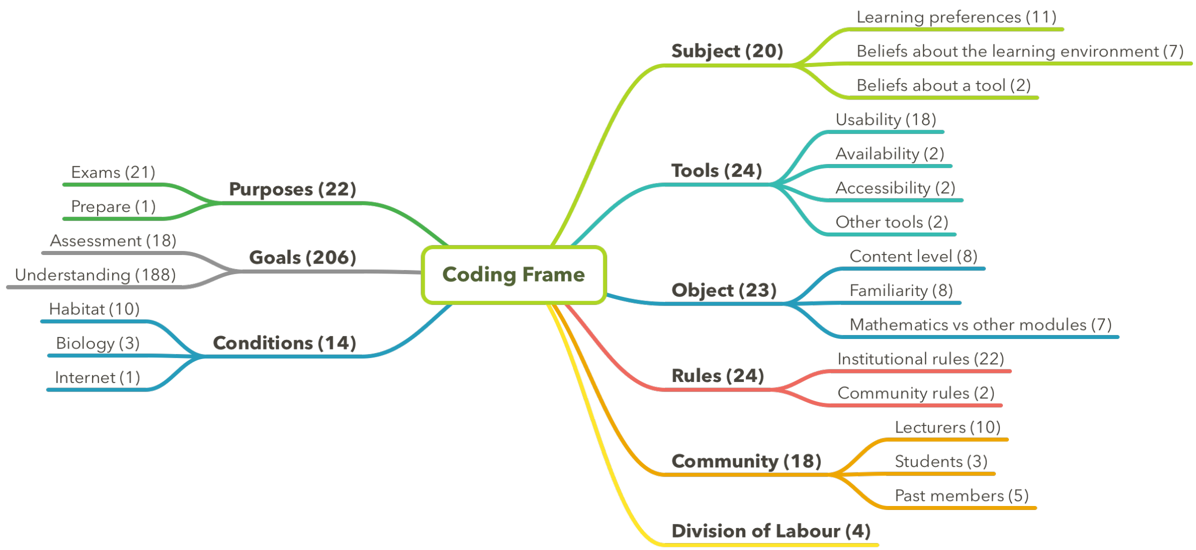


Figure 6.25: An expanded version of my coding frame used for analysing the interview data. On the left are placed the main categories and their subcategories related to Leontiev's version of AT and on the right the ones related to Engestrøm's version of AT. Coding frequencies are provided within each parenthesis.

By employing Engestrøm's version of AT, passages related to students' activity system (subject, tools object, community, rules and division of labour) were identified and in total 113 segments were coded. These were treated as factors influencing undergraduates' tool preferences at the ***collective plane*** (

Table 6.93). In terms of the **subject**, undergraduates' ***learning preferences***, ***beliefs about learning/learning environment*** and ***beliefs about tools*** were identified as affecting tool choices. Regarding **tools** themselves, a tool's ***usability***, ***availability*** and ***accessibility*** or the presence of ***other tools*** were found affecting undergraduates' tool preferences. In relation to students' **object**, the content of mathematics involved (***content level***), the ***familiarity*** with a mathematical topic and the different nature of mathematics when compared to other disciplines (***mathematics vs other modules***) were also recognised as influential. In terms of the **rules** governing students' activity system, ***institutional*** and ***community rules*** were found as having an impact on undergraduates' tool choices. With regards to the social group that the subjects belong to (**community**), ***lecturers***, other ***students*** and subjects from past activity systems (***past members***) were also identified as influential. Finally, the different roles that undergraduates and their lectures have (**division of labour**) were recognised as having an effect on undergraduates' tool choices.

Table 6.92: Examples demonstrating the exam-driven nature of students' ***purposes*** as identified in the interview data (subcategory ***exams***). These have been also presented at Table 6.53.

"I will only use the notes really to help me with the exercises in the HELM workbook because I know… ***the aim of this… module is to pass the exam you know…*** that's really why I am doing the module… well that's not quite right but... You know the... Basically, I have to/ ***I'm learning the maths... basically just so I can sort of pass the exam you know…*** Of course I enjoy the maths and I like understanding it but... you know that's what obviously the university is set up/ before you... you have to learn the maths so, you pass the exam... so I have to look at the HELM workbooks, see the exercises/ see what might be in the exam and then use my own notes to help... understand the exercises and... help me with the exercises... that's how I'd use my own notes if that makes sense…" (SI10)
"I went... this time... I went through back over all the tutorial sheets and I liked to do as many past papers as I can as well... ***cause then I know what to expect.. And like if you're looking at past papers it's, it's kind of a realistic expectation of what the exam's gonna be*** so that's why I like to do them, I literally just do as many things as I can and… if I'm stuck on a certain question, I'll like flip back through my own notes and work through it that way but I just work through as many questions as I can.." (SI2)
"...and again, what I hope to achieve from that. I suppose.. ***to be able to answer the questions in the exams*** because.. they are similar… they are going to be similar to those.." (SI13)
"Well... I probably filter all the derivations and stuff that. I like knowing how they working stuff but ***often we don't need actually know them for the exam..*** So I'll just look for example questions maybe, sometimes write those down and just like the other key bits of information.." (SI5)
"I use them as.. sort of the.. ***what I need to know basically in order to get through the exams…*** and actually what I supposed to be learning…" (SI3)
"It's because… I actually/ I don't want to just have the answer, I want to learn the method… I want to see what the answer would be and I would use online resources like that to learn the method… So therefore, I teach myself how to apply that knowledge to.. not just that question but if it comes up in the future/ ***it prepares me for exam…*** It comes in two parts, one preparing you for doing it in the real world and one ***preparing you for the exams so you can just do it straight off…*** " (SI4)
"…the first time he said for example, next week or on Monday I'll finish of this topic and I'll start differential equations.. So at that point I think to myself over the weekend.. I'll sort of find my books and just have a quick../ ***retro quick flick of what is differential equations, how to do them, just sort of.. so I am prepared for the next lecture…*** so I sort of think… Ok, this is how we did them, whether it's similar or different to the method Joe will use, I will sort of be prepared of what to do… So.. have a look a t first and then after a lecture again, I'll probably go back to my notes, my old notes and have a look, do they work, is it the same.. if it's the same or the same level I'll sort of keep the notes somewhere near.. and then just come back to them if I need to…" (SI12)

Table 6.93: Examples demonstrating how components of undergraduates' activity system influence their tools choices.

Main category	Subcategory	Example
Subject	Learning preferences	"I think it's how I learn… I find that *I am.. a quite sort of visual learner*.. I tend to be so that's why maybe I use more online videos rather than textbooks or anything like that… I just think it's just… what works for me…" (SI10)
	Beliefs about learning	"…which I guess I've *never been to the Maths Learning Centre,* I guess you can go and do it there as well, it's just like, sometimes *when people are teaching stuff, they kind of explain it one way* and.. even if you asked them to kind of go over it, sometimes they are like, stuck in that way of explaining it. So I just use videos as a different way…" (SI2)
	Beliefs about a tool	"I believe that maybe Facebook wouldn't have reliable or worthy resources that would be helpful enough, I just assume that you probably can get more reliable and trustworthy resources just by Googling or look videos at YouTube/ YouTube is quite a big part in helping me, maybe other people but… *I don't just see Facebook as a way to help yourself in the academic way*…" (SI4)
Tools	Usability	"…it's *a lot quicker just to type* into Wolfram Alpha's some terms.. [in comparison to Mat Lab]" (SI5)
	Availability	"Recommended textbooks/HELM… yeah these.. you know, the university advices you.. you always… So yeah I mean.. *If the recourses are there you use them*." (SI14)
	Accessibility	"it's so much not easier.. *convenient to use* these resources, the online stuff on Learn and the notes because there are right there at my disposal, *only two clicks from actually looking at them*.." (SI8)
	Other tools	"Although interesting enough I don't use the MLSC, nearly as much as maybe.. I could or should… (why's that?) It's an incredible resource but.. yeah I just haven't been… I think… from the *tutorials sessions* you can kind of answer all of your questions… But yeah… I'm not sure…" (SI14)
Object	Content level	"There's getting *less and less resources the higher into education I get*… Like I remember in GCSC there was plenty of like BBC Bitesize… [www.bbc.co.uk/education] and then the higher I've got there's less to choose from… less available…" (SI9)
	Familiarity	"HELM [workbooks].. I actually../ at the beginning of the year I didn't really used HELM that much.. I think because it was some kind of a repetition from what I've learned before.. at A-levels.. So because of that I didn't feel like I needed the extra support of.. yeah doing other examples.. So *I only started using* that probably on January, *when I started learning new things that I haven't learned before*…" (SI13)
	Mathematics vs other modules	"Um.. Yeah.. I'd probably say with my accounting modules that I purely use just my written notes I think.. Obviously there would be times where I'd speak to people, text people and things/ that they are on that side of my course.. *But I think it's a lot different to Maths* in the sense that basically last semester I had a law module which I needed to do/ for part of my accounting accreditation.. Basically I just used the notes, cause as long as you learn the cases.. and learn that there's not much more you can do…" (SI7)
Rules	Institutional rules	"In maths, in the *whole course* we have something like 4 or 5 different topics… and *after each topic we have a test*… So I would say… they definitely peak [use of the top-5 list of tools], sort of towards the end of the topic *close to the tests*… and then *definitely before the exam*.. or so… they definitely peak at the end of the topics…" (SI12)
	Community rules	"[Do you prefer communicating with other students that you live together?] Definitely with people that I live with because… I am closest to them in general.. I don't know it *might sound a bit cheeky* if I just *ask someone I don't really speak to everyday*, "how you do this?" and then just not speak to them…" (SI7)
Community	Lecturers	"I suppose Lecture Capture… [recorded lectures hosted on Learn] *the lecturer did say* at the end of each lecture if you want to go over this lecture, please go on Learn and you can see the lecture again…" (SI13)
	Students	"Um.. there's like one or two occasions and then that's when I talk to people on my module again and they'll kind of *suggest a video* they found helpful and things like that…" (SI2)
	Past members	"Wolfram Alpha.. that's from my A-level.. *A-level maths teacher*.. *he recommended it*.. so that's why I use that…" (SI14)
Division of Labour		"Maybe if there's something you don't quite understand, *you are more comfortable stopping your friend* and explain it *than maybe stopping a lecturer*…" (SI7)

In deciding which of the above factors are more or less important, a number of approaches were used. First, by examining students' responses about whether the use of their top-5 list of tools varies throughout the semester, I noticed that some of them answered in terms of ***assessment*** i.e. they responded by using terms related to in-class tests and exams[51] (Table 6.94). This suggests that during a semester, undergraduates structure their activity around ***institutional rules*** related to ***assessment,*** which implies that ***institutional rules*** are among the important factors influencing undergraduates tool choices. This interpretation is also supported by the analysis resulting by using Leontiev's version of AT i.e. that ***purposes*** related to exams, are playing a crucial role in structuring students' activity; in fact ***institutional rules*** related to assessment could be seen as the factor responsible for the formation of ***purposes*** related to ***exams*** (as already suggested by the diary data analysis). In other words, when data are analysed at the ***individual plane*** the most important factor affecting undergraduates' tool preferences was identified to be ***purposes*** related to exams (which are treated as deriving from a subject's choices). However, by expanding the unit of analysis at the ***collective plane*** a more inclusive interpretation is offered, namely that the most important factor is ***institutional rules*** related to exams, which in turn give rise to individual exam-driven ***purposes***. Since rules related to assessment were identified as responsible for shaping undergraduates' higher level goals i.e. ***purposes***, it is proposed here that assessment rules influence undergraduates' activities at the ***ensembles/purposes level***.

Second, in identifying factors having a secondary role in shaping undergraduates' tool choices, the coding frequencies and the number of students reporting instances for each subcategory was used. In this way, the factors identified as secondary were related to students' ***learning preferences*** and ***beliefs about learning*** (**subject**); a tool's ***usability*** (**tool**); the ***level of mathematics*** and students' ***familiarity*** with it (**object**); ***lecturers*** and ***past members*** of students' social environment (**community**); and finally, aspects of the physical environment (***habitat***) in which students act (**conditions**). In order to provide evidence supporting this interpretation, Table 6.95 is used. Table 6.95, consists of the main categories and their subcategories that were identified as being important by the above described approach (counting the coding frequencies and the number of students reporting instances for each subcategory). For example, the subcategory ***learning preferences*** had a coding frequency 11 and 7 students referred to their learning preferences when justifying why they use certain tools. In contrast, the subcategory ***beliefs about a tool*** had a coding frequency of 2 and only 2 students referred to their beliefs about a tool when justifying their tool choices. In addition to this, the data summarised at Table 6.95 suggest also that these factors influence undergraduates' tool choices at the level of ***actions/goals***. For example, students' ***learning preferences*** seems to shape what tool is being used (e.g. being a "visual learner" results using online videos). The ***content level*** and ***familiarity*** with a

[51] This of course could be interpreted as something cultural given how universities function but students' adherence to exams (as demonstrated by the analysis based on Leontiev's version of AT) argues against that.

mathematical topic seem to also affect the ***actions/goals*** level since they influence whether an online video can be used (content level) or whether a tool should be used depending on a student's familiarity with a topic. Finally, ***habitat*** is related to the ***operations/conditions level***.

In sum, at the individual plane, the factor recognised as having primary significance was undergraduates' exam-driven ***purposes*** and the one having a secondary function was found to be ***conditions*** related to the physical surroundings of a subject (***habitat***). At the collective plane, ***institutional rules*** related to exams were identified as responsible for shaping undergraduates' ***purpose***. In addition, a number of secondary factors were identified; these were related to students' ***learning preferences*** and ***beliefs about learning*** (**subject**); a tool's ***usability*** (**tool**); the ***level of mathematics*** and students' ***familiarity*** with it (**object**); and finally, ***lecturers*** and ***past members*** of students' social environment (**community**).

Table 6.94: Examples of students' answers related to whether the use of their top-5 list of tools varies throughout the semester.

"I think… In maths, in the whole course we have something like 4 or 5 different topics… and after each topic we have a test… So I would say… they definitely peak, sort of towards the end of the topic close to the tests… and then definitely before the exam.. or so… they definitely peak at the end of the topics or when after a lecture I don't fully understand what the lecturer went through…" (SI12)
"Hum.. I think when… yeah.. it's when we are coming up to… tests, exams you know.. obviously I use them a lot more (laughing).. the thing is, there's a lot.. there's always a lot going on.. at uni so… it's yeah.. I think it's natural that.. as you get to a test you'd focus on one thing much more than you would.. other subjects.. so yeah, in terms of frequency of using all of these things it would be hum.. near test time, exam time.. which is quite often because as you know, the structure of our course is lots of little tests and one big at the end, which I think is really good as well.."(SI14)
"So I would say.. my friends.. so other students, I probably tend to use more around exam times… Or in-class tests or something like that… My own written notes.. I probably tend to use those… Sort of towards.. I don't know.. probably just before I'm started to revise for exams.. So I use them more to just get a.. general overview of what's going on.. But I think… I tend to use more these resources.. as it comes up to in-class tests but not as much obviously for exams… as it comes to exams I would use more of definitely the Learn website to view past papers, HELM workbooks to do the questions in the back.. so they would definitely peak more.. so… towards the end of the year…when exams are coming up… So it probably peaks with exams or in-class tests… yeah…" (SI10)
"I don't tend to look at YouTube during the semester, that's definitely just before an exam when I am doing revision… Other students and my notes are pretty much constantly, LEARN it's just if I want to use practice tests before and then… the website [Wolfram Alpha] it's just occasionally anyway… if there's like a certain graph or something…" (SI9)

Table 6.95: Additional factors shaping undergraduates' tool choices. The first column from left is the main category from either Engestrøm's (subject, tools, object, community) or Leontiev's version of AT (conditions). The second column includes the corresponding subcategory for each main category, Numbers in parenthesis follow the format: (coding frequency, number of students). The third column contains mini narratives summarising why a tool is used (e.g. being a "visual learner"), the tool mentioned and whether is used or not for that reason (e.g. using online videos) and the interviewees reporting that (e.g. SI10, SI2).

Main category	Subcategory	Tools mentioned
Subject	Learning preferences (11, 7)	Being a "visual learner": using online videos (SI10, SI2)
		Being a "doer": using HELM workbooks (SI13)
		Being "old fashioned": printing resources from the Learn website (SI5)
		Alternative explanations: using external online tools (SI6, SI11)
		Preferring to work on my own: not using other students (SI6)
		Personalised knowledge: using notes instead of online tools (SI9, SI1)
	Beliefs about learning (7, 5)	Teachers are not able to offer alternative explanations: not using MLSC (SI2)
		Engineers are applied learners: suggesting a different structure for lectures (SI3)
		Feeling like being in college: not using problem sheets (SI11)
		Complicated problems for a module: not using problem sheets (SI11)
		Different explanations: other students (SI1)
		Better understanding in the long term: preferring to work with other students (SI1)
		Better teaching method: preferring to use www.examsolutions.net instead Khan Academy (SI7)
Tools	Usability (18, 8)	Khan Academy: SI13
		Online videos: SI2, SI4, SI9, SI11
		Wolfram Alpha: SI5, SI4
		Social media: SI7
Object	Content level (8, 5)	Not finding material for university mathematics: online videos: (SI12, SI2, SI4, SI9, SI11) Appropriate only for certain topics: Wolfram Alpha (SI4, SI9)
	Familiarity (8, 3)	Using when not familiar with a topic: notes (SI12)
		Using when not familiar with a topic: online videos (SI12, SI13, SI2)
		Using when not familiar with a topic: social media (SI12)
		Using when not familiar with a topic: HELM workbooks (SI13)
		Using when not familiar with a topic: other students (SI2)
Community	Lecturers (10, 5)	Suggested by a lecturer: using HELM workbooks (SI13)
		Suggested by a lecturer: online lectures (SI13)
		Not understanding the lecturer: using the HELM workbooks (SI4)
		Used by a lecturer during a lecture: Wolfram Alpha (SI8, SI9, SI1)
		Different lecturers: taking notes or not (SI8)
	Past members (5, 3)	A-level maths teacher suggested it: Wolfram Alpha (SI14, SI4)
		Mother who is an A-level teacher suggested it: Wolfram Alpha (SI7)
		A-level mechanics teacher suggested it: online videos: (SI7)
Conditions	Habitat (9, 5)	Living with students on the same course: using other students, instant messaging (SI7)
		Sitting next to students during a lecture: using other students (SI9, SI11)
		Living with a person that has a maths degree: not using online videos (SI2)
		Not wanting to go somewhere: not using MLSC (SI12)

Finally, I would like to mention an interesting finding related to the notion of contradictions. Engestrøm (2016) notes that the primary contradictions of any modern activity system can be treated as a variant of the general primary contradiction found in the socio-economic formation of capitalism, namely the tension between the ***use value*** and the ***exchange value*** of commodities. This is probably what the analysis of undergraduates' goals suggests: students are in a sense divided between the ***use value*** (goals related to understanding) and the ***exchange value*** (goals related to exams) of their undergraduate studies. This interpretation is supported by how some of the students expressed their experience of learning mathematics at a tertiary level. In particular, two of the interviews recognised in an explicit way the exchange value of their undergraduate studies in terms of succeeding in exams. For example, student SI13 when asked to reflect on whether her top-5 list of tools was helping her to achieve her goals, replied:

> "In general yes.. The only thing is.. honestly with the exam papers I think.. if.. if I look back on my times that I didn't do so well.. I would say that if I've done more.. spend more time on the exam past papers../ because at the end of the day.. they are so similar to the ones that you'll get in the test… I could have like.. significantly increase my mark by just using it… ***and it's not about I don't know that***, I think it's just again about the time factor.. and that you have to compile so many stuff to do.. that I just don't.. That if I had the time I would have done it.. Yeah that's the only thing.."

Similarly, while student SI8 was describing how he uses various resources hosted on the Learn website, he mentioned the first time he realised that in order to succeed in exams, he had to use past exam papers:

> "As I've told you it didn't start for mathematics anyway [using past exam papers], [it] started with another module that I had difficulties with.. […] So... I found out that after I could solve the exercises and after I kind of understood what was going on.. and I solved some really easy exercises on that.. […] I found that there weren't adequate exercises to solve.. Or they were too easy I believe.. I couldn't find more hard exercises.. So... I went to the past exams papers and.. [I thought] let's see what is going on with the past exam papers, are they actually that easy? And I actually found that they were harder.. the past exam papers and.. I thought to myself, what if for other modules this happens as well? Like the exercises I find them easy but if I go to the past exam papers I see the exercises there are more difficult to solve.. ***That's unfair***.. [my emphasis] So... For that reason that's how it started for me.. And that's how I decided that… look it should be good to, after tackling each subject on different modules.. I should be looking the past exam papers […] So that was how it started.. And for that particular reason, then I thought that, look I should actually see what's going on with other modules and their past exam papers as well, and that was my first year in mechanical engineering, cause I knew that, hey it's not the foundation year anymore, it's not going to be easy, ***maybe I am being tricked here***! [my emphasis] (laughing)"

Likewise, when SI4 when asked how he uses the HELM workbook replied in a way implying a logistic approach to his learning of mathematics:

> "It probably changes over time... When it came to revision... I used to... First year, I used to do all the tutorials and go through every single part in the book [HELM workbooks] ... ***Now I've kind of tried to cut down that by to find out the core method*** [my emphasis]... Trying to find out the ***key points***.. I use post notes quite a lot, like make very brief 'this is this', little bullet points step by step, so you know that.. Yeah I don't actually tend to these days to do any of the exercises or tutorials um.. because ***it seems to take a lot more time and I tend to go straight to past papers*** which.. you know.. you know the format of that.. It probably would help me understand a broader range.. like to understand the subject a lot more if you could do tutorials.. Because they have such a broad range that helps you to understand… but.. I think due to time... of how much other stuff that goes on, just to make sure that you can keep on track.. Even just ***do the necessary learning of that topic***.. And then you apply it and try to see where you've gone wrong, see where you've gone right and just well.. Try and be as efficient with time as you can..."

However, this was not the case with all students. A third student (SI11) when asked at the end of the interview if she had anything else to add, replied:

> "At university it feels more like… I'm using all these materials and I am learning all these ***only for the exams*** [student's emphasis]… Whereas before I just wanted to know everything… [laughing] like in A-levels, I would like to know stuff that's not on my syllabus, it's not going to be on the exam because I think it will help me to learn the stuff that are in the exam… Whereas now I feel like there's so much information, that I can't do that anymore… And I feel like that's not helping me learn this material because I can't connect to everything and see how it's all working… But also just a note on the exams.. a lot of it it's just memorising proofs whereas I like it when we apply maths a bit more… but… yeah…"

The above excerpt is again an example of a student recognising ***how things work*** in a university setting but it's a little different than the previous two. This is because the first two students (SI13, SI8) had recognised and ***accepted*** at some point of their undergraduate life the importance of succeeding in exams and using certain tools that can help them do so. However, the third student (SI11) recognised this in a disappointing tone; her comment implied feeling regretful about how learning university mathematics ***is*** and expressed her opinion about how learning mathematics at a tertiary level ***should be***, indicating thus a contradiction. A similar response came from student SI10, who mentioned that it's all about the exams after all (see Table 11). At the end of his interview, this student seemed to be worried about giving a wrong impression or gave a second thought and when asked whether he would like to add something else, replied:

> "I don't know.. I mean.. Anything I would like to say is.. sort of.. looking

back at this.. I think I gave the impression that I'm only focussing on trying to do the exam.. You know I am doing all of this but actually.. I do enjoy maths and.. I do like learning about maths.. (laughing) Regardless of the exams..

Chapter 7 Conclusions

In this chapter, the answers to my four research questions are presented. In section 7.1 descriptive statistics from the survey data are used in identifying the tools that undergraduates in the sample use when studying mathematics (RQ1). In section 7.2, Exploratory Factors Analysis results from the survey data are interpreted from a Wartofskian and Activity Theory perspective in proposing a typology of the tools used by undergraduates in the sample (RQ2). In section 7.3, Cluster Analysis results from the survey data are used in recognising tool-use profiles in the sample (RQ3). In section 7.4, the factors accounting for undergraduates' tool choices (RQ4) are identified by using quantitative (section 7.4.1) and qualitative data (section 7.4.2), followed by an integration of inferences (section 7.4.3). The chapter concludes by this study's limitations (section 7.5), implications for research and practice (section 7.6), my comments on using Activity Theory as the theoretical framework for this study (section 7.7) and finally my plans for the future (section 7.8).

7.1 Answer to RQ1: What tools do undergraduates use when studying mathematics?

In answering RQ1, 606 mathematics and engineering undergraduates were surveyed. Based on the reported frequency of use (1=never, 6=always) tools were categorised into three groups: ***high-use*** (students' notes, the Learn website, other students, textbooks), ***mid-use*** (staff at tutorials, online videos) and ***low-use*** (Wolfram Alpha, instant messaging, lecturers, pre-university notes, other textbooks, online encyclopaedias, social media, and the MLSC). By accounting the tools placed in the high and mid-range, we can clearly see undergraduates' ***preference*** for ***institutionally-led*** tools (Figure 7.1) i.e. tools either provided to them by their institution (Learn website, textbooks, staff at tutorials) or linked to their institution's teaching practice (students' notes). In terms of using people as mediators of learning, the survey data demonstrate undergraduates' preference for peers and less for staff at tutorials (mostly lecturers or PhD students). Finally, the use of online videos in an equal frequency to staff at tutorials is a noticeable result of the survey.

Before proceeding on placing my study's survey results within the wider literature, I would like to underline a few facts making this task difficult. First, most of the studies reviewed in section 3.2 do not report on the extent to which a tool is used (in a numerical or other way) but rather mention the percentage of undergraduates using a particular tool, meaning that inevitably the comparison is not absolute (in the sense of comparing numerical results). Second, some of them do not report on the use of individual tools but rather on groups of similar tools e.g. lectures, tutorials and workshops (O'Keefe et al., 2014) or online resources in general (Shé & Mac an Bhaird, 2017). Finally, another obstacle was comparing my results with those from studies investigating the use of tools for only personal or for personal and learning purposes.

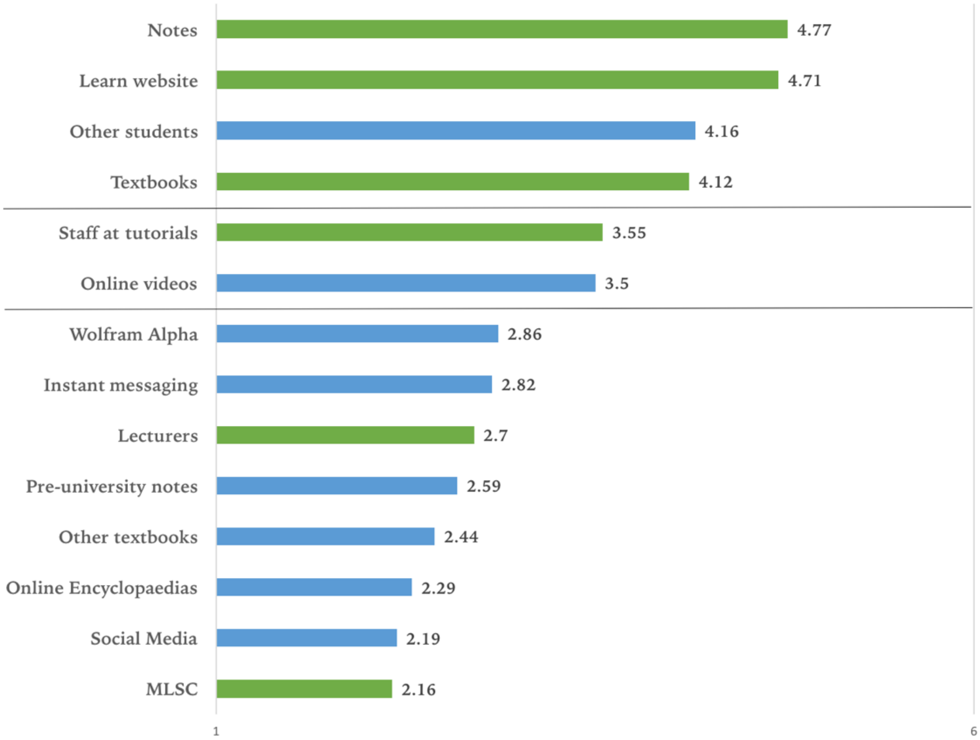


Figure 7.1: The place of institutionally-led (green) and external tools (blue) at the high (top) mid (middle) and low use (bottom) ranges.

At the high-use range, the survey results are overall in agreement with studies reporting that undergraduates rely mostly on traditional and lecture based tools such as notes and textbooks (O'Keefe et al., 2014; Shé & Mac an Bhaird, 2017) or using frequently their institution's VLE (Henderson et al., 2015; 2016; Judd & Kennedy, 2010) with exceptions for the latter being the studies by Conole *et al.* (Conole, 2006) and Shé *et al.* (2017). In terms of using other students as a tool, figures seem to be higher than those reported in the literature (O'Keefe et al., 2014).

With regards to the tools found in the mid-use range, the survey results for online videos appear to be sitting in the middle of the findings reported in the literature i.e. neither too low (Henderson et al., 2015) nor high (Henderson et al., 2016). For tutorials, the survey results are below the figures reported by O'Keefe *et al.* (2014) although the authors reported the combined use of lectures, tutorials and workshops.

Finally, for the tools populating the low-use group, survey results offer a mixed image in terms of replicating or not the results found in the literature. The use of Wolfram Alpha by undergraduates is reported by only one study (Shé *et al.*, 2017) but results are presented in conjunction with other online tools (Khan Academy, YouTube), thus a comparison was not possible. On the other hand, instant messaging and social media are tools widely acknowledged in the literature and the survey data results indicate a disagreement with studies reporting high use for either learning (Bullen et al., 2011; Judd & Kennedy, 2010) or both learning and personal purposes (Costa et al., 2016; Gallardo et al., 2015; Thompson, 2013), although one of the studies reported low use (Henderson et al., 2015). With regards to lecturers, survey results replicated low use as reported by the only study acknowledging lecturers as resources (O'Keefe et al., 2014). The results for online encyclopaedias are in agreement with studies reporting low use (Hampton-Reeves et al., 2009; Henderson et al., 2015; Judd & Kennedy, 2010) but diverge with those reporting online encyclopaedias as being particularly popular (Costa et al., 2016; Flavin, 2013). With regards to support centres, the survey results are in agreement with the low figures identified by the two studies undertaken in an undergraduate mathematics setting (Shé & Mac an Bhaird, 2017). Finally, pre-university notes and textbooks chosen by undergraduates (other textbooks) were not investigated by other studies, thus no comparison was made.

When the survey results were examined separately for mathematics (N=420) and engineering students (N=186) a few statistically significant differences were identified, with the most notable being that of engineering students using substantially more textbooks (HELM workbooks). The rest of the differences concerned instant messaging, the Learn website, Wolfram Alpha, other students, other textbooks and online encyclopaedias. If we group tools into high, mid and low-use as done for the whole sample (high $4 \leq M$; mid $3 \leq M < 4$; low $2 \leq M < 3$) we can notice that (Figures 7.2, 7.3):

1. the ***high-use*** range includes the ***same tools*** for both samples, ***except textbooks***
2. the ***mid-use*** range is more ***rich*** for ***mathematics*** students, since it includes in addition ***instant messaging*** and ***Wolfram Alpha***
3. the ***low-use*** range includes the ***same tools*** for both samples, ***except*** instant messaging and Wolfram Alpha for mathematics students.

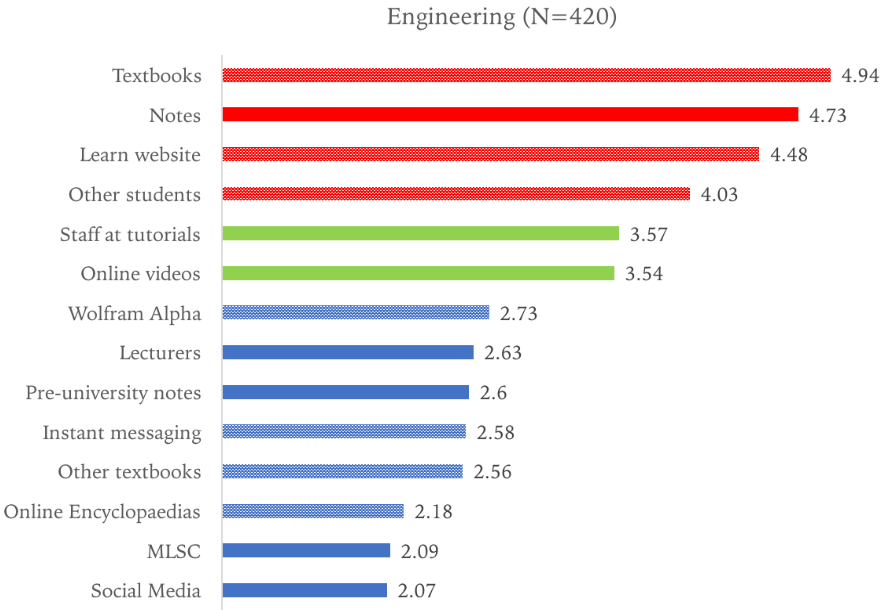


Figure 7.2: The high (red), mid (green) and low-use tools (blue) for engineering students. Bars with a pattern indicate the statistically significant differences with mathematics students (Figure 7.3)

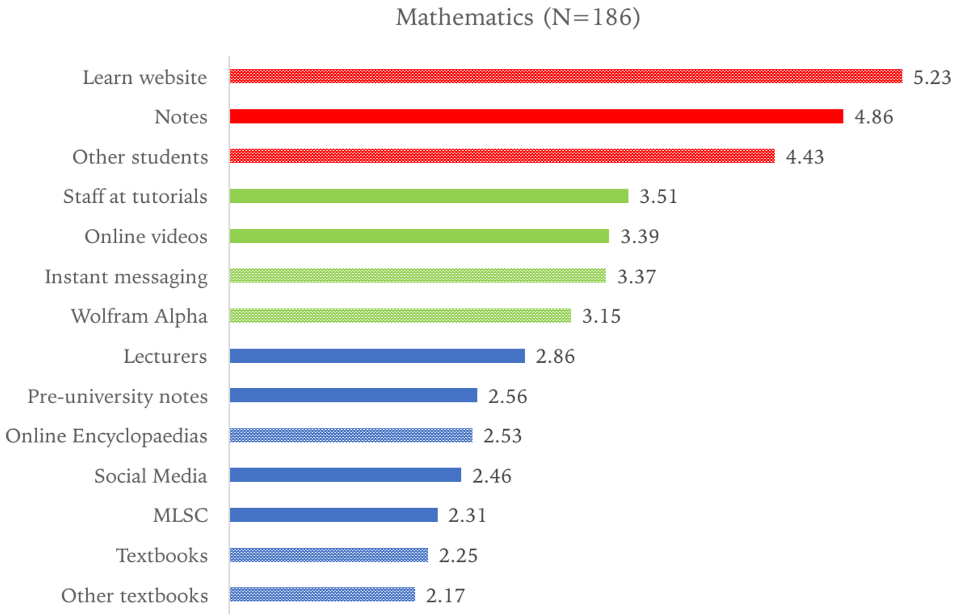


Figure 7.3: The high (red), mid (green) and low-use tools (blue) for mathematics students. Bars with a pattern indicate the statistically significant differences with engineering students (Figure 7.2).

Finally, analysis of the diary data identified the presence of student-generated tools used for revision purposes such as flash cards, mind maps and definition sheets (section 6.3.5.1). This could be an indication of tools used by undergraduates but not identified by the survey data.

In sum, the survey data showed that overall, undergraduates in the sample prefer using mostly institutionally-led tools (notes, textbooks, the Learn website), other students and online videos. Even when examined separately, both mathematics and engineering students demonstrated a preference for institutionally-led tools (notes, Learn website) and other students. However, mathematics students do not use textbooks, yet they have a more rich tool-box in terms of using more external to their institution tools (online videos, instant messaging, Wolfram Alpha) than engineering students.

7.2 Answer to RQ2: How can the tools used by undergraduates be categorised?

In answering RQ2, survey data from a sample of 606 mathematics and engineering students were analysed by performing an Exploratory Factor Analysis (EFA[52]). Results suggested the presence of 5 types of tools in the data: ***peers*** (instant messaging, other students, social media), ***teachers*** (lecturers, MLSC, staff at tutorials) ***external online tools*** (online encyclopaedias, Wolfram Alpha, online videos, Learn website[53]), ***the official textbook*** (recommended textbooks/HELM workbooks, other textbooks) and ***students' notes*** (students' lecture and pre-university notes).

When compared to other typologies found in the literature (see section 3.3), the above classification of tools differs in terms of scope in 3 areas: first, it takes into account any kind of tools that undergraduates may use while studying mathematics whereas most of the reviewed typologies acknowledge only digital/online tools (Conole & Alevizou, 2010; Engelbrecht & Harding, 2005; Eynon & Malmberg, 2011; Pea, 1987; Thompson, 2013; Tondeur et al., 2007); second, it adopts a student perspective in contrast with the general tendency to neglect students as users (Engelbrecht & Harding, 2005; Kidwell et al., 2008; Laurillard, 2002; Pea, 1987; Roberts, 2014; Roberts et al., 2012); and finally, the proposed typology is positioned in tertiary mathematics settings, something generally missing for the literature since only one typology was found to be related with university mathematics (Engelbrecht & Harding, 2005). From a methodological point of view, most of the available studies do not explicitly state the criterion used for classifying tools (in my case it is undergraduates' actual use of the tools) and only a few are based on empirical data (Eynon & Malmberg, 2011; Thompson, 2013; Tondeur et al., 2007).

The results were also interpreted (Table 7.1) by using Wartofsky's hierarchy of artefacts (Wartofsky, 1973) and Leontiev's version of AT (e.g. Leontiev, 1981b). From a Wartofskian perspective, each type of tool corresponds to the different secondary artefacts that undergraduates use when studying mathematics. When examined from an Activity Theory point of view (Leontiev), different types of tools correspond to thematically related actions that students undertake when studying mathematics.

[52] A statistical method similar to Grounded Theory, used for grouping together variables that have something in common.

[53] The Learn website is an institutionally provided tool but due to its low factor loading (.36) when compared with for example online encyclopaedias (.58), it contributes less than the rest to the factor, thus the name external.

Table 7.1: The proposed typology of tools (left) and its equivalence with secondary artefacts and actions (right).

Typology of Tools	**Secondary Artefacts (Wartofsky) - Actions (AT)**
(1) Peers	Interacting with peers
(2) Teachers	Interacting with teaching and support staff
(3) External online tools	Searching for additional/alternative sources of information
(4) The official textbook	Studying the official mathematical textbook
(5) Students' notes	Taking notes during a lecture

The above interpretation for some types of tools such as peers, teachers, the official textbooks and students' notes is in my view straightforward. However, it is open to debate whether external online tools are used for searching additional/alternative material. In order to validate/enhance the interpretation for external online tools, qualitative data are used in this section. Based on the examples provided in Table 7.2, we can see that online encyclopaedias[54] are used as a reference tool, Wolfram Alpha for checking calculations and online videos for finding alternative views on a topic. Thus, the title "searching for additional/alternative resources of information" seems to be legitimate since it summarises the actions performed when using online videos (searching for alternative sources of information). However, it needs to be expanded for including the actions performed when using online encyclopaedias (remembering) and Wolfram Alpha (performing calculations). The updated typology after incorporating insights from qualitative data with the EFA results, is presented at Table 7.3.

[54] Only student SI1 reported online encyclopaedias in his top-5 list of tools.

Table 7.2: Excerpts from the interview data demonstrating the nature of undergraduates' use of external online tools.

External online tools	Examples
Online encyclopaedias	"Yes, so if I'm using an online encyclopaedia it's probably just for like a brief.. a brief thing, just to quickly look something up, so for example if I couldn't remember…" (SI1)
Wolfram Alpha	"…if I'm not confident that's the right answer I will go to this…" (SI14) "So Wolfram Alpha hum, is a great resource for checking my solutions to a problem, the classic example…" (SI1) "I usually use W.A. if I had to draw a graph and I just want to double check that I've done it right…" (SI9)
Online videos	"…Then I go through the process if I don't understand something I'll probably… try question from a tutorial or ask a friend.. and as revision… and a sort of making sure I understand it, I would have a look at online videos and… get.. a different way of explaining it, to explain it to me, so.. I sort of get.. the lecture way and the video way and somehow that usually combines in my head somehow and that sort of works for me…" (SI12) "Yeah, I think I use it when someone explains it, explains it to me in a way I don't understand, so I use it to try and find a different way of explaining it…" (SI2) "But then if there is a YouTube video that is relevant then that's really handy to hear another explanation…" (SI9) "Yeah, I'd say that if there's something that I don't understand from the lecturer's notes, I'll to see if the video says it in another way, that I would understand… So if it's a completely different way of getting to the same idea then I'd like to see what it is… Only if I don't understand the first way…" (SI11)

Table 7.3: The typology of tools (left) and its equivalence with secondary artefacts and -updated- actions (right).

Typology of Tools	Secondary Artefacts (Wartofsky) - Actions (AT)
(1) Peers	Interacting with peers
(2) Teachers	Interacting with teaching and support staff
(3) External online tools	Remembering, performing calculations and searching for alternative sources of information
(4) The official textbook	Studying the official mathematical textbook
(5) Students' notes	Taking notes during a lecture

7.3 Answer to RQ3: How can undergraduates be profiled according to their tool-use?

In answering RQ3, a Cluster analysis was performed on the survey data for a total sample of 606 undergraduates. Results revealed 5 different groups of students: (1) the ***peer-learning group***, consisting of undergraduates demonstrating above average use of peers, instant messaging apps and social media; (2) the ***online-learning group***, including students demonstrating above average use of online videos, online encyclopaedias, Wolfram Alpha and the Learn website; (3) the ***blended-learning group***, comprised by students reporting above average use of all the tools at their disposal; (4) the ***predominantly textbooks-learning group*** including students demonstrating above average use of textbooks only; and (5) the ***selective-learning group***, consisting of students demonstrating above average use of textbooks, online videos and lecturers.

Despite the differences found in other studies (e.g. sample composition, tools acknowledged), the above results seem to be aligned with findings reported in the literature. In particular, the ***peer-learning*** group resembles the ***social-intensive*** group reported by Costa *et al.* (Costa et al., 2016) and the ***socially-focused intensive*** users found by Kovanović *et al.* (2015): all three groups of students were identified for their preference of interacting with their peers either by using social networks and video sharing tools (Costa et al., 2016) or through a VLE's discussion boards (Kovanović et al., 2015). The ***online-learning*** group corresponds to the ***online lectures*** groups identified by Inglis *et al.* (2011) although only one online tool was used in their study (online lectures) and this was provided to students by their institution. Furthermore, the ***blended-learning*** group seems to be equivalent with the ***high/intensive*** groups identified by many studies (Bos & Brand-Gruwel, 2016; Del Valle & Duffy, 2009; Eynon & Malmberg, 2011; Kovanović et al., 2015; Lust et al., 2011; 2013): students fitting in this profile demonstrated above average use of all the tools available to them. Moreover, the ***predominantly textbooks-learning*** group seems to resemble the ***no/low-use*** group identified by many studies in the literature (Bos & Brand-Gruwel, 2016; Costa et al., 2016; Eynon & Malmberg, 2011; Inglis et al., 2011; Kovanović et al., 2015; Lust et al., 2012; 2013). This is because although students in the ***predominantly textbooks-learning*** group had below average use on all tools except textbooks, their use of textbooks was lower than the one reported by the ***selective-learning*** and ***blended-learning*** groups. Finally, the ***selective-learning*** group, shares the same characteristics as the ***selective/incoherent users*** who chose to use only some of the tools available to them (Bos & Brand-Gruwel, 2016; Lust et al., 2011; 2013).

As mentioned earlier in section 3.4.5, the literature on undergraduates' tool-use profiles can be conceptualised as a continuum with two extreme poles, the ***no/low-users*** and the ***high/intensive users***. When other characteristics of tool-use are taken into account (e.g. the time spent using a tool), then these two extremes appear to have variations such as ***intensive active*** vs ***intensive superficial users*** (Lust et al., 2013). The same has been also reported by only one study for the middle of this continuum, the so called ***selective users***: Bos and Brand-Gruwel (2016) by taking into account the frequency of use and the type of tool, identified the ***selective online users*** i.e. students who were selective in their tools use and showed above average use of online materials. In this sense, the ***online-learning*** group corresponds to Bos and Brand-Gruwel's (2016) ***selective online users***. This indicates that also the ***peer-learning*** group is related to the ***selective users***. In fact, this suggests that both the ***online-learning*** and the ***peer-learning*** groups are ***variations*** of ***selective users***, something not widely recognised in the literature.

7.4 Answer to RQ4: What factors can account for undergraduates' tool choices?

In answering RQ4, findings from both the quantitative (QUAN) and qualitative (QUAL) strands of my study are merged. First, results deriving from QUAN and QUAL data analysis are discussed and then inferences from both are incorporated into a meta-inference which serves as the final answer to RQ4.

7.4.1 Answering RQ4 by using QUAN data analysis results

In answering RQ4 from a QUAN point of view, survey data from a sample of 590 undergraduates were analysed. This was done by performing a Multinomial Logistic Regression, a statistical method testing whether an outcome variable, in our case cluster membership (denoting students' tool preferences), can be ***predicted*** by a linear combination of two or more variables, in our case a subject's qualities (degree, year of studies, conceptions of mathematics) and goals pursued (i.e. the object of Vygotsky's mediational triangle). Results suggest that in terms of a ***subject's*** qualities, ***conceptions of mathematics*** (the ways students conceive the nature of mathematics) cannot explain undergraduates' tool preferences, however, ***degree*** (engineering or mathematics) and ***year of studies*** (first or second) do: it is more likely for ***mathematics undergraduates to use peers, online tools or blend different tools*** than for engineering students and also for ***second year students to use online tools or blend different tools*** than for first year students[55]. In terms of a subject's ***goals*** (object), results suggest that goals can indeed explain undergraduates' tool preferences. In particular, by conceptualising undergraduates' goals from the narrowest to the broadest (to pass -> acquire mathematical skills -> understand the theory of mathematics -> open your mind) we can observe that aiming for broader goals results in a more rich tool box (to pass -> acquire mathematical skills: peers -> all tools). However, this trend appears to have a "***discontinuity***": when students aim for understanding the theory of mathematics instead of using less tools (than the blended-learning group), they just use their textbooks and only when even broader goals are pursued (open your mind) undergraduates' tool-box is populated by more tools (selective users). Figure 7.4 presents a visualisation of this.

[55] The association of cluster membership with degree and year of studies was also identified while exploring the composition of cluster in terms of degree and year of studies (section 5.2.3.4).

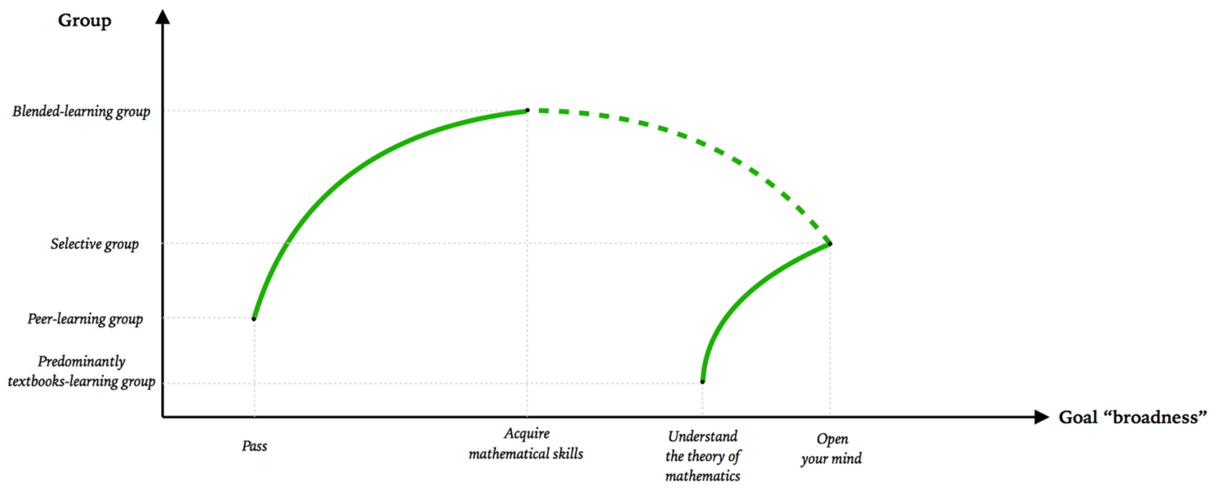


Figure 7.4: Moving from narrow (left side of x axis) to more broad goals (right side of x axis), results in a more rich tool-box (y axis corresponds to the groups identified by Cluster analysis and indicates the number of tools used). Note that the graph is used purely for illustrative purposes and does not incorporate assumptions found on graphs with mathematical content (for example, goals on the x axis do not have equal distances between them neither the number of tools in each group on the y axis).

Undergraduates' subject specialism (degree) was recognised as a factor associated with students' tool preferences by Inglis *et al.* (2011) and Povey and Ransom (2000): in the first study, mathematics students were identified as preferring to use the support centre (MLSC) and engineering students the online lectures found on their institution's VLE; in the second study, a group of STEM students reported seeing the use of technology for learning and doing mathematics as detrimental to their learning. However, this study's results highlighted that undergraduates in STEM disciplines (mathematics, engineering) do use technologies when doing and learning mathematics (contrasting Povey & Ransom, 2000) and in fact, mathematics students are more likely to use peers (instant messaging, other students, social media), external online tools (online encyclopaedias, Wolfram Alpha, online videos) or blend all the tools available to them (contrasting Inglis et al., 2011). Although in this study the type of degree was treated mostly as a subject's quality, the results from the Conole *et al.*'s study (2006) agree with the findings presented here, i.e. that disciplinary demands (e.g. using certain technologies in the mathematical sciences for manipulating data) is a factor that shapes undergraduates' use of technology.

In terms of undergraduates' goals, Lust *et al.* (2013) found that students aiming at goals related to learning and understanding are more likely to use all the available tools (in an intensive and active way), whereas those pursuing goals related to performance are more likely to be selective in their tool-use. Lust *et al.*'s (2013) results are partially in agreement with this study's findings: when moving from the goal "pass" to the more broad "acquiring mathematical skills" indeed this results in using all the available tools. However, when moving from "understand mathematics" to "open your mind" although the number of tools used increases, choices are selective. As we saw, students aiming at passing their module, are more likely to use only peers (instant messaging, other students, social media) as tools i.e. they do not rely on other technologies either provided to them or found elsewhere. This adherence to exam related goals as a factor shaping tool choices seems to be related to the Jaworski *et al.*'s study (2012) in which many undergraduates conceived the use of GeoGebra as irrelevant or unhelpful in helping them passing the exams.

Unluckily, none of the reviewed studies examined whether being a first or a second-year student influences tool choices. However, it reasonable to assume that as students advance further to their studies, they become more familiar with a variety of online tools and/or blend more tools when studying mathematics. This may be related to a number of factors, such as social interactions or the increasing difficulty of mathematics involved in their studies.

7.4.2 Answering RQ4 by using QUAL data analysis results

In answering RQ4 from a QUAL perspective, diary and interview data from a sample of 4 and 14 students respectively were analysed by using a Qualitative Content Analysis (QCA) approach. QCA is a method for describing in a systematic way the meaning of qualitative material. The diary data analysis was performed at the individual level (Leontiev's version of AT) and results suggested that undergraduates structure their activity around higher level goals (purposes) related to assessment (exams, in-class tests, coursework). The interpretation offered, identifies undergraduates' exam-driven goals as the main factor influencing their tool preferences. Following this, the interview data were analysed at both the individual (Leontiev's version of AT) as well as the collective level (Engestrøm's version of AT). At the individual level, results were similar to those for the diary data: undergraduates' activities are shaped by higher level goals related to assessment. At the collective level, the rules governing undergraduates' activity system, in particular those related to exams, were characterised as being the most influential factors in relation to undergraduates' tool choices. Since the interview data analysis also took place at the collective level, the tentative interpretation offered at the end of the diary data analysis was reinforced: when examined at the individual level, undergraduates' exam-driven goals influence their tool choices but when examined at the collective level, these goals are regarded as a product of the rules governing undergraduates' activity system. In addition, a number of secondary factors shaping undergraduates' tool choices were identified. These were related to students' learning preferences and beliefs about learning (subject); a tool's usability (tool); the level of mathematics and students' familiarity with it (object); lecturers and past members of students' social environment (community); and finally, aspects of the physical environment (habitat) in which students act (conditions). Rules related to exams were interpreted as influencing students at the ensembles/purposes level, whereas for secondary factors it was suggested that they shape students at the actions/goals level.

Undergraduates' fixation to institutional requirements, has been reported by Orton-Johnson's study (2009), who found that among the main factors shaping students' non-use of blended learning resources was their adherence to the course's reading lists (seeing reading lists as anchors structuring and guiding their work). Similarly (but from a more psychology oriented perspective), Cano and Berbén's study (2010) underlined the important effect that the types of goals emphasised ***by***

instructional practices have on undergraduates' approaches to learning mathematics.

7.4.3 Integrating QUAN and QUAL inferences

The QUAL results demonstrate that at the individual plane, the main factor influencing undergraduates' preferences for institutionally-led tools (notes, Learn website, textbooks) is higher level goals (purposes) related to exams. This interpretation is also supported by QUAN data, in particular the part of the questionnaire dealing with undergraduates' goals, in which the most popular goals were found to be related to exams (Table 7.4).

Table 7.4: Descriptive statistics (mean) for undergraduates' goals when studying mathematics (N=623 listwise).

Goals	Mean
To get a high mark (60% or above)	5.71
To pass your maths module (+40%)	5.25
To acquire mathematical skills	5.10
To understand mathematics	4.90
To understand the applications of mathematics	4.88
To enjoy mathematics	4.40
To understand the theory of mathematics	4.31
To acquire a mathematical way of thinking or philosophy	4.16
To satisfy your intellectual curiosity	4.09
To open your mind	3.91

By expanding the unit of analysis at the collective plane, QUAL results indicate that undergraduates' exam-driven higher level goals are consequently a result of the rules governing their activity system, in particular rules for assessment. In other words, undergraduates construct their individual activities according to the assessment rules regulating the activity system in which they act. This interpretation explains why certain tools were found in the ***high-use range***; they are all consistent with rules of undergraduates' activity system. The QUAL data do support that rules related to assessment exert great influence but it is plausible that the high-use tools are in alignment with other rules too. For example, the use of notes is in line with the explicit (but not strict) rule of attending lectures and the implicit rule of note-taking during lectures. The use of the Learn website (university's VLE) is also consistent with rules related to the centralisation and standardisation of learning, which serve institutional needs (Murphy & Rodríguez-Manzanares, 2013) and textbooks (HELM workbooks, engineering students only) align with rules related to standardisation of the curriculum (Roberts et al., 2012). Even the popularity of other students as a tool could be partially interpreted as a result of rules related to providing mass education[56].

[56] Nevertheless, data from both interviews and diaries indicate that students seem to be more aware

Consequently, since the high-use tools can fulfil undergraduates' higher level goals, others become less popular i.e. they are found at the ***mid-*** and ***low-use*** range of tools. Apart from rules related to assessment, a number of other factors was identified in the interview data that can additionally be accounted as influencing undergraduates' tool preferences. These additional factors were characterised as secondary in relation to the role that exam-driven goals/rules for exams have and were found to be related with students' ***learning preferences*** and ***beliefs about learning*** (**subject**); a tool's ***usability*** (**tool**); the ***level of mathematics*** and students' ***familiarity*** with it (**object**); ***lecturers*** and ***past members*** of students' social environment (**community**); and finally, aspects of the physical environment (***habitat***) in which students act (**conditions**).

The QUAN data analysis results identified a number of other factors shaping undergraduates' tool use preferences which seem to be secondary in nature too. This is because Multinomial Logistic Regression results highlighted factors affecting the choice of tools mostly belonging to the mid- low-use use range, namely instant messaging, social media, other students (***peer-learning group***); Wolfram Alpha, Learn website, online encyclopaedias, online videos (***online-learning group***); lecturers, staff at tutorials, MLSC (***selective learning group***). In particular, being a mathematics student increases the possibilities of using instant messaging, social media, other students (***peers***), Wolfram Alpha, the Learn website, online encyclopaedias and online videos (***online tools***); being a second year student increases the possibilities of using Wolfram Alpha, the Learn website, online encyclopaedias and online videos (***online tools***); and having more broad goals increases the probability of using lecturers, staff at tutorials, MLSC (***selective learning group***).

In sum, two types of factors shaping undergraduates' tool choices were identified:

- ***primary***, which are related to the rules (for assessment) governing students' activity system and shaping undergraduates' individual activities at the level of ensembles/purposes
- ***secondary***, which are related to students' themselves (**subject**: year of studies, degree learning preferences, beliefs about learning), the goals they pursue (narrow versus broad goals), other subjects participating in undergraduates' collective activity (**community**: lecturers and past members), a tool's characteristics (**tools**: usability) and finally, the nature of university mathematics and students' familiarity with certain mathematical topics (**object**: content level, familiarity). These secondary factors seem to be influencing undergraduates' individual activities at the levels of actions/goals and operations/conditions.

Results of this study pinpoint at a number of factors that can explain why certain tools are found in the high-use range while others don't. However, the interpretation offered ***does not explain*** why some undergraduates prefer using tool "A" whereas other don't e.g. why some students use online videos while others don't. This is due

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of rules related to assessment.

to this study's focus and design which resulted data not appropriate for accounting why some students use a tool (e.g. online videos) whereas others don't (e.g. they prefer using their notes).

7.5 Limitations

As with any piece of research, a number of limitations exists and here I acknowledge the most important. First, due to the interpersonal character of the research undertaken (interacting with other humans during interviews and the diary data collection period), inevitably the researcher (me) had some influence on participants and therefore on the data, even in the case of the questionnaire (Cohen et al., 2011). The involvement of humans in collecting the data is also related to another limitation, namely the self-reported nature of the data collected: practically there is no way to assess participants' honesty and accuracy but to my best knowledge every measure was taken to ensure that participants would fill the questionnaires accurately and engage with me in a sincere way during the collection of qualitative data. Second, limitations of this study are related to the sampling method used (convenience sampling), in which case no claims of generalisability or representativeness of a population can be made (Basit, 2010). Finally, the theoretical framework used in choosing what aspects of undergraduates' tool-use are worthy to look at i.e. Activity Theory, might have limited my perspective.

7.6 Implications for research and practice

Although no claims of generalisability are made, I think this study highlighted a number of issues currently not being addressed either by research or in educational practices. First, I strongly believe that the question whether undergraduates blend their learning (in the sense of mixing different tools) should no longer be posed; students ***do blend their learning*** and qualitative data support this claim. To me, the issue of finding students not blending their learning (e.g. Inglis et al., 2011; Lust et al., 2013) is artificial because it seems to be more related to what researchers define as blended learning but more importantly to what we count as tools. This is also related to our conceptions about "where" learning takes place and has a great impact over research and educational practices. As Engestrøm (Engestrøm, 2016) comments, currently their exists an adherence in the learning sciences to think that learning takes only place in formal places e.g. within a classroom. In my view, the literature review highlighted exactly this: most of the research is focused on institutionally-provided tools and neglect tools that students themselves can choose.

Another implication deriving from the results of this study, is related to the literature focusing on how students approach their learning e.g. surface, deep, strategic/achieving (Biggs et al., 2001; e.g. Marton & Saljo, 1984). In my view, scholars following this line of research neglect a very important aspect of students' learning, that is their wider sociocultural context, in particular -as this study highlights- ***the rules*** governing Higher Education Institutions (HEIs)[57]. As researchers and educators, we must acknowledge the impact that societal activities have over students' ways of learning: as the findings of this study suggest, although students are found to be driven by exam-related goals, this is a result of the rules regulating how HEIs function and should not be attributed entirely as stemming from individuals' practices. As seen in the literature review, there are numerous studies criticising the limited tool-box undergraduates employ or their passive/not innovative ways of using technologies (e.g. Bullen et al., 2011; Henderson et al., 2015; 2016; Thompson, 2013).

7.7 Comments about using Activity Theory

Although I found the use of AT extremely helpful in answering my research questions and in widening my perception, I encountered a number of issues while using it as my theoretical framework and I would like to comment on those here. The first is related to what is regarded as tool in AT; indeed this is a limitation of AT in its current form, already discussed by Kaptelinin and Nardi (2006) and mentioned in chapter 2. Another issue I encountered was the lack of analytical tools that operationalise well AT concepts, which is also mention by Kaptelinin and Nardi (2006). Finally, in terms of using AT in understanding certain aspects of tool-use I too, like John Monaghan (Monaghan et al., 2016), feel a little disappointed with regards to what AT has to say about tools although this should be expected since "when the unit of analysis is the activity system itself, AT does not provide great insight on tool use" (*Ibid.*, p.262).

7.8 Future directions

It is widely accepted that any piece of research creates more questions than the ones initially attempted to answer and this is definitely true in my case. In the future, I plan investigating tool-use in undergraduate mathematics by incorporating a number of different methods and theoretical perspectives. In terms of the methods I envision to use, I am planning incorporating a combination of diaries and radio frequency identification devices (e.g. Cattuto et al., 2010) for capturing both self-reported and behavioural data respectively. With respect to the theoretical approaches used, I am very keen on examining tool-use from an instrumentation (e.g. Trouche, 2005) and a social network analysis (SNA) perspective (e.g. Scott & Carrington, 2011), with the former providing the means for investigating how tools are used by undergraduates and the former enabling me to explore how social interactions shape tool-use (not well articulated in Activity Theory).

[57] An exception to these approaches is the study by Cano and Berbén (2010) who underlined the relationships between approaches to learning and goals emphasised by instructional practices.

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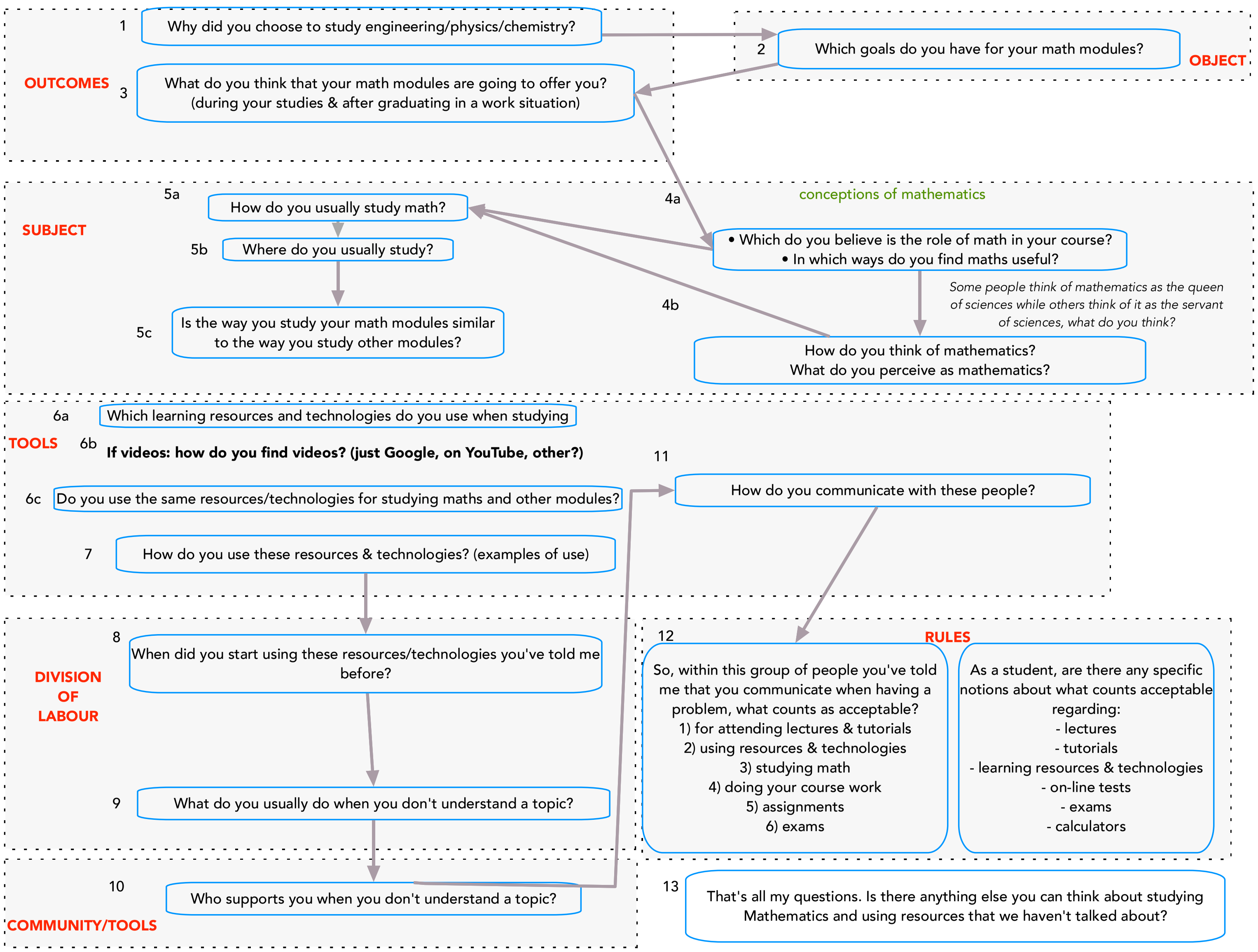
Appendices

Appendix A

Pilot study's interview protocol


OUTCOMES
1 Why did you choose to study engineering/physics/chemistry?
3 What do you think that your math modules are going to offer you? (during your studies & after graduating in a work situation)
OBJECT
2 Which goals do you have for your math modules?
SUBJECT
5a How do you usually study math?
5b Where do you usually study?
5c Is the way you study your math modules similar to the way you study other modules?
conceptions of mathematics
4a • Which do you believe is the role of math in your course? • In which ways do you find maths useful?
Some people think of mathematics as the queen of sciences while others think of it as the servant of sciences, what do you think?
4b How do you think of mathematics? What do you perceive as mathematics?
TOOLS
6a Which learning resources and technologies do you use when studying
6b If videos: how do you find videos? (just Google, on YouTube, other?)
6c Do you use the same resources/technologies for studying maths and other modules?
7 How do you use these resources & technologies? (examples of use)
11 How do you communicate with these people?
DIVISION OF LABOUR
8 When did you start using these resources/technologies you've told me before?
9 What do you usually do when you don't understand a topic?
RULES
12 So, within this group of people you've told me that you communicate when having a problem, what counts as acceptable?
1) for attending lectures & tutorials
2) using resources & technologies
3) studying math
4) doing your course work
5) assignments
6) exams
As a student, are there any specific notions about what counts acceptable regarding:
- lectures
- tutorials
- learning resources & technologies
- on-line tests
- exams
- calculators
COMMUNITY/TOOLS
10 Who supports you when you don't understand a topic?
13 That's all my questions. Is there anything else you can think about studying Mathematics and using resources that we haven't talked about?

Appendix B
Questionnaire

Names of investigators
Marinos Anastasakis
Dr Carol Robinson
Prof Stephen Lerman

Loughborough University

Department
Mathematics Education Centre

Basic purpose and expected benefits of this research
This survey is part of a study that aims at increasing our understanding of what kind of learning resources and technologies undergraduates use when studying Mathematics. The results will inform both research and practice and will also help Loughborough University to provide a better learning experience to undergraduates like you in the near future.

Description of the survey
The survey consists of 3 main parts:

- Part 1 is an established questionnaire by K. Crawford, S. Gordon, J. Nicholas and M. Prosser, aiming at exploring your views about mathematics.
- Part 2 aims at identifying what kind of resources you use when you study for your mathematics modules and to what extend these resources are used. It also includes questions regarding your lecture attendance and how useful you think lectures are.
- Part 3 explores your goals, aims and intentions regarding your mathematics modules.

Your participation, privacy and confidentiality

- Your participation in this study is voluntary and you are free to withdraw at any time.
- By choosing not to participate, your grades will not be affected now or in the future.
- This front cover sheet will be removed by the researcher from the rest of the questionnaire after it has been collected to ensure that nobody else (besides the first researcher) will have access to your personal details.
- All of your responses will be anonymised (you will be assigned with a code) and data will be securely stored.
- By completing the questionnaire, we assume that you are happy to participate in this study.
- We might contact you in the future for a follow up study but you can refuse to participate.

General information		
Name:		
Student ID:		
Is English your first language? (please circle)	Yes	No

Part 1: This part of the questionnaire asks about your thoughts regarding the nature of mathematics. Please answer **all questions** by circling the most appropriate response. Do not spend a long time on each question: your first reaction is probably the best one. Do not worry about projecting a good image.

		Strongly disagree	<-------------------		------------------->	Strongly agree
1	For me, mathematics is the study of numbers.	1	2	3	4	5
2	Mathematics is a lot of rules and equations.	1	2	3	4	5
3	By using mathematics we can generate new knowledge.	1	2	3	4	5
4	Mathematics is simply an over-complication of addition and subtraction.	1	2	3	4	5
5	Mathematics is about calculations.	1	2	3	4	5
6	Mathematics is a set of logical systems which have been developed to explain the world and relationships in it .	1	2	3	4	5
7	What mathematics is about is finding answers through the use of numbers and formulae.	1	2	3	4	5
8	I think mathematics provides an insight into the complexities of our reality.	1	2	3	4	5
9	Mathematics is figuring out problems involving numbers	1	2	3	4	5
10	Mathematics is a theoretical framework describing reality with the aim of helping us understand the world.	1	2	3	4	5
11	Mathematics is like a universal language which allows people to communicate and understand the universe.	1	2	3	4	5
12	The subject of mathematics deals with numbers, figures and formulae.	1	2	3	4	5
13	Mathematics is about playing around with numbers and working out numerical problems.	1	2	3	4	5
14	Mathematics uses logical structures to solve and explain real life problems.	1	2	3	4	5
15	What mathematics is about is formulae and applying them to everyday life and situations.	1	2	3	4	5
16	Mathematics is a subject where you manipulate numbers to solve problems.	1	2	3	4	5
17	Mathematics is a logical system which helps explain the things around us.	1	2	3	4	5
18	Mathematics is the study of the number system and solving numerical problems.	1	2	3	4	5
19	Mathematics is models which have been devised over years to help explain, answer and investigate matters in the world	1	2	3	4	5

Part 2: This part of the questionnaire explores the kinds of resources you use in order to support your learning of mathematics. In particular, it asks **how often** you use the following resources when studying for **your mathematics modules**. Please answer **all questions** by circling the most appropriate response. Note that ***never*** here means either "***never use***", "***never heard of before***" of a particular resource or "***not applicable***".

	Resources	Never <-----					----->Always
20	**Your own written lecture notes**	1	2	3	4	5	6
21	**On-line videos** (e.g. YouTube, Khan Academy)	1	2	3	4	5	6
22	**Recommended textbooks/HELM workbooks for your maths modules**	1	2	3	4	5	6
23	**Social media** (e.g. Facebook Groups)	1	2	3	4	5	6
24	**Learn website** (e.g. lecturer's notes)	1	2	3	4	5	6
25	**Review Lecture Capture**	1	2	3	4	5	6
26	**On-line encyclopaedias** (e.g. Wikipedia)	1	2	3	4	5	6
27	**Instant messaging** (e.g. WhatsApp)	1	2	3	4	5	6
28	**Other textbooks that you choose** (e.g. textbooks with problems)	1	2	3	4	5	6
29	**Wolfram Alpha**	1	2	3	4	5	6
30	**Your pre-university notes** (e.g. A-level mathematics notes)	1	2	3	4	5	6
31	**Other students**	1	2	3	4	5	6
32	**Lecturers** (e.g. after a lecture, via email)	1	2	3	4	5	6
33	**Staff at tutorials** (e.g. lecturer, PhD student)	1	2	3	4	5	6
34	**Staff at the Mathematics Learning Support Centre (MLSC)**	1	2	3	4	5	6
35	**Other (please specify):**	1	2	3	4	5	6
36	**Other (please specify):**	1	2	3	4	5	6

From the previously described resources (20-36), choose the **top five** resources that you **use the most** and place the corresponding numbers below (*e.g. 23 for Social media, 20 for your own written lecture note etc.*).

Rank	Your top 5
1st	
2nd	
3rd	
4th	
5th	

The following questions explore your experiences regarding the lectures for your mathematics modules. Don't worry about projecting a good image; it is very important to answer as truthfully as you can. Remember that no-one else than the first investigator will have access to your personal details and that data will be anonymised.

		Never <------------------------------------>Always					
37	How often do you attend lectures?	1	2	3	4	5	6

		Not at all<---------------------------------->Very useful					
38	How useful do you think the lectures are?	1	2	3	4	5	6

Part 3: This part of the questionnaire explores your **goals**, **aims** and **intentions** for your mathematics modules. Please answer **all questions** by circling the most appropriate response. Your goals/aims/intentions are:

		Disagree <-------------------------------------->Agree					
39	To pass your maths module (+40%)	1	2	3	4	5	6
40	To open your mind	1	2	3	4	5	6
41	To satisfy your intellectual curiosity	1	2	3	4	5	6
42	To understand mathematics	1	2	3	4	5	6
43	To get a high mark (60% or above)	1	2	3	4	5	6
44	To acquire a mathematical way of thinking or philosophy	1	2	3	4	5	6
45	To understand the theory of mathematics	1	2	3	4	5	6
46	To understand the applications of mathematics	1	2	3	4	5	6
47	To acquire mathematical skills	1	2	3	4	5	6
48	To enjoy mathematics	1	2	3	4	5	6
49	Other (please specify):	1	2	3	4	5	6

From the previously described goals, aims and intentions (39-49), choose the **top five** that you consider **the most important** and place the corresponding numbers below.

Rank	Your top 5
1st	
2nd	
3rd	
4th	
5th	

Participating in interviews

We are very interested in having a more in depth discussion regarding your learning experience. Interviews will be very informal and will last for 45 minutes. If you are particularly interested in taking part, please tick the box below.

☐

Appendix C
Interview protocol

INTERVIEW PROTOCOL

MOTIVE

(1) Why did you decide to study Mathematics/Engineering?

MOTIVE+DEVELOPMENT

(2) Do you feel that the same reasons described before stand also for today?

TOOLS

(3) Do you use other resources besides the ones listed in the questionnaire?
(4) Do you use these resources for your other modules as well?
(5) Do you think there is a difference of how you use online resources as opposed to attending lectures, getting help from other students/friends, etc.?

TOOLS+WHY

(6) Why using these resources (your top-5) instead of others? Reasons?
(7) Why using a tool at all? What makes you say, "Ok, now I need to use this (a resource) in order to do that"?

TOOLS+DEVELOPMENT

(8) When did you start using these resources?
(9) Does the use of these resources vary throughout a semester? Do you use the same resources throughout the semester?

TOOLS + SOCIAL CONTEXT

(10) Do you use resources that a friend, a lecturer or another person have suggested to you since you've entered University?

ACTIONS-GOALS

(11) Could you please give me some examples of how you use your top-5 list of resources?
[**describe what do you do? + what do you want to achieve?**]
- when do you stop using a tool?
- **GOALS**: what do you seek? Understanding, Correct answer, Idea of procedures to follow?

ACTIONS-TRANSFERABILITY

(12) Do you use these tools in the same way for all of your modules? (more or less)

MULTIPLE RESOURCES

(13) Using more than one resource at the same time? Examples?

CONDITIONS

(14) What kind of difficulties do you encounter with when studying mathematics?

- Related with the resources that you use
- Related with the rules that the University has
- Related with what you want to achieve

(15) Are there times that you want to do something but you feel restricted?

INTRO TO FUNCTIONAL ORGANS

(16) Do you feel that these tools and the way you use them help you to get the “answers” and support your learning of mathematics?

(17) Based on which criteria do you conclude that a tool was successfully used and the goal has been achieved?

FUNCTIONAL ORGANS

A. Knowledge+Skills for the Tool

(18) How confident do you feel regarding how well you can use a tool?

B. Range of Solvable Tasks

(19) How do you recognise which task (group of problems) can be “solved” with a particular tool?

C. Translate Goals into Tool Functionality

(20) Do you think you can map what a tool can do (its functions) with what you want to do (your goal)?

D. Meta-functional, limitations

(21) How do you decide that a tool is “not good for the job”?

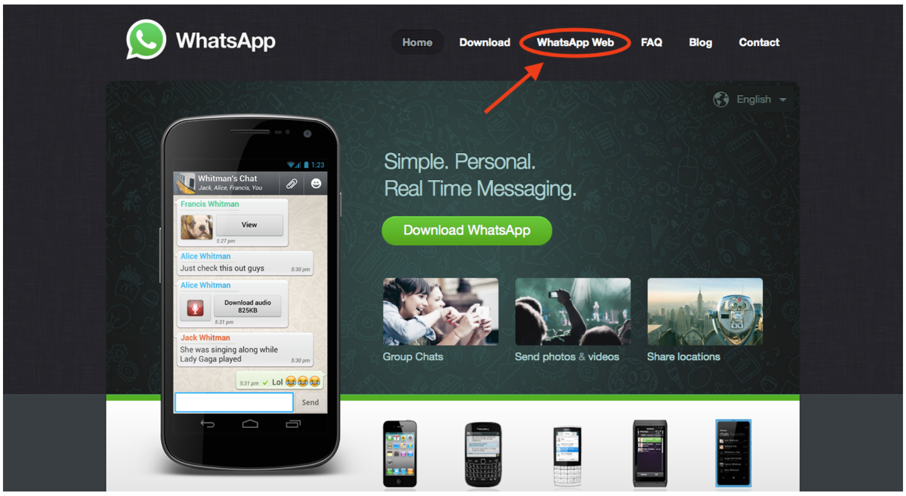
E. Meta-functional, troubleshooting

(22) What do you do when a tool malfunctions?

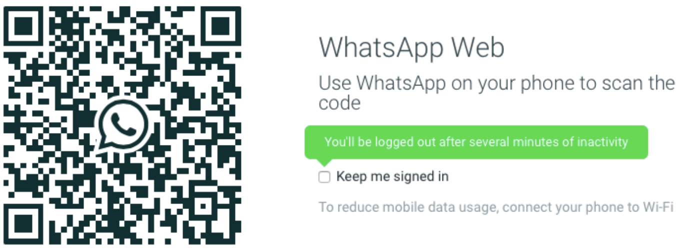
Appendix D
Instructions for the diarists

USING THE WEB VERSION OF WhatsApp

- Go to https://www.whatsapp.com
- On the top bar, click WhatsApp Web (https://web.whatsapp.com/)



Depending on your mobile device, follow the onscreen instructions in order to scan the code onscreen using your smartphone's camera. After the first login, you will be redirected automatically to your account (make sure to use your personal computer or to logout if using another computer).



Android users:

Open WhatsApp => Menu => WhatsApp Web, and use your camera to scan the code on screen

iPhone users:

Open WhatsApp => Settings => WhatsApp Web, and use your camera to scan the code on screen

Windows Phone users:

Open WhatsApp => Menu => WhatsApp Web, and use your camera to scan the code on screen

BlackBerry 10 users:

Open WhatsApp => Swipe down from top of screen => WhatsApp Web, and use your camera to scan the code on screen

BlackBerry users:

Open WhatsApp => Chats => Menu key => WhatsApp Web, and use your camera to scan the code on screen

Nokia S40 users:

Open WhatsApp => Swipe up from bottom of screen => WhatsApp Web, and use your camera to scan the code on screen

Nokia S60 users:

Open WhatsApp => Menu => WhatsApp Web, and use your camera to scan the code on screen

GENERAL INSTRUCTIONS

Constructing the diary is a relatively straightforward procedure. At the end of each day you will spend 5-7 minutes answering the questions below. If you didn't use any resources on a particular day just send "didn't use any resources" or something similar. If you are not able to fill in your diary on a particular day, please try fill it in as soon as possible the following day. If you miss a few days, please do not give up, just start over again on the next day you are able to. Please note that if the number of entries becomes to small, we will have to discontinue.

THINGS TO CONSIDER WHEN MAKING THE DIARY ENTRIES

Each day you will have to be able to provide us information related to how you use a particular resource. The resources can be either the ones from your top-5 list or other new resources that you are just starting to use or even resources that you use from time to time. In each diary entry you will need to answer to the following questions:

DIARY QUESTIONS		
1	WHAT?	What resource(s) if any did you use? Which one was most useful?
2	PURPOSE?	What did you want to achieve?
3	HOW?	Describe how you used the most useful resource.
4	WHY?	Why did you choose this particular resource?
5	EVALUATION?	Did you finally achieve your goal?
6	DIFFICULTIES?	Did you encounter any difficulties while using this resource?

EXAMPLE		
1	WHAT?	Meeting with my friend Tom.
2	PURPOSE?	To solve a problem sheet for our MAAXXX module.
3	HOW?	We met at my place, had problem sheets printed and tried to solve them.
4	WHY?	I couldn't solve some of the problems on my own, and Tom is really good at maths.
5	EVALUATION?	We solved all questions but I couldn't understand the last question (see photo)
6	DIFFICULTIES?	I was very tired (was out last night), my neighbours were really noisy.

Page 4 of 5

The answers do not have to be lengthy but it is essential to be as precise as possible.

LIST OF RESOURCES FROM THE QUESTIONNAIRE

1) Your own written lecture notes
2) On-line videos
3) Recommended textbooks/HELM workbooks for your maths modules
4) Social media (e.g. Facebook Groups)
5) Learn website
6) On-line encyclopaedias (e.g. Wikipedia)
7) Instant messaging (e.g. WhatsApp)
8) Other textbooks that you choose (e.g. textbooks with problems)
9) Wolfram Alpha
10) Your pre-university notes (e.g. A-level mathematics notes)
11) Other students
12) Lecturers (e.g. after a lecture, via email)
13) Staff at tutorials (e.g. lecturer, PhD student)
14) Staff at the Mathematics Learning Support Centre (MLSC)

If you have any questions about the diary, please use WhatsApp to send a message to the principal investigator (Marinos Anastasakis) or send an email at M.Anastasakis@lboro.ac.uk

Appendix E

Example of a fully transcribed interview (S1)

First question, why did you decide to study mathematics?
Hum, well, I was, it was one of the subjects I was best at school, hum, I didn't enjoy writing essays that much, also maths tend to have quite high employment rate, hum, it's funny, I initially, I actually went to university to study geography, hum, and I went to Leeds University and I dropped out cause I absolutely hated it, and re-thought and realised, from a young age what I really enjoyed was maths hum, because a lot of other subjects you spend a lot of time, just learning things of by hard, whereas in maths if you have the tools you can work out things yourself and.. not to just have to.., rely like.. on a bank of information, it's kind much more logical.

Ok, so in a sense, you were enjoying, you were good at maths since high school/
Yeah, it's funny, in my younger years at primary school, so between ages 4 and 11, I was always really strong in maths and then when I went to secondary school I went to a really academic secondary school with a lot of very intelligent guys, hum, like a couple of my friends went to Harvard and Cambridge to do Maths, so I didn't think I was good, I was like, ok I'm probably not good for maths to do in University because in my school I wasn't that, I wasn't at the top but that's why I didn't apply originally to do maths, hum, but when I dropped out of University when I was studying Geography I realised, "no actually on a national level I am good at Maths", it was just in my particular circumstances I didn't think I was…

Ok, and… yes of course of good employability rates as you said… Ok, so has this changed? This is your second year? (yeah) So since, when you decided to that OK I am going to study Maths, the reasons for studying Maths have they changed, now in the second year?
I guess… when I first chose to study Maths I probably didn't do it so much for the employability reasons, hum, and it was more/ because I enjoyed the subject, hum, the second year is slightly more challenging, hum, and I suppose the motivation to get you through that, is the kind of end goal of having the employability in the end, hum, yeah so I suppose it's changed slightly in that kind of perspective but not really as I still enjoyed it, hum still enjoy the challenge/

But it has become more evident that, as you proceed, hum, that you, the hard work that you need to put (yeah), so you don't only need to enjoy a subject but also have something as a return in the end…
Yeah, I feel like at this stage, sometimes when it's difficult, hum, I just, you have just to struggle through because you want the end goal, whereas when you are younger you just choose the subject you enjoy, hum, it's not that I do enjoy, I still enjoy but the motivation is slightly different maybe...

Ok, alright now, in the questionnaire you wrote that you use/ your top-5 list hum, of resources is the Learn website, your notes, other students, online encyclopaedias and Wolfram Alpha. Did you find the resources listed here representative in a sense, so do you think that, more or less students use these type of things, these kind of resources?
More or less than me?

You and other students that you know. So was this a representative/
Is this a representative section of the resources? Yeah, I think you've got most of them covered, I mean there are some on here that I'd say students don't use very much at all/

Such as?
Hum, pre-university notes, not so used, maybe in first year a little bit, hum, online videos I think is an interesting one I think, I've never used them and a lot of students don't use them but there I know few, very few students who use them a lot, a lot, and really helpful to them, so I think it's maybe interesting, I think if you are struggling on a particular topic they can be useful and I think some students probably should look into that resource because it does, I know it helps some students a lot but the majority of students don't use it at all. Hum, social media not, I wouldn't say people use that for their studies/

So for example you don't use, you don't join a Facebook group/
Oh, I see what you are saying, in terms of just for the communication. Yeah that's fair enough, I didn't think of it in that/

Ok the way it was listed here, didn't… Ok, so maybe I need to change this because (yeah slightly) you didn't recognise it as Facebook groups/

Yeah, I kind of thought of Facebook posts about Maths that kind of thing rather than just using it as a tool for… I mean I use… I still wouldn't say I use it that much, I mean I use a one WhatsApp, I suppose that's social media maybe/

Actually this is instant messaging…
Oh yeah, so I didn't put that as never, yeah I have a WhatsApp group, with a couple of colleagues on my course, so yeah social media, even then I wouldn't/I think some people do have Facebook groups, hum, yeah it's just, yeah…

Ok, so more or less you use these resources listed here (yeah) and this is your top 5 (yeah). Do you use these resources for all of your maths modules?
Hum, Wolfram Alpha no, because for example a module like…, hum, a very theoretical module like Probability Theory, I wouldn't need to use it, I mean Wolfram Alpha I just use, I'd, I was more last year, I used it a bit in the first semester for the more methodical modules, like, I mean I don't know how well you know the undergraduate modules (some of them, I also do some tutorials), yeah, like Mathematical Methods, for example I am doing Maths Methods 3, so for some of the kind of longer problems it's nice to use it to check if, check your solutions, hum, I mean obviously/cause I study hum, I don't study straight Maths, I study Maths with Accounting and Financial Management (ok), hum, so obviously for my accounting modules I wouldn't use Wolfram Alpha [laughing] (yeah [laughing]), it's main/yeah for my kind of computational modules which involve, ca- calculations I'd use Wolfram Alpha to check it, hum and obviously the top 2 there apply to all my modules (yeah), hum, all the other 4 actually probably apply for all my modules, yeah..

So you use these 4 to other modules too but Wolfram Alpha/
Just for computational (yeah) methods, hum, or maybe things like in first year Linear Algebra, hum, Geometry/one of my geometry modules/ so yeah I do use Wolfram Alpha but not for all of them..

Ok, so you don't use for example Geogebra, or I don't know, Excel when you study?
Hum, Excel…? No, I'd use Excel, I would actually use Excel for some of my accountancy modules, hum, I assume this is just focussing on my maths modules, yeah... I would not say I use Excel for my maths modules..

Ok, and you know for me resource or tool is something that you use in order to do something (to do something else yeah). Alright, now hum, next question, so why do you turn to resources at first place, so why using a tool at all?
Why am I using a tool? Hum…

Some of them, some of these questions may sound stupid or tricky (yeah), for there are, I am not seeking for correct (yeah) and wrong answers (yeah), I'm just trying to look through your eyes (no that's fine)
Hum, I would use a tool to help me in some way, I mean that might be to help me is quite a broad phrase, it might mean to help me in terms of hum, the direct computation of a question, for example Wolfram Alpha or it might be to help me in terms of my organisation at University, so for example where you've put hum instant messaging I wouldn't use that to help me do a calculation [laughing] that's kind of/so I use differ/I use a tool, a tool can be any kind of/like you've said any kind of resource and some of them apply directly to my/to help me when I am stuck on a mathematical question and some of them are just to kind of organise my/organise my studies, hum, yeah I mean there's a lot of different types of tools..

Ok, so yeah it's, it is connected to what you want to do
Yeah, exactly

Hum… Ok, so could you please tell me/you know some/ as you said some students and it is evident in my data that use a lot for example online videos or some of them do not use at all their own written lecture notes (oh really? [surprised]). Yeah some of them put 3 or 2 [in the Likert scale], so why do you think… there are a lot of things to choose out there, so why do you think you…/Use my notes?/ Yeah, not just your notes but why you use these [resources]?
Hum, so I think the point you've made about the lecture notes is really interesting, hum, because for me if I didn't use my lecture notes, then what's the point of writing [laughing]?/I mean am not/I'm not saying, I'm not saying what I do is right, but/and the other what they are doing is wrong but I think, the reason I made the lecture notes in the first place is so that I can use them, and if i was just going to use, if I was going to use more just videos and hum, online encyclopaedias and textbooks and not using my notes, then I wouldn't put so much/ I wouldn't put the effort into making them in the first place, hum, I like using my notes because, hum, they're person/ it's a

personalised resource, so when I'm/ so I use them in the kind of the revision, they're good for me because I've made them myself so, if I know there's a particular style of notation which I struggle with, when I'm taking it from a lecture, I can kind of put a little note on the side saying this means this kind of thing, whereas if I'm using an online video, that video is made for the general pub/ for the general student community, so it's not personal to how I best learn if you see what I mean, whereas with my notes I can tailored them to however I think I best learn, hum, so that's why I am using my notes, hum, the Learn website is great, I mean it's not specific to me in the way my notes are but it's so specific to the module, so if there's kind of hum, past papers or exam tests on Learn, I know that's/ I like using that as a resource cause I trust it, because I know that's the material I know I'm going to be tested on, whereas if i am using notes or some explanations from an online resource, it's not/ I'm sure it's very credible but it's not specific to the actual exam that I'm going to be sat, hum so that's the reason I like using the Learn website, other students it's great because hum, for one it's a break from personal like study on your own, it's nice to have interaction, hum and also I think when you learn maths is always great to have different inputs hum, they've might say something that you've not considered, you might say something they've might not considered, hum, I'd say/I've said online encyclopaedias is great for just a quick, if you want/if you just can't think of something and you want to quickly look it up/ I wouldn't say I use it for.. detailed study, just if I'm stuck on a particular thing, I'd often just put it quickly in and see what comes up hum… and Wolfram Alpha just happens to be my favourite tool, I mean.. there's probably might be better ones that I just haven't come across, just for computation, I mean it's just the one I knew so I've, I don't use it, I don't use it all the time but certainly in a few modules just like I've said before it's nice to/for checking answers/I'm sure there are similar tools out there that do the same job or probably better. I mean, that's just the rationale behind my favourite ones.

Ok, so for example, online videos do not have this "personal" touch (yeah) and are not connected (?not specific?) with some modules? ok. Now, some of these questions might not be applicable to your top-5 but ok.. So, when did you start using these resources?
When did I start? (yeah) Well the Learn website I would say when I came/first came to the uni, my notes… I mean (you've always) yeah, I mean I only use my university notes since I came to University but I've always used my notes [laughing].

The same thing with other students I guess?
Hum… Yeah, I suppose, I suppose actually when you're, when you're at school, you probably use, I would say, overall you use other students more because whenever you're learning you are in a classroom environment and there's normally like 20 to 30 other students and there's probably more interaction but then when you go/but in school once you go home you don't have so much interaction so, but I would say I've used other students all the way through hum, and… Wolfram Alpha, Wolfram Alpha I started using when I came to University maybe, I think we… one of my lecturers used it in a lecture in maybe like in the second week of term in first year and I was like wow that's quite cool..

So a lecturer (yeah) showed you Wolfram Alpha and you…
Yeah, I mean he wasn't, he wasn't showing to us in terms of you should go and use this, he was just, he just used it to quickly in a lecture and I was like, wow that's quite a good tool and I… like I said I'm sure there's very/lots of programs that can do the same thing hum, and online encyclopaedias, I mean I've always used them hum..

So, also during your secondary education?
Hum, I suppose actually now you say it, I probably didn't use them in maths in my secondary education because the material was not, not basic but it was kind of hum, you've sort learned it from the teacher more and your teacher would set you work from a textbook, hum there wasn't so much kind of theory that you'd have to look up on online encyclopaedias so, yeah I suppose I probably only started using that doing more kind of theoretical study in undergraduate maths rather than secondary school level maths.

Ok, alright… and you told me yeah, more or less that hum, you saw it, Wolfram Alpha you saw it from yeah. So these two [pointing on the questionnaire at Wolfram Alpha and Learn website] you weren't using them before, for example during your secondary education and at some point… Ok. Hum… Alright now, the next part, I would like to…, so this is your top 5 list and I want you to describe me and give me examples how you use them (ok). So what we can do, at least for the Learn website [starting the computer in order to start capturing the screen]. So I want you to give me some examples how you use this, this and this [pointing at the top-5 list] but let me…

Ok… [still trying to set up properly Quick time player, launch Safari and navigate to the Learn website]. No let me start Quick Time…

Ok, now you can tell me more or less how you use/
How, yeah how I use Learn for… So, I mean there is a number of ways how I'd use Learn, hum, classic example is if a lecturer has put some kind of hum questions in that folder for the particular module which I want to use, hum so for example Maths Methods 3 is the kind of computational maths module I am doing at the minute, hum, and the lecturer uses Learn and he puts, he'll put kind of problem sheets on Learn, so for example if I want to go and practice my particular ability in/on a topic hum.. I could go to learn maybe Fourier series and open up the problem sheet and then a lot of the time I printed of hum, and then that would be all that I'd use Learn for [laughing] just to access this, hum… that's a kind of basic way I use it, and then… once I finished , I'd probably, I'd probably hum practice the questions on/handwritten on paper and if I was struggling I could use the lecturers' worked solutions which [accidentally closes the window]/ So then I can go on to the worked solutions for that particular topic.. hum.. and then compare, compare what the lecturer sees as a model solution to my solution, so this is, this is, this is an example of why I think Learn's great because this is the exact kind of questions which I'm going to be asked in the exam, so I can see a direct example and also a direct example of what the lecturer believes is the model answer hum, so for example if you are looking an online video it might be a really good solution but the lecturer might have a preference of this kind of solution, so if I can, if I can work out how to present out my solution in this kind of format, then that's going to be the way I'm going to get the best mark, hum.. So problem sheets, here the lecturer also put mock exams on Learn, so I can see literally hum, a kind of carbon copy what I'm going to be assessed on, hum, so that's a really good resource, hum, I suppose Learn is more of kind of access point for resources, rather than… a tool in its self, meaning like I've said before, there's a lot of different types of tools, my notes are kind of a direct mathematical tool, Learn web, the Learn website in itself is just a portal for accessing other tools, hum, so… I mean that's an example of how I use it for this module, and… for another module like… hum, my Marketing, this is/actually that's not maths related but it works in the same way…

Yes, so more or less you use Learn (yeah) in the same way for other modules too (yeah) non mathematics/
So, for example, it doesn't really matter what the module is itself but the lecturer will have lecture slides from all the lectures so I can go into them and review them hum, and obviously its also an access point for finding out my results and things (yeah). So that's, that's how I use Learn…

And also I guess past papers?
Exactly yeah, past papers and, and I think that was the one on, ?had? past paper in for methods, hum, yeah, well past papers and the kind of mock exams, so it's kind of directly, directly/where is your modules, so you kind of seeing what are you exactly going to be assessed on…

So, in particular for Learn website, you/what you do is, you want to find for example lecture notes/
Practice questions, yeah

Mock exams or past papers (yeah) and could you please relate some of your actions with your goals? I am using some kind of jargon here (yeah)… so you've told me what you do usually and what do you want to (achieve) achieve usually?
Yeah, so for example I would/one of the things I've showed you is using the problem sheets and the reason I do that is to… improve my ability on/in doing the kind of computational questions that I am going to be asked in the exam, so if I'm/if I'm successful in doing the problem sheets hum, I know that, when the exam comes around, which in the end of the day is… the important thing in the end of the term, hum, if I've done the problem sheets I'm gonna know that, I can do the material that is going to be asked on the exam, so, that's great because… if you're doing/if you're looking at/I mean, I'm not criticising online videos but if you're working on online/if you're watching an online video that's your learning but you're not/you don't 100% know that you're gonna be, you're gonna be improving on ?something? that's gonna help you for the exam, so I like using Learn and doing the problem sheets that the lecturer set because once I've done it, I know that, I'm confident that I'm going to be able to do the material that's on the exam, because it's very similar to what it's going to be on the Learn website…

So, for example, you are seeking understanding (yeah), correct answer (yeah), idea or procedure (yeah) to follow/
Yeah, I mean I'm seeking understanding and the correct answer but you could say that there other resources where that's also true (yes of course) hum, the reason I like Learn as opposed to some other ones is because not only you get the understanding and, and improving your ability but you're confident that you're doing that, in material that it's directly related to what you are going to be examined on at the end of the day, at the end of the term...

…You are sure that you are working towards (a specific goal), yeah direction, yeah it's specific/

Whereas if you're watching a, oh let me use a different example, if you are, I don't know, if you are using an online encyclopaedia you might be doing, you might just strain onto material that you don't actually need to know, so it's all about efficiency of learning (yes) in some words, and Learn you know when you're working form material from Learn you know you are not going to be wasting your, wasting your effort because it's all, it's all, you know it's the right stuff.

Ok, do you think your use of learn varies throughout the semester?
Hum…, yeah I suppose in terms of, what I use it for, I mean, earlier on in the semester, it might be for example if I've, if I've had to miss a lecture for some reason for catching up, hum, printing out stuff whereas later on in the semester is more for, just grabbing a mock exam and (yeah) it's not so much for material, by the end of the semester I like to have all my notes and stuff constructed and then I use Learn just to access the mock exam and, hum, yeah.

Ok, so, how about your notes, how you (yeah), first of all how do you take your notes?
Yeah, so how I use my notes.. I mean.. So I and construct a set of notes hum, throughout the lecture time for a particular module, hum and I'm not.. I don't like to be too.. the way I like to do my notes is I don't like to be too strict, like sometimes when if I'm in a lecture and I don't and it's quite hum, conceptually difficult to follow I might say ok, I'm gonna live my notes and just try and listen and then try and maybe copy the notes after, cause some times if you are making your notes, it's harder, it's quite difficult to listen fully and make notes at the same time, so you are making notes sometimes and you're just copying, and it's ?? going in. Hum, so sometimes if I'm making notes and I feel like it's not, I'm not actually processing the information, hum, I might just leave the notes and listen in the lecture and then try/and then come back to the notes in the end, hum, so hopefully then/ ideally in the end of the semester I'll have my own full set of notes along side the lecturer's material, hum, and I can compare, I compare my notes to the kind of lecture, the lecture notes that the lecture's made, and then when it comes to revision, hum, I'd, what I'll do when I revise is take my notes from the whole module and try to condense them into a really short, condensed format, hum, and then obviously the process of doing that also helps in my revision not just for the resource, hum, and then towards the end of the revision in a kind of couple of weeks before exams I just practice questions, practice past papers questions, hum, and then when I get stuck try to and refer to my notes hum… I guess my notes you could say I use it more as a process rather than for the actual resource itself, sometimes it's the process of making the notes which helps my learning rather than using the actual notes I then made/

/like a textbook for example, do you mean this?
Yeah, kind of, almost the opposite, so I make a set of notes on a module and/but the reason I do that is the process of making the notes, is what helps me learn, hum, so for example I might, for/in a particular module I might make a whole set of notes and then, once I've made them not use them that much, but it's the process of making the notes in the first place, over a long period of time which helps me learn, rather than reading them/I mean I obviously, I'd look back over them but I spend more time making them than using them, that kind of thing...

And, how do you usually make your notes? I mean, hum, do you just try and copy what the (yeah) lecturer does?
Yeah, I mean.. I tend to.. So... The lecturer will normally have a set of notes which he shows throughout the course of the lectures, at the front of the lecture theatre, and I'll tend to, copy it but not copy it directly, so sometimes like I think I said earlier if there's like a particular notation which I think is confusing, I'll rephrase it, hum, and I guess it's just a kind of personalised copy of the lecturer's notes which I'm trying to make..

Ok, so and you also told me that it's the actual process of making (yeah) notes/
I think that's kind an interesting/well don't to ?? sound/but I think it's quite interesting point because people talk about making/sometimes students will say "ah, I've made these notes do you want me to send you them?" and sometimes I think "why? I don't really want them because the way you learn is by making the notes in the first place" rather than looking at the notes.. So, a lot of students will send like on a page, on a Facebook page I mean, "ah I've got the notes for this module, does anyone want to use them?" and it's very nice but I think the important thing about notes is most of the learning is done in making the notes rather than reading them after you've made them kind of thing. So, yeah, there's some kind of two different sides of your impersonal notes, there's using them after you've made them and the process of making them in the first place. So what I am doing is, over the course of the module I'll make a long set of notes and then my revision would be, try to condense them into a shorter version (ok), hum, yeah…

Alright, hum… So, actually when you use your notes, hum, it's not like for example an online encyclopaedia (yeah) or.. that you just go there (yeah) have an answer and come back/

I mean I do that, at the end of/during revision time and if I'm practicing a question and I'll go to refer to the notes I've made but the reason I've put them so high up is based on the process of making them in the first place, that's the resource/it's kind of a strange concept "the resource is making the resource" sort of thing..

I completely understand what you mean. Ok, so then let's move to other students so.. this is again a resource, could you please tell me why for example you prefer students rather than the MLSC or?/
Hum, it's a good point. I think hum, I like using other students because they are often in a similar situation to me/

And what do you mean "similar situation"?
In terms of.. they might be struggling with a particular concept hum, and I think if you want to resolve hum, something you are having difficulty with, with another students it's a really, it's a really/in the short term it might be difficult because it might take you a few hours to do, whereas if you were to go to the Learning Support Centre you'd have a teacher there who would be able to show you how to do it, probably more quickly but in the long term the benefit of working with someone/working out for yourself hum ?and you're? kind of struggling and then, bouncing ideas of each other, this is a really satisfactory way of working things out and I think it's just a good way to learn because, you're kind of working out for yourself, just in a team/ and also/ and team-work obviously, the kind of team-work skills that you develop from that really useful hum,/ and also to be honest it's quite enjoyable (yeah of course) because you can go you know and like on/ maybe on a Sunday afternoon during term time, hum, one of my friends who does my course, hum, we might go and.. watch the football and then when the game finishes do some studying together so… it's kind of social I suppose hum..

Ok, and… right, would you like to show me how you use online encyclopaedias?
Yeah, so I suppose in that instance, it's just for.. for looking things up so, maybe I don't know, like, what could I be looking for.. hum… [… preparing the screen recording…] Yes, so if I'm using an online encyclopaedia it's probably just for like a brief.. a brief thing, just to quickly look something up, so for example if I couldn't remember hum, the… what can I look up? Hum… (dot product or cross product, something like that) Yeah, yeah, hum, I'd probably just put into Google hum, and then, if it's something, if it's something quite simple hum, I sometimes use Wikipedia for example hum, Wikipedia tends to be better if you are looking for something theoretical whereas for dot product it's not immediately obvious where/ it's not immediately obvious kind of the process of how to calculate it, so then I go back and look for a kind of resource which might be more.. hum computational rather than theoretical hum, so.. so for example this resource...

This is something that you have accessed before?
No, no. It tends to/ it just looks like be like/ it's like a school or some kind of educational website, so those kinds of websites tend to have more kind of computational notes rather than paragraphs of text hum, so I mean here, yeah.. [accidentally clicks a link to Wolfram site] so, yeah it gives me the formula and an example. I mean, so I suppose, I use online resources for looking up things briefly rather than to use extensive sense of notes.

Alright, so you're/ are you also concerned about the validity of [online resources]?
Yeah that's a good point hum.. I suppose when I use online encyclopaedias, I tend to do it for.. I tend to do it to look up things which I've already covered before maybe in a lecture that I just can't remember from the top of my head, hum, so I tend to/ so hopefully when I see something I'll remember it from before and know it is correct/ I don't know how I'd use an online resource if I was learning something initially hum, so for learning something in the first instance I tend to always use hum, lecture notes, like lecture time or my own notes or the Learn website, I use online encyclopaedias if I'm kind of/ if I'm studying and there's something/ there's a concept I've learned before but I can't remember it so I just quickly type it in and click on something and then I'll tend to know if it's valid or not because I'll be able to recognise it because I have studied it before, it's just something I cannot remember from the top of my head. Might just be one equation which I will recognise and just can't remember hum, so I have to just trust my own instinct I suppose [laughing].

And also you use more or less in the same way online encyclopaedias throughout the semester so, it's spread, its use is spread?
I suppose, I probably don't use it so much right from the beginning of a semester because in the beginning you're learning a lot of new material hum, so I probably wouldn't, it tends to be towards the end if I'm looking back at something I've learned at the start/ so for example if towards the end of a semester we're learning a topic which is based on some old material, and there's some kind of equation from the old material which I can't recall, that's where I'd just quickly look it up on an online resource, and I'll hopefully recognise it, so and I probably do that/ yeah more towards the end where I'm doing/ when I'm studying which is based on old material which I need to

quickly refer back to hum, and occasionally maybe during revision hum, if I want to look quickly something up, so yeah, probably not so much in the beginning because I don't use it so much for new material, it's just for reference.

Ok, and of course by online encyclopaedias you are not only referring/ you are also referring to other online "things" (yeah) not just (yeah)/
Well I don't know what you'd define as an online encyclopaedia, I suppose Wikipedia obviously but I kind of, I don't know if rightly or wrong we are just assume that to me any kind of online resource which wasn't computational in the way that Wolfram Alpha is..

Ok and finally Wolfram Alpha.. So how do you… [use it?]
So Wolfram Alpha hum, is a great resource for checking my solutions to a problem, the classic example.. if something/ if you can't do it with the calculator such as like a complex integral, so if I'm doing it, I thing I used it a lot/ I remember using it a lot last, in the first year during Mathematical Methods, Mathematical Methods 1 in the first year, a lot of it is, you spend a lot of time just getting really good at fast doing integrals.. and obviously you can't check your results on a calculator, so Wolfram Alpha is really good to have open just to check that you've got it right

So would you like to show me an example?
I mean, I often tend to use Maple as well. I suppose that's kind of a similar kind of tool. Do you know Maple?

Yeah, of course. So you also use it [for Maple]… So you use Google as your search engine? (yeah) This is DuckDuckGo so this is different. Ok you are here…
So for example I normally just use it to check, most common use is to check the results of an integral, so for example/ and the great thing about Wolfram Alpha is you can combine like text and numbers so..

Which is different the way Maple works (yeah exactly)… or Mathematica…
Yeah, so you can type this for example into Wolfram Alpha and, it will normally give you the solution and also gives you the graphs… I mean sometimes I use it just if I can't remember like a direct result so, I mean hopefully I'd always remember this [pointing on the screen] but like if there's something/ you have the set/ ?set solutions to integrals, if there's one that you can't remember of the top of your head you can just type in and it then comes up, so it's kind of good resource in that sense as well, as well as for checking the solutions to like a long, a long integral. Yeah and that's what I'd use it for.

Ok, and… So you use different resources, we can say for different purposes…So depending on what you want to do you choose (a different resource) a different resource. And I guess, do you, are there times that you use multiple resources? At the same time?
Yeah sure, I mean, I can easily be using maybe 3 of these resources at the same time so, if I was for example doing some, just some problems sheets the lecturers have, I might choose to work with another student and using, I mean we use the Learn website cause that's where we get the problem's sheet from, I might refer to my notes for a question and then if there's a gap in my notes if I've missed something like an equation which I didn't have time to copy in the lecture I might quickly try and use an encyclopaedia to reference it, and check my answer with Wolfram Alpha [laughing] so I could, yeah I mean, it's not like you'll use the one or the other, my most common study habit just… I suppose if I'm sitting in my room studying on my own, I almost always use the Learn website to get my resources like my problem sheets or a past exam paper or looking over the lecturer's notes to update my notes, so I almost always use the Learn website and 90% of the time I have my notes which I've written, kind of on the side, so that's those of the two which I so often interchangeable but like I've said you can use, I/you often use all those resources on the same time/ well not often but you can easily use all those resources at the same time ??I mean they're?? different kind of resources..

Ok, now..[asking permission from the student to continue because the interview has lasted more than 45 minutes]

Ok, do you think there's a difference of how you use online resources as opposed to attending a lecture or getting help from another student/friends?
Yeah, they are very different, so, I mean when you're attending a lecture your/ that's often when you are learning something for the first time, it's new material, and using other students as a resource that's tends to be very much for kind of practicing your/ if, I often do kind of/ I think I mentioned before/ problem sheets with another students

because you can work together and if get stuck on one, you can help each other out, that's a very different kind of learning experience to when you're in a lecture, it's very much, you're sitting receiving information rather than interacting, so lectures as resources are very very different to the way you learn when you're with other students, and I think that both are important.. The lectures are crucial cause that's when you learn new material and obviously you can refer back to it from the notes that the lecturer provides, but it's a very different resource to the way I use other students for practicing our knowledge.

Ok, now.. So the next question maybe is weird (that's fine [laughing]), it's difficult you know to explain it (phrase it yeah), yeah, so under which conditions do you usually use a tool? And… So, conditions from my point of view are the things that you don't have control over them (ok) and you have to adapt the things you do. So when usually you use the Learn website, your notes, friends, any of these top-5 list of your resources, are there things, factors that/ (influence which you ones you choose, is that what you were saying?) Yes, influence what you do, for example let's say that you want to.. to do a problem sheet, so all the things that influence what you do, so your actions, are conditions. I don't know if this helped…
Are you saying which conditions, which conditions influence which one I choose? Or…

Maybe we can cover it later, this, so based on which criteria do you use/ so are there times that a condition restricts you from using this or another resource?
Ok, I think I see, yeah, so you're saying under which conditions do I do which one?

So in general but you can pick up any resource..
Ok, so for example, let's say, other students, using other students, so you're saying under which conditions/ what influences my choice to do that.. So I would tend to use other students, if I was, the most common reason I would use other students is if I want to kind of practice a skill in mathematics, so if there's a particular problem sheet based on, I don't know... like, Laplace transforms, and I want to work on that skill that would be, working on a particular skill is a condition, if you'd like a time when I tend to use other students to help me, because I wouldn't use an online encyclopaedia because it's very computational and it's about practicing a skill rather than looking up to staff, so I'd sit down with another student ?one, two three and work through the process together and kind of practice that comp/ that particular skill, whereas for example if I wanted to.. if I was.. revising a concept which I already knew how to do, or revising some theory, mathematical theory, that might be a time when I'd just only use my notes and the Learn website and maybe an online encyclopaedia to look something up or review something rather than other students because that's much more of a kind of just a personal review process where you are just looking over things and you don't need, you don't need the interaction so much to develop it cause it's not so much of a process.. I don't know if that's…

Yeah, you actually, I need to rephrase this but you've answered one of my next questions that is… for example how do you select/decide which tool is suitable/
Oh, ok, yeah that's kind of what I've thought you are..

So, you told me that you select students if you want to practice a skill (yeah), if you want to use something as a reference you use Learn or (my notes or an encyclopaedia occasionally)..

Ok, so maybe, so let's say what is a condition.. Imagine that we have a student who is dyslexic, so the student does not have control upon his dyslexia right? He cannot choose to be or not to be [dyslexic]. So this student will have a problem when taking notes, taking lecture notes, so this is a condition, the condition is I am dyslexic, I don't have control over my dyslexia and I have to cope with this…
Ok so you're saying what conditions do I have?

Yeah, but not.. things that you don't have control/
Ok, that I have to overcome by using resources. Ok let me think.. So... I'm trying to think of an example..

So one example could be… you send a text to a friend, let's gather and do some problem sheets but she or he says I am away, I have other staff to do, so this is a condition..
Yeah, so it's kind of, like an issue that you have to overcome in order to (yeah restriction)… restriction.. Hum.. ok, so.. hum.. Could you say a restriction is if you have to miss a lecture for some reason or.. (yes, if you're sick or something) Yeah, so for example if I was ill and I have/ well ?it happened before if I'm ill and I miss a lecture or if I once had to go home for an appointment with my doctor at home and had to miss like some couple of lectures in the module.. then in that condition I would tend to use the Learn website and probably other students to help me catch up with the material I've missed.. Hum.. and I'll try and get/ try and make my own copy of the

notes without being in the lecture which is obviously more difficult so in that instance I would use the Learn website and try and borrow some notes from another student.. hum I guess another condition like the one you've said if I was, if I wanted to meet up and practice something.. whatever and who ever I wanted to work with was unavailable or busy, then obviously I'd have to change, I mean one I could, often if there was something that I was reasonably comfortable doing myself, I'd probably just sacrifice working with someone else and just doing on my own in that instance. Hum, because it's the same/ you're doing/ I'm doing the same as if I would have been with them, it's just a slightly less valuable resource for ?? doing it, hum, I mean obviously depends on the circumstances they might say oh yeah we can work on that next week and if there was something that wasn't immediate, it was just a practice then yeah fine.. Hum, or if it was something I wanted to work on that specific date then I'd probably then just go to the library or working in my room and work on myself, which would be a compromise less useful when ?? doing it, but it's not particularly/ personal study for other things is better but for computational practice I'd rather do with someone else but it's not, it's not the end of the world if I had to do it on my own, I mean, I often do it on my own it's just better if I, sometimes is more resourceful doing it with someone else.

Ok, other conditions? (Hum, yeah let me try to think…) We can come back if…
Yeah I'm just trying to think of a condition that might.. (It's a strange question) No, you know it's an interesting point, I just can't immediately think of like some kind of condition that might affected me… No I can't think of one..

So, at the end of the day do you find these resources to be useful? Do they get the job done? (yeah) When using them of course..
Yeah, I mean, when you're learning you have to use some kind of resource hum, like this is quite a personal choice, these are the ones that tend to work for me best, but I'm quite, I'm quite happy with the resources I use, hum, of the ones I don't use, I should/ I mean I probably should use the MLSC more, if was being self-critical I'd, there're probably instances where I should/ I could use that but I often tend to try and work on it with another student just because it is more enjoyable, hum, I mean, I guess I can try using online videos a bit more but it's just about personal choice, I mean the ones I use tend to work for me/

So you have tried for example online videos and they don't work?
Yeah, I've probably not given, not given them as much of a chance as I could, I mean, I've tried to use them on/ for a couple of topics in the past and they haven't being great but maybe I just wasn't choosing the better videos I don't know.. So I would be very open to, in the future, if I was struggling and my resources won't working for me, I'd be very open and looking into it and maybe I/ I mean yeah, I am open to change, I think you have to be..

Ok, so more or less you have tested in a sense these resources (yeah) and (yeah, I would never)..
Yeah, I've tested these and overall as a general rule of thump these are the ones that work best for me, that's not to say I never gonna to try the other ones/

Yes of course, under these, the circumstances of your study here these/
Overall these are the ones I tend to use the most.

Ok, now the last questions, sorry if I am keeping you up... So do you instantly recognise which tasks are solvable with/
With each resource? (yes) Yeah, so when I have a task, I tend to know the best way to go about it so, if my task is to practice some questions, I would know, the first thing I do is go to the Learn website to access the material that I want to use, and I would know that, and probably gonna have my notes next to me, whereas if my task was, ok here's some theory to revise for a test I'd think ok theory what do I need? Probably my notes which are based on the theory then maybe have my laptop/ my computer if want to refer to an encyclopaedia.. I guess you just know based on your previous, your.. yeah your previous habits in what tends to work for that kind of task.. So I normally know which ones I'm gonna use. I mean if during the course of doing a task I think another one might be helpful then obviously I can turn to it as ??? but I normally know at the start of a task which resources I'm going to use.

And do you think that you can map what a resource can do with the things that you want to achieve so… translate what Learn can do? Do you feel for example confident using all these resources? For example, Learn? (do I feel comfortable using them?) Know how to use them/
Yeah these are the ones I use so, I suppose I know how to use them, I mean there's probably, there's probably some aspects of Wolfram Alpha which I don't know how to use and obviously online encyclopaedias is quite a

broad sense so there's probably, I imagine a number of websites which, a number of lots of websites I don't use which wouldn't know how to use.. I suppose, I use my notes, may there's/ maybe I could improve the way in which I use that resource but.. I'd say I know how to use them..

Do you have any problems when using a tool?

So yeah, the one that you've mentioned using other students if they're not available then that's an issue with that tool, my notes, the issue that I might have is if I have a gap where I've missed a lecture for some reason and then I could try and overcome that by borrowing a friend's notes or reviewing the lecturer's notes on the Learn website.. The Learn website, I don't suppose, I can't imagine ?? an issue with a tool.. unless the lecturer hadn't put up some staff yeah, maybe then I send them an angry email why haven't you put the ?? on Learn yet, I needed for my notes...