Rules, Prototypes or Examples? A Framework for Understanding Transfer Events

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Abstract

The purpose of this article is to propose and evaluate a framework for analyzing individual transfer events. The framework is grounded in the psychological literature on categorization, and considers that abstractions leading to transfer are represented by rules, prototypes or exemplars, or a combination. An empirical evaluation of the framework is carried out using an interview study and employing content analysis and grounded theory to analyze the data. The results demonstrate that it is both possible and enlightening to classify acts of transfer described by individuals as based on rules, prototypes and exemplars. A main finding is that individuals use these modes both in isolation and combination. Furthermore, individuals use rules and examples in a combination of ways that are not documented in the literature. This analysis may serve to reconcile the perspective that transfer relies on decontextualized knowledge with the alternative that it is based on rich representations of specific knowledge. The framework and associated methodological tools can be used in a classroom context by researchers to investigate individual acts of transfer and by teachers to support learning.

Rules, Prototypes or Examples? A Framework for Understanding Transfer Events

In a broad sense, the term transfer is used to describe the idea that learning in one situation can influence behavior in future situations that differ from the original learning context. Transfer is an area of primary importance to education and cognitive psychology, since without transfer, all learning would remain unused. Therefore it has attracted considerable interest over recent decades (see e.g., the reviews in Lobato, 2006; Marton, 2006).

Research concerning transfer has led to a number of conceptual and theoretical advances. Early research concentrated on investigating rates of transfer between previously determined learning and transfer situations (see e.g., Gick, 1985; Gick & Holyoak, 1980; Gick & Holyoak, 1983), in what has been described as the *classic approach* to transfer. Partially in response to the lack of observed transfer in these situations, emphasis in more recent studies has been on approaching transfer from an *actor-oriented perspective* (Lobato, 2003) where the emphasis is on particular acts of transfer and understanding the processes that learners engage in during them. Although the research has led to some useful theoretical constructs to analyze transfer, examined in more detail below, it has proven difficult to operationalize them in relation to particular acts of transfer. As Lobato (2006, p. 444) points out, what is needed are "approaches with sufficient specificity to allow for the explanation of instances of transfer in classrooms". Therefore, theoretical developments that readily lend themselves to empirical investigation can be useful in order to address questions of this type within educational settings.

Issues of human cognition that are related to transfer, such as categorization, have a long tradition of research in cognitive psychology (see e.g., the review in Braisby & Gellatly, 2005; more details on this literature are provided below). Indeed, the literature on category formation and categorization provide a useful framework for analyzing transfer within education.[1] As will be argued, this research in psychology can provide useful insights to the research in education.

The purpose of this article is to propose and evaluate a framework based on categorization. Transfer in a problem-solving situation is analyzed as occurring when the new problem is categorized with earlier problems requiring a similar solution. The framework comprises three key models from the psychological literature on categorization suggesting that transfer is based on rules, prototypes or exemplars, or a combination of these. This framework is evaluated empirically via an interview study, employing content analysis and grounded theory to analyze the data. The approach aligns with Lobato's (2003) proposed actor-oriented approach, addressing a number of key weaknesses in the literature to date.

The results demonstrate that it is both possible and enlightening to classify acts of transfer described by individuals as based on rules, prototypes and exemplars. A main finding is that individuals use these modes both in isolation and combination, providing evidence for the ecological validity of the psychological models. Furthermore, additional richness in the interview data provides evidence that individuals use rules and examples in a combination of ways. Firstly, examples are used to support thinking, either replacing rules or being used to derive them; secondly, they are used as a communication tool, either to clarify concepts within a rule, or to illustrate a rule; thirdly, when the distinction between two categories is multidimensional (i.e., it can be expressed as a number of sub-rules), participants at times use a rule for one dimension and examples for another.

The above results are not documented in the transfer literature. They may serve to reconcile the evidence that transfer is supported by decontextualization of knowledge (e.g., Bransford, Brown & Cocking, 2000), and that it is due to specific knowledge which is used in particular situations (e.g., diSessa & Wagner, 2005; Wagner, 2006). The analysis here reveals that both rules and examples are used, thus suggesting that both perspectives are valid and, in fact, the two modes appear to interact.

The article is presented according to the following outline. First, drawing on the related research in education and psychology, a framework for classifying transfer events is proposed, based on concepts from the categorization literature. Then, the empirical approach is described and the results are presented and discussed. Potential extensions, using the methodology employed here, are also provided.

A Framework to Analyze Transfer

Transfer in Education

The issue of how prior learning in one situation influences behavior in another has long been a theme in educational research. Lobato (2006) and Marton (2006) review a number of research contributions dating from the beginning of the twentieth century to the present day, comparing the theoretical understandings and methodological paradigms involved. This research motivates and informs the framework for analyzing transfer described here. Hence, to contextualize the proposed framework, I first discuss the relevant literature. In particular, the next section begins with a description of a key distinction between the philosophies and paradigms associated with transfer research, namely the classical and actor-oriented approaches. This is followed by a discussion of the concepts in transfer that are relevant to the current analysis. The aim is to demonstrate that they remain difficult to operationalize, whilst, as discussed below, the framework proposed here leads to concepts that are empirically distinguishable.

Classical and Actor-Oriented Approaches

The classical perspective centers on the idea that transfer between two situations occurs to the extent that they share common elements. Over time, the interpretation of what constitutes common elements has shifted from Thorndike's (1913) original conception of identical attributes of the situation towards an understanding of commonalities as features that are perceived by the human mind as similar (e.g., Bransford et al., 2000). However, despite this evolution, other aspects of the underlying philosophy that have generally been implicit in the approach, have remained static (Lobato, 2006, describes some of these theoretical concerns). In empirical work, this leads to the observer imposing predetermined "correct" mappings between learning and transfer situations to be investigated. The emphasis is on the task itself, rather than individual perceptions or manipulations of it, that may be due to personal histories, the environmental or social situations. Transfer, in this research paradigm, is considered to be due to the representation of knowledge in a decontextualized form (see e.g., Bransford et al.). An additional limitation of empirical work arising from the classical approach has been the failure to observe strong transfer effects, or indeed, any transfer at all (see, for example, Gick & Holyoak, 1980). However, as people appear to engage in spontaneous transfer in everyday life, this has led to what has been described as the "transfer paradox" (Haskell, 2001). This implies a gap in our understanding of the processes of transfer.

Partially in response to these concerns, Lobato (2003) described an alternative paradigm in the form of the actor-oriented perspective. This approach emphasizes the individual's perceptions of the learning and transfer tasks and the connections between them, without making prior assumptions about what these connections might be or about their correctness (Ellis, 2007). Although this perspective still considers abstraction as an important aspect of transfer, the meaning of the term has been broadened to encompass notions of abstraction as collective or situated, such that they no longer rely on the decontextualization of knowledge (see Lobato, 2006, for a range of views). In fact, some authors, such as diSessa and Wagner (2005), and Wagner (2006), consider that transfer is supported by rich representations of specific knowledge which is used in particular situations. Unlike classical transfer studies that are characterized by experimental and pseudo-experimental studies, investigations that fall under the actor-oriented approach include alternative methodologies such as case studies (e.g., Lobato & Siebert, 2002), observation and interviews (e.g., Ellis, 2007). These approaches provide greater sophistication in the questions that can be addressed, in particular relating to what Salomon and Perkins (1989), who can be viewed as precursors to this movement, refer to as the *how* in addition to the *what* of transfer.

Theories of Transfer

The most commonly discussed distinctions of relevance to both perspectives relate to the degree to which transfer occurs. Salomon and Perkins (1989) refer to the amount and distance of transfer. The *amount* of transfer is the size of the effect of prior learning on transfer. The *distance*, often distinguished via the terms *near* and *far* transfer (Detterman, 1993), relates to a measurement of the difference between the two situations. Finally, it is possible to distinguish between *domain-general* and *domain-specific* transfer, notions which relate to the specificity of transfer effects. Although the amount of transfer may be directly measurable – at least in some specific situations (although see Schwartz & Bransford, 1998, for an example of a situation in which this is not the case) – measuring the distance and specificity of transfer relies on metrics that Salomon and Perkins (1989) argue are non-obvious and may in fact be logically ill-defined. A related issue is one of *trivial* versus *non-trivial* transfer, leading to the question of whether transfer is conceptually or methodologically distinguishable from learning (see Salomon & Perkins, 1989, for a discussion of this point). Because of the relative nature of these distinctions, and the difficulty of ensuring that they are well-defined, clear operationalizations of the distinctions remain elusive.

In contrast to the distinctions described above that relate to the effects of transfer, Salomon and Perkins (1989) concentrate on the mechanisms of transfer. They describe two types of transfer that they label low-road and high-road transfer. *Low-road* transfer is described as transfer that occurs without reflective thought. Its application relies on extensive, varied practice and transfer is "unintentional, implicit, based on modeling and driven by reinforcement" (p. 122), and thus "unlimited by processing capacity" (p. 121). *High-road* transfer occurs through the intentional and mindful abstraction of principles embodied in learning experiences. Salomon and Perkins (1989) take care to detail many of the empirical implications of their model.[2] These predictions are often assumed to be correct (see, for example, Fuchs, Fuchs, Prentice, Burch, Hamlett, Owen et al. (2003). Fuchs et al., 2001) but empirical verification of the framework has remained partial and usually implicit (see e.g., Tanaka, Curran, Sheinberg, 2005; Nokes & Ohlsson, 2005, for empirical evidence regarding these predictions). In a review of transfer studies, Pugh and Bergin (2006, p. 148) point out that authors "rarely define the type of transfer they are investigating as high-road or low-road," or indeed categorize it at all. This situation may be due to the difficulty of distinguishing operationally between the two types at the level of a single act of transfer.

More recently, Marton (2006) has argued that the role of similarity has traditionally been overplayed in educational research on transfer. He suggests that further attention needs to be paid to consideration of the differences between two situations as an additional measure involved in understanding transfer. He points out that in order to be able to transfer knowledge from one situation to another, problems need to be identified as similar. In order for this to happen, he argues that it is necessary to attend to and "discern" differences between problem situations, as well as similarities. Numerous examples are given to highlight the lack of transfer when difference is not made salient, compared to better transfer when it is. Marton's considerations are timely as similar concerns regarding the importance of difference are leading to improved understandings of related areas of cognition in psychology (Stewart & Morin, 2007). However, empirical investigation and development of the framework in the educational arena is likely to be contingent on our ability to operationalize the concepts of similarity, difference and discernment in a way that is germane to educational inquiry.

New Directions

The classic approach to educational research on transfer has been subject to challenges relating to both theoretical and methodological aspects. These have resulted in a broadening of conceptions of transfer and an openness to new methods of enquiry. However, the theoretical distinctions made in the literature have proven difficult to operationalize. Because of these limitations, predictions have typically remained broad and as a result, capturing the detailed mechanisms behind particular acts of transfer has until recently not been a priority. Although some progress has been made in this direction, with the studies of Lobato and Siebert (2002) and Ellis (2007) exemplifying this approach, Lobato (2006) suggests that the search for new theoretical understandings and methodological approaches for the investigation of transfer are likely to be profitable. It is argued here that such new understandings may be obtained by looking to the existing literature in psychology. The next section outlines the reasons to believe that a particular area of the psychological literature – that of category development – may yield useful insights.

Categories and Transfer in Psychology

The literature in cognitive psychology that focuses on category formation and categorization provides a useful framework for analyzing the issue of transfer from an educational point of view. In fact, research in educational transfer has already hinted at this association. A variety of authors working in the sphere of education come very close to making the suggestion that categorization is important in considerations of transfer. For example, Marton (2006, p. 509) discusses the importance of the act of "discerning principles", claiming that "in order to draw upon the earlier problem as a resource for dealing with the second problem, the problem solution must somehow be discerned from the specifics of the problem". Gentner, Loewenstein and Thompson (2003), and Gentner and Holyoak (1997) discuss *analogy*, an area of the literature typically associated with category formation and categorization in psychology. Gick and Holyoak (1983) use related concepts such as *schema* to refer to the structure that learners use to sort problems into types according to their solution process, whilst Ellis (2007) makes the connection between transfer and *generalization* of principles in mathematics. Finally, other authors explicitly state as one of the stages of transfer, the necessity of categorizing problems according to the problem solution (Cooper & Sweller, 1987).

An examination of the literature indicates that very similar approaches have been used to investigate categorization in psychology[3] and transfer in education. Johansen and Palmeri (2002) describe the main research approach used to investigate categorization. The overall scheme of such studies consists of a learning phase and a testing phase. During the first stage, subjects learn to distinguish between two categories that usually vary along a single dimension (e.g., length of a line). For example, this may be achieved via a categorization task with feedback provided on the accuracy of categorizations; typically explicit rules are not provided. In the second stage, subjects carry out a further categorization task without feedback, where the main interest is in how participants categorize *unseen* exemplars of the categories concerned. In other words, the primary interest is in participants' performance in a transfer situation, and indeed, this second stage is often referred to as the "transfer" stage (e.g., Smith, Patalano & Jonides, 1998). Transfer studies in education following the classic approach often employ a very similar methodology, also relying on a learning phase and a transfer phase. However, in the educational literature, typically only a small number of examples is involved in the learning phase (see, for example, Gick & Holyoak, 1980).

The literature on categorization represents a major theme within cognitive psychology. The sustained interest has led to the generation of a number of models and theories that may provide the impetus for the development of new methodological approaches in education. These models are described and reviewed in the next section.

Models of Categorization

Since every instance of our experience is technically unique, the ability to categorize our knowledge allows us to treat distinguishable instances as equivalent and as a result apply knowledge we have acquired to understand, reason and make predictions about the world (Medin, Ross & Markman, 2005). In other words, categorization allows us to transfer our learning to similar but distinct experiences. Experimental studies using the paradigms described above and complementary approaches have led to the development of a number of models of categorization that consider abstraction in three main ways. As is customary, the models are presented according to whether abstraction is based on *rules*, *prototypes* or *exemplars* (see e.g., Braisby & Gellatly, 2005; Johansen & Palmeri, 2002).

Early "classical" models assume that categories are represented by rules that can be used to determine category membership. These consist of the necessary and sufficient attributes of exemplars of that category. For example, the necessary and sufficient condition for determining whether a number is even is that it leaves a whole number on division by two. It is assumed that when individuals carry out categorization tasks, the attributes of instances are considered in order to decide which category-defining rule applies.

Prototype models conceive of abstraction not as rules that define the features of a category, but as the construction of a representation of a "typical" exemplar or *prototype.* This prototype embodies the typical features of the category, such that when people encounter a new instance, they are assumed to compare it to the prototypes they possess and categorize it with the prototype providing the closest match.

Exemplar models assume that during learning, individual exemplars of concepts are stored verbatim. During categorization, new instances of a concept are compared with stored instances, and are categorized as belonging to the same category as the most similar stored exemplar. More recent models (e.g., Stewart & Morin, 2007) include, in addition the comparisons with the most similar stored exemplar, dissimilarities between the new item and exemplars from different categories.

Although rule-based models are intuitively pleasing, it has been found that for a majority of concepts, people are unable to provide defining attributes, and when they do, there is often disagreement among individuals (Medin et al., 2005). Furthermore, since these models fully define concepts, they fail to account for typicality effects often found empirically (e.g., robins are considered more typical birds than penguins) (Rosch & Mervis, 1975). Indeed, even well-defined categories such as evenness demonstrate typicality effects (Armstrong, Gleitman & Gleitman, 1983), so although rules are probably used, additional effects appear to come into play. Typicality effects also pose problems for prototype models. In particular, if prototypes are assumed to embody clusters of shared properties, they should be stable, yet they appear to change depending on the context (see Braisby & Gellatly, 2005 for a review). Finally, exemplar models outperform prototype models in a wide range of studies (see Medin et al., for a review). Although the three groups of models are often considered as competitors (see Smith et al., 1998, for a review), one alternative is that the different processes are used in combination.

Recently, a number of authors have approached categorization from the perspective that it may rely on a combination of rules, prototypes and exemplars (see Medin et al., 2005, for more details). To the extent that these studies employ research designs that involve a transfer stage, the results also inform us on the use of combined processes in transfer. Since, as we will see, combined processes in transfer are a main finding in this paper, we highlight the main results in this area emerging from the research in psychology.

Firstly, Allen and Brooks (1991) found that rule and exemplar strategies of categorization were not simply used for different types of category, demonstrating that at least for certain categories, both were used. Furthermore, when both of these categorization strategies were available, exemplar-based processes appear to act faster (Allen & Brooks, 1991; Smith & Kemler, 1984) and may partially override rule-based categorization. Nokes (2005) also found relative shifts towards use of exemplar-based approaches on transfer problems when surface characteristics mapped easily onto those of training problems. However, individual differences in strategy use emerged, with some participants employing rules and exemplar-based approaches for the same problem. Finally, if left to learn categories on their own, individuals tend to generate simple rules that allow them to categorize according to a single dimension, and persist in their use until exemplar-based modes take over (Johansen & Palmeri, 2002; Regehr & Brooks, 1993).

In summary, some interesting findings include the relative rapidity of exemplar-based approaches, the initial reliance on simple rules and gradual shifts towards exemplar-based categorization over time, dynamic adaptive shifting on particular problems towards use of exemplars when available, and the existence of individual differences in use of the two modes. These results were obtained using a combination of paradigms that rely on computer models and *dissociations* (different patterns of results) arising when rule-based and exemplar-based modes lead to different categorizations. However, one criticism of the approaches that rely on dissociations is that they do not easily support the investigation of rule and example use in situations where both lead to the same categorization. A critique of both dissociation and modeling approaches used above in relation to the education is their reliance on experimental methods that do not address the concerns relating to the distinction between researcher-oriented approaches and actor-oriented approaches. Unless combined with other techniques, such as Nokes's (2005) use of think-aloud, these approaches are inappropriate for the qualitative investigation of individual use of rules and exemplars. Furthermore, they do not translate well to the complex learning situations experienced in classrooms. Nonetheless, it is possible to apply the findings of these studies in a way that is applicable to educational research, and that can furthermore be replicated in teaching situations, as is described below.

The Categorization Framework in Transfer

Research in psychology has demonstrated that categorization probably involves a combination of rules, prototypes and stored exemplars and it is this result that forms the backbone of the framework to analyze transfer proposed in this article.

Within this framework, transfer is analyzed as occurring when a new instance is experienced as belonging to the same category as previously experienced instances. In the context of problem solving, this means that transfer occurs when a new problem is categorized with prior problems that can be solved using the same approach. The duality of the relationship between categorization and transfer explained above suggests that categorization models may serve as a useful lens through which to investigate transfer. In particular, it is predicted that individuals use a combination of rules, prototypes and exemplars in transfer, and that these modes can be identified in individual acts of transfer. Furthermore, these distinctions can be distinguished using methods of data collection and analysis that are germane to educational research, and that align with actor-oriented approach promulgated by Lobato (2003).

The remainder of this article is concerned with an empirical validation of the framework. The main aim of this study is to determine whether it is possible to identify the three modes as forming the basis of acts of transfer. In order to illustrate the value of this approach, additional questions relating to the ways in which the modes are combined in transfer situations will be considered. The empirical study and the results emerging from it are described below.

Method

Methodological Considerations

The goal of the empirical study is to evaluate the usefulness of the framework described above in an educational context, taking into account the guiding principles and ideas from the educational literature. The approach employs semi-structured interviews for data collection, and a combination of content analysis and grounded theory for the analysis. The interview questions relate to particular transfer situations in an educational domain where it is reasonable to expect use of rules, prototypes and exemplars. Computer programming was selected as the area of enquiry since well-defined rules exist to categorize many problem types, although learners are not explicitly rewarded for understanding these rules since the learning focuses on the skill of programming.

This area of enquiry presents a number of advantages as a case study of the use of the framework in educational research when compared with categorization studies in psychology. Computer programming is a complex skill that relies on an ability to transfer knowledge to construct specific responses to new problems. In addition, the categories of interest are generally multidimensional and hierarchical, as well as presenting real-world value. Finally, learning is carried out in an educational context, rather than a laboratory.

The data collection and analysis approach are consistent with many of the theoretical and methodological suggestions of educational theorists. In particular, they develop and operationalize alternative conceptions of abstraction, missing from earlier studies of transfer. In addition, the verbal data collection process, instantiated here via interviews, provides a rich source of information on the specific processes of transfer, in line with the actor-oriented perspective.

Finally, the approach employed could also be used by teachers in classroom situations. In particular, it models much more closely their usual interactions with learners than experimental methods. Furthermore, it provides rich information about student knowledge, providing greater scope for addressing problems of understanding.

Participants

Participants were all first year undergraduate students studying an introductory programming course. This course formed part of the first year computing science program at a large research-oriented university in the UK. Female students were strongly outnumbered by male students on the course.

Recruitment was carried out via an email request for volunteers as well as announcements made during lectures. Twelve students were recruited to take part in the study in return for a small payment. All volunteers were male; this is consistent with of the distribution of males and females on the course. Of the participants, ten were of British origin, and two were Asian. One student was subsequently excluded from the sample as his level of English interfered with his understanding of the questions and ability to respond. Final course examination results demonstrated that the sample represented the full range of student achievement on the course. Some of the participants had previously studied programming individually or at school, but none had prior experience of this particular programming language, *Ada*.

Data Collection and Instruments

Individual interviews were carried out by the author in a small room booked for this purpose. The interviews took place during the second semester, when students had been learning Ada for approximately 15 weeks. With agreement from participants, all interviews were audio-recorded.

The aim of the interviews was to gain information on how students applied their knowledge in a transfer situation. Semi-structured interview questions were therefore developed and related to particular situations where transfer was expected. The semi-structured format supported relatively straightforward comparisons between respondents, and the flexibility to follow up on incomplete or ambiguous responses as appropriate.

Since the programming structures learnt during the course represent and embody solutions to particular types of problems, some questions related to these structures and how they were used in a transfer situation. Others questions were concerned with formatting and syntax. One of the critical factors in writing the interview questions was to avoid significantly biasing the responses towards rules, prototypes or exemplars. Questions were therefore phrased to ask students how they "decided when to use" particular structures. Some questions explicitly considered choices between two structures whilst others simply asked how individuals decided when to use a particular structure. Some example questions, and the correct answers in rule form, are shown in Table 1 below.

[Table 1 about here]

Data Analysis

Interviews were transcribed in full, with attention paid to pauses, false starts and exact phrasing as these were considered to be potential indicators of ease of expression, previously identified as a factor in distinguishing between explicit rules and exemplar-based categorizations (see e.g., Smith et al., 1998). Interview transcripts were then analyzed in conjunction with any notes made by the participants during the interviews. The assumption was that the way in which learners explained the concepts would provide pointers to the most accessible form of knowledge for them.

The research paradigm draws on both critical realism and interpretivism by assuming the *objective existence* of *multiple, subjective ways* of experiencing categories, which may or may not be consciously understood by the research subject and must therefore be inferred as accurately as possible by the researcher. Data analysis was carried out using the techniques of content analysis (e.g., Krippendorff, 2003; Neuendorff, 2002). In line with this approach, data were classified according to pre-defined and theoretically-driven categories, and existence of these categories sought within the interview transcripts (Hardy & Bryman, 2004). These categories were labeled *rules*, *prototypes* and *examples* and defined as described previously in the review of the psychology literature. Although correctness of responses was noted, it did not form part of the categorization process.

It was noticed early in data analysis that pure cases of examples, rules or prototypes were rare and that students tended to use a combination of forms in their explanations. It was also noted that examples served a variety of roles. As a result, a second stage of data analysis was undertaken following the principles of grounded theory (Glaser & Strauss, 1967) to establish the ways in which examples were used in conjunction with rules. The data were coded in an iterative manner until theoretical saturation was established, and additional coding led to no further changes.

The excerpts reported below form a small part of the data set and represent particularly clear examples that illustrate the concepts effectively. Pseudonyms that preserve gender and ethnic origin have been used for all participants. The interviewer, also the author, is referred to as the researcher for the remainder of the article.

Results and Discussion

Results

Overall, the results of the empirical study correspond well with the predictions of the framework. In particular, it was demonstrated that rules, prototypes and examples are used in student descriptions of transfer in computer programming. Furthermore, it was found that these can co-exist for the same situation, and often for the same individual.

Use of Rules

On a number of occasions, students provided responses in the form of rules, using these to clearly delimit the problem-solving situations mentioned in the question. Sometimes rules may be incorrect or incomplete, but from the student's perspective, they give the conditions under which a particular programming structure is to be used, and do not leave certain cases uncategorized. Several participants provided a rule when asked how they decide to use `for` and `while` loops when writing a program.[4]

> Ben: Like `for` loops are for if you're doing something a fixed number of times, `while` loops are for if you ... doing something depending on a condition that's going to change. (Ben on `for-while`)

> Eddie: Well, I would use a `while` if I didn't know how many repetitions I was about to make, and I would use a `for` if I did. (Eddie on `for-while`)

Rules were also provided in other areas, although some were partial or incomplete from an observer's perspective. Eddie provides an incorrect rule when referring to how he uses a semicolon, whilst Tim provides a rule that is incomplete when describing when he uses arrays.[5]

> Eddie: I use it at the point where I've either reached the end of a line or I have reached, er, the end of a statement within a line. (Eddie on semicolons)

Tim: (Pause) When I have an array of values that need to be, that I need to hold. Well, if I've got a range of values, I'd store them in an `array`. (Tim on arrays)

Use of Examples

In a number of instances, students simply provided a list of cases in which a particular construct or programming concept would be used. The question pertaining to the decision to use a semicolon provided a number of examples of this type, the most illustrative being that of Elwin.

Elwin: I think you leave them out at end of lines after some loops, but if I don't know, I just put them in all over [...] like a `while`, starting to define a loop, that sort of thing, I'm just trying to think, they probably don't go at the end of `if` ... er ... sort of `for` loop `for` something in `loop` and probably the not at the end of `if end` loops, oh, I'm not sure. (Elwin on semicolons)

In this excerpt, Elwin appears to be unable to provide a rule to distinguish between those lines which require a semicolon at the end, and those which do not. However, he does provide a list of examples of lines where semicolons are not required: "starting to define a loop", "`if`". When he pauses to think, the result of his reflection is simply to add to the list, rather than to provide a generalization. Halsey provides another example of this mode of categorization in response to the same question:

Halsey: If it's at the end of ... a line ... or if it should be, somehow [...] because it's used more often than not, I prefer to remember where it isn't supposed to be ... and then not use it in that case and just use it everywhere else [...] it's when you're ... you know doing your `begin` ... of like a procedure or ... I mean program or whatever ... and at the beginning of `ifs` and loops, stuff like that" (Halsey on semicolons)

Here, the list of examples is longer, and Halsey's use of "stuff like that" probably indicates that he is aware that there are probably other examples that he has not mentioned. He also explicitly states that he chooses to remember the cases where semicolons are not used.[6]

Use of Prototypes

In some instances, students referred to a single prototypical example that had the features of a typical situation in which a particular structure was used. Halsey uses this approach in his explanation of how he chooses between `for` and `while` loops:

> Halsey: If it was ... if it was just like a counter, that was running, that I was using, I'd say I would use a `for`. If it was, loop, you know, going round and round based on a condition, it would be `while`. (Halsey on `for-while`)

In this excerpt, the loops that Halsey describes are typical, but do not embody all cases. During the course, the examples of `for` loops were often written in the format described, with the counter either labelled "I" or "Counter"; however, other forms are valid. His description of the `while` loop is also is one of a typical `while` loop rather than a definition, since while many loops do go "round and round", a `while` loop may run just once or not at all, if the condition is immediately satisfied.

In relation to the other categories, his description does not qualify as a rule because he simply describes one case and then the other without explicit comparison. In particular, he fails to make reference to any critical property that would allow him to distinguish between the `for` and `while` situations. This means that some cases requiring loops remain unclassified. The excerpt does not qualify as use of examples because he refers to a single example of each case which appears to embody the entire concept, rather than to a list of examples. His use of "if it was" and "just like a ..." indicate a certain level of abstraction, in that they imply that other cases may exist.

Combinations of Rules, Prototypes and Examples

The examples in the sections above provide evidence for the use of examples, prototypes and rules. However pure cases were not very common and students tended to respond using a combination of these three types. In these cases, examples served a variety of roles in their responses. Four primary categories of combined rule and example use were established and these are described below.

First, some students provided a rule followed by an example or examples. In these instances, the examples appeared to serve as illustrations, supporting only the communication of the rule rather than the student's thinking. In illustrating a rule, students tended to explain how the example was related to the general rule. One such example is presented below.

Ben: You're doing something a fixed number of times [...] the for loop, erm, you know you're going, going between like one and a certain amount of and you know you're going to iterate that many times. (Ben on `for-while`)

In this excerpt, Ben first provides a rule for deciding to use a for loop, and then provides an example ("like one and a certain amount") that he links explicitly to the rule.

Secondly, some students initially provided examples when answering the question, and later were able to provide a rule. At times, the rule appeared be deduced during the interview, based on the examples presented. In other cases, the rule appeared to be remembered during the course of the discussion, and simply stated. Even if the rule was known, the examples nonetheless appeared to be more accessible to students in these cases.

A clear example of deduction was provided by Elwin in an extension to the question concerning `for` and `while` loops. In particular, he refers the kind of expression that can be placed between the words **`while`** and **`loop`** at the beginning of this kind of loop.

Elwin – Oh, it could be say `while` … … technical ones like `not Found`, where `Found` is sort of a Boolean value, er … I suppose it could be any kind of expression sort of to do with … `while` E is equal to five, or whatever ... just something that's … take it there's gonna be a value to come back? Perhaps, does it always have to come back with a Boolean value, then?

Interviewer – It does.

Elwin – Yeah, it does, doesn't it! (Sounds surprised)

Interviewer – You'd not thought about that before?

Elwin – No … no! (laughs) (Elwin on `while`)

Duncan: A semicolon is used at the end of a line ... except on ... the `begins` ... loops, and `ifs`, so if it's like a statement, I, you don't use a semicolon at the end of it. (Duncan on semicolons)

In this extract, Duncan begins by giving a list of programming forms that are not followed by a semicolon, and then states a rule. It is worth mentioning that his rule is incorrect, and it is not clear what he understands by the word "statement" in this excerpt.

Thirdly, on a number of occasions, students used examples, embedded within rules. They appeared to do so primarily after they referred to a concept for which they were not sure of the correct technical name. Two examples of this use are shown below.

Henry: When you want to separate chunks, I guess ... so for your `procedure`, your heading, your `end`, you'd indent the whole lot. (Henry on indentation)

Steve: Just think of it as kind of like, a statement [...] ... er ... like a loop, you wouldn't have it, for the start of a loop, or yeah, just generally similar things [...] you can't for any loops or arrays ... like any kind of erm, I don't really know how to describe it, but any kind of sort of command-type thing. (Steve on semicolons)

In these excerpts, Henry uses a non-technical expression "chunks" as a label for the concept he is trying to explain, whereas Steve uses the technical term "statement", but his comment that he does not really "know how to describe it" indicates his lack of confidence in the term (which is actually used incorrectly).

Fourthly, for some of the questions posed, the choice between two structures relied on coordinating information on a number of dimensions, so that they could be expressed as a number of sub-rules. In these cases, students sometimes discussed one dimension using a rule, and another using examples.

Henry: With a `case` it's only one variable ... you can have then it's different things it can be ... like one, two, three, four ... (Henry on `case-if`)

Henry gives a rule to state that the `case` only works when the tests relate to a single variable, but provides a rule with clarification for the second condition that relates to multiple tests.

Dan: (Pause) No, I, I, I ... `array` just whenever there is, I can see that I'm using ... erm ... a particular group ... of data ... which I know that ... it is going to be the same. And I'd like to be able to search or sort it. (Dan on `array`)

Dan is not particularly clear about what he means, but uses a rule to refer to the multiple nature of the data, and that it will be of a particular type. However, in referring to the fact that arrays are only useful if you need to use the data items more than once, he simply provides two examples.

> Steve: Erm, well, `for` would be kind of like if I know some exact values that I want it to commit to or ... and ... the `while` would be more to do with like keeping the code running while it's not an `End_Of_File` or something. (Steve on `for-while`)

In the excerpt, Steve uses a rule to describe how he chooses to use a `for`, but gives a prototype example in the case of the `while`.

Discussion

The main findings of the empirical analysis reported above are as follows. Firstly, it was possible to distinguish empirically between use of rules, prototypes and examples in learner accounts of transfer in a complex conceptual domain, thus supporting the use of this distinction in education. Secondly, the different modes of transfer were all evident in the empirical data, both in isolation and in combination. New results were established concerning the ways in which exemplars and rules were used in combination by the participants in this study. In particular, the study highlighted several different uses of examples in combination with rules, with use of examples serving to support rule derivation, to replace a rule in either conception or presentation of two contrasting categories, or to supplement a rule as a communication technique. Both rules, and a combination of rules and exemplar-based approaches were used in contrasting categories where rules were multi-dimensional.

Overall, the study demonstrates that the proposed framework provides research tools in the form of a classification system for transfer events that is well grounded in the psychological literature. Furthermore, these tools can be used within the context of the actor-oriented perspective to investigate issues related to the mechanisms of transfer behind particular transfer events. In particular, they allow researchers to investigate individual transfer events as they occur within a classroom context.

The proposed framework provides a potential resolution to the debate on whether transfer is supported through the decontextualization of knowledge (e.g., Bransford et al., 2000) or based on concrete experience and supported by the enrichment of specific knowledge employed in particular situations (e.g., diSessa & Wagner, 2005; Wagner, 2006). As the analysis suggests, both rules and examples are used, thus suggesting that both views are valid and, in fact, the two modes appear to interact.

Furthermore, the methodological approach validates the psychological models through triangulation of methods in order to demonstrate that the results obtained in experimental psychology are not simply a methodological artifact, and have value in the educational domain. Nonetheless, although all three modes of categorization appeared in the results, they only rarely did so in isolation, and many examples of the conjunctive use of more than one mode were provided. This result is in line with more recent models that are used to investigate the combined use of different modes.

It would be interesting to see whether the results reported here are replicated in other domains, with female participants, and using a range of data collection methods. In addition, the framework proposed can be applied to extend this work by analyzing further questions. For example, it could be used to investigate the reasons for the result that studying contrasting examples during learning improves rates of transfer (e.g., Schwartz & Bransford, 1998, Schwartz & Martin, 2004; see Marton, 2006, for a review of studies in this area). For instance, does the study of contrasting cases lead to explicit knowledge of rules relating to the differences between cases, or to a better encoding of the examples themselves? As another application, the framework may explain the observed differences in problem-solving ability between contextualized and decontextualized settings (see e.g., Schliemann & Carraher, 1985, and Tirosh & Graeber, 1994, for examples).

Conclusion

Lobato (2006) suggests that, following shifts in understandings of transfer in the educational literature, new methodological approaches are needed to further investigate the issue empirically. The main aim of this article has been to identify an area within the psychological literature that can inform the development of new methodological tools to be used in line with current philosophical and theoretical trends in transfer research. These can allow investigators to work in classroom settings to examine the mechanisms and micro phenomena of particular transfer events. The literature on category formation and categorization was identified as appropriate for this purpose, based on the methodological parallels with transfer studies and other indicators of the importance of categorization for transfer.

A framework was presented that explains transfer as occurring when a problem-solving task when the new problem is perceived to be in the same category as earlier problems that can be solved using the same technique. Three key models from the psychological literature indicate that category formation and categorization are based on rules, prototypes or exemplars, or a combination of these. An empirical investigation was carried out that demonstrated that classifying acts of transfer described by individuals as based on rules, prototypes and exemplars was both possible and enlightening. In particular, it was found that individuals used these modes both in isolation and combination, providing evidence for the ecological validity of the psychological models. Furthermore, additional results were obtained that have not been discussed in psychology, notably that individuals use rules and examples in a combination of ways in their descriptions of transfer. Firstly, examples are used to support thinking, either replacing rules or being used to derive them; secondly, they can be used as a communication tool, either to clarify concepts within rules, or to illustrate a rule. Finally, it was found that when the distinction between two categories was multidimensional (i.e., could be expressed as a number of sub-rules), participants at times used a rule for one dimension and examples for another.

This paper provides a theoretical framework that provides predictions that can be investigated empirically. The associated methodological tools described here can be used in a classroom context by both researchers and teachers to investigate and support learning respectively. Their use can be applied to the understanding of known effects and results, as well as to pose future questions.

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Appendix

Glossary of Programming Terms

Ada is the programming language that the learners involved in this study were studying. The terms are explained in the context of the Ada programming language. Their use may differ in other programming languages.

`Array` – A collection of objects of the same type which can be selected by an index belonging to the index subtype of the array.

`Begin` – Keyword that is used to delimit the beginning of the body of code. For example, it precedes the code within a procedure.

Boolean – In Ada, the Boolean datatype can take the values True and False.

`Case` – Used to compare one specific variable against several expressions.

`End_Of_File` and `End_Of_Line` – When reading in from a file, return true or false according to whether the end of the file or line is reached, respectively.

Expression – Something which can be evaluated to produce a value which can be stored or otherwise processed.

`For` – A loop that iterates a specified number of times. For loops can always be written as `while` loops, but the syntax of the `for` loop is easier and clearer.

`If` – The main conditional statement in Ada. Used to perform different computations or actions depending on whether a programmer-specified condition evaluates to true or false.

Indentation – Used to delimit logical blocks of code, thus making it more readable.

Loop – A section of code which is repeated ('iterated').

Procedure – A subprogram which is invoked by a procedure call statement.

Semicolon – Used to terminate statements. Also used to separate parameters in procedure headers.

Statement – An instruction to carry out some action; a single step within a program.

Type – Every object has a type which specifies the set of values allowed and the primitive operations which it provides.

`While` – A loop that has a condition at the beginning. The statements in the body of the loop are repeated as long as the condition is met. If the condition is not met at the very beginning then the statements inside the loop are never executed.

Footnotes

[1] Educational research on transfer has hinted at this association (see e.g., Marton, 2006, Gentner & Holyoak, 1997; Ellis (2007); Cooper & Sweller, 1987; more details are provided below).

[2] For example, they claim that low-road transfer is likely to be associated with skills that are acquired through experience giving rise to behavioral patterns whilst high-road transfer is more likely to occur in situations such as formal education where a “language in which abstractions can be encoded” (Salomon & Perkins, 1989, p123) is provided. Knowledge that leads to low-road transfer is considered to be slow to acquire, and the transfer itself of relatively short range, but applied quickly. The knowledge underpinning high-road transfer is more rapidly acquired, but applied more slowly in transfer situations. It is predicted to transfer over greater ranges, but not necessarily provide for greater amounts of transfer as higher levels of abstraction may lead to the difficulty of connecting situations.

[3] Where the distinction is helpful, the expression *category formation* will be used to refer to the learning of categories, with *categorization* used to denote the process of deciding whether an instance belongs to a particular category. However, it is worth noting that the literatures concerning these two notions, and indeed concept development, are often poorly differentiated (Medin, Ross & Markman, 2005) and they are considered together here.

[4] When use of words such as `for` and `while` refers to the Ada keyword, formatting is in `Courier`. A glossary of programming-related vocabulary, that includes keywords and other specialized vocabulary, is included in the appendices.

[5] Interview questions and complete rule-based responses are included in the appendices. Eddie's explanation is incorrect in that semicolons are not used at the end of all lines; Tim's rule is incomplete in that he does not explain that the values must all be of the same type.

[6] In both of these examples, it could be considered that "at the end of a line" represents a partial rule; however, the participants are aware that does not provide a criterion by which to distinguish between situations that require a semicolon and those which do not.

Table 1

Sample Interview Questions and Correct Answers Expressed as Rules

Question posed	Answer in the form of a rule
How do you decide to use a semicolon?	Semicolons are used at the end of statements, and for separating parameters in procedure headers.
How do you choose between a `for` loop and a `while` loop?	A `for` loop is used when the number of iterations is known prior to execution of the loop; a `while` loop is used otherwise. Another possible explanation is that a `while` loop is used when iterating according to a condition.
How do you use indentation?	When a statement is used to direct execution within a program, it may include within it a block of other statements. If so, the embedded statements are indented (inset).
How do you decide to use an `array`?	An `array` is used to store lists of values of the same type, when values may need to be used more than once during program execution.
How do you choose between a `case` statement and an `if` statement?	A `case` statement is used to determine which of a range (usually greater than two) of sections of code to execute, according the value of a single variable. An `if` statement, on the other hand, can be used when the tests refer to a number of different variables.