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Contemplations on Results from Investigating the Personal Epistemology of Computing Students

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***Abstract*— "Personal Epistemology" is the analysis of the ways in which an individual perceives what constitutes knowledge, its boundaries, how it is justified, and how it is related to learning. While investigation of metacognitive strategies used by students is now an established research topic within Computer Science and Information Technology education, the study of personal epistemology is relatively undeveloped. This is so despite there being significant epistemological issues associated with learning the subject itself, such as those concerned with the way in which programming exercises change from convergent to divergent problems, or the process by which software project management problems very quickly become ill-defined. In this paper, we describe a preliminary investigation into the personal epistemology of two cohorts of computing students. We review some models of personal epistemological development and describe an empirical study in which we investigated the dimensions of epistemological beliefs of two cohorts of computing students. The results show that there appears to be a wide range of epistemological belief amongst computing students. Finally, we make some observations about the importance of personal epistemology for learning in Computer Science and outline further work in this area.**

Keywords – personal epistemology, epistemological beliefs, learning, ill-structured problems.

I. Introduction

Personal epistemology, that is, an individual's conception of knowledge and their understanding of the process of knowledge acquisition and learning [1], has been an ongoing area of research in educational psychology for over thirty years now. While it has only recently begun to be studied as part of subject-specific pedagogical research, it has nevertheless been applied to a wide and growing range of disciplines. In part, this interest has been generated by evidence that more "sophisticated" epistemic beliefs are correlated with higher-order, metacognitive skills which may have a direct impact on learning. For example, there is evidence that epistemological considerations play an important role in the self-regulation of learning, that more "sophisticated" beliefs are often correlated with higher-order learning outcomes [2], and that epistemological factors play an important role in the solution of ill-structured problems [3].

The subject itself has been termed "the subjective counterpart of philosophical epistemology" [4]. The difference between the two is that personal epistemology investigates how the philosophical concepts affect the individual at a psychological level [5] and recent research has tended to focus on how it relates to learning and its application to pedagogy. As a research field, it may be considered to have originated in the developmental psychology of Piaget [6], while its application to tertiary education began in the mid-1960s with the work of Perry [7]. While subsequent work has reconceptualised personal epistemology in a number of different ways, there are common elements that run through the work of almost all researchers such as the recognition that an individual's understanding may develop over time. Following Perry, this may be seen as taking place in a one-dimensional, linear fashion or it may occur within some kind of multidimensional space characterised by the kinds of different epistemological beliefs suggested by Schommer [8]. Regardless of the details, this development is considered to have important implications for learning and consequently for teaching and assessment practices. Development in an individual's personal epistemology is seen as a progression from an initial phase characterised by a simplistic or naive conception of knowledge in which propositions and theories are seen as dualistic (right or wrong), to more nuanced and sophisticated "evaluative" views which take account of evidence and judgement. It should also be noted that while many researchers use these terms, there are some [9] who question the practice of using psychologically-loaded words such as "naive" and "sophisticated" and instead prefer to describe the ends of the development spectrum as "non-availing" or "availing" depending on whether such beliefs inhibit or promote learning.

Most educators would agree that one of the most important goals of a university education is to encourage the development of learner autonomy so that an individual may deal with the challenges posed by lifelong learning. There has been much recent work on the development of sets of graduate attributes which address this need for post-university, professional competences [10], many of which are based on the use of higher level, metacognitive skills such as analysis, reflection, and critical thinking. However, research has tended to show that educators struggle to promote development of such skills despite acknowledging their importance [11]. The relevance of an individual's beliefs about knowledge for such metacognitive activities may play a part in this and can be seen, for example, when considering self-regulatory skills such as planning, monitoring and evaluation, all of which involve the prioritisation and integration of information from various sources. A key element in this is the ability to engage in a process of justification of one chosen alternative over others. Such justification, however, requires the evaluation of claims about knowledge, the forms it takes, its sources, how it is constructed and how it may be apprehended. These concerns are essentially epistemological in nature and suggest that such issues play a crucial role in determining a person's fundamental orientation towards learning and the strategies that are chosen to engage with a subject.

In order to start to investigate this field in the discipline-specific context of Computer Science education, we feel that it is necessary to look at the epistemological responses found in a range of students. In previous work [12], we made a small-scale, preliminary analysis of the epistemic beliefs of a relatively mature cohort of students based on data gained from Schommer's "Epistemological Beliefs Questionnaire" [13]. In this paper we compare that data with another set from a group of first-year students who display a much greater range of responses. We believe that this gives us some understanding of the scope of epistemological belief that is present in computing students. It would also appear that there is a need for an instrument that is much more finely tuned to the subject itself.

We begin this paper by presenting an overview of some of the relevant background research in the field before describing the developmental model that underlies Schommer's questionnaire which was used to try to gain insight into personal epistemology of our students. We discuss the results of this experiment and finally we conclude by suggesting further research directions that would be relevant to Computer Science Education.

II. BACKGROUND

A. Epistemology and Computer Science Pedagogy

The primary motivation for our current work is consideration of the evidence that students' epistemological beliefs do indeed affect the choices they make about the way in which they learn by influencing a variety of cognitive and metacognitive strategies. These include the explicit choice of learning strategies [14], academic performance [15], cognitive processing [16], openness to conceptual change [17], text comprehension [18], moral reasoning [3], and strategy use [14]. Research suggests that the sophistication of an individual's epistemological beliefs has a strong impact on learning. Students who believe that knowledge is certain are more likely to draw absolute conclusions from contingent information [8] while those who believe that an individual's capacity for knowledge is fixed are less likely to persist in formal education [13]. Students who believed that knowledge is quickly acquired are more likely to comprehend information poorly while those who believe that knowledge is simple are more likely to settle for a memorization study strategy rather than using higher-level cognitive processes such as critical analysis, elaboration and reflection [19]. Moreover, students who view ability as innate and thus fixed may be less inclined to develop and use advanced reasoning skills when thinking about ill-structured issues [3]. An appreciation of the importance of these beliefs by teachers may therefore contribute to a greater understanding of the psychology of student learning and so may provide insights into more effective pedagogical strategies in areas for which reflection and critical thinking are required.

One such area would be the solution of divergent or ill-structured problems. This class of problems typically does not have single optimal solutions and there may only be heuristic procedures to find acceptable results among a range of possibilities. Consequently, there is a greater need to justify any option that is chosen. A number of common pedagogical practices, such as group projects, involve these open-ended problems and we would anticipate that this field of study would contribute to our understanding of effective practice in these areas. In addition, careful attention to epistemological issues may contribute to a greater understanding of the transition from convergent to divergent problem-solving that frequently arises in computer science education. Examples include the increase in complexity that occurs as novice programmers undertake more sophisticated tasks and the transition from "programming" to "software engineering". This work also connects well with our earlier efforts to develop a theory for setting up open-ended group project learning environments [20, 21, 22].

Finally, there is an important link between epistemology and perceptions of knowledge within a discipline-specific context and the concept of identity. A basic question about subject identity is what it means to be, say, a computer scientist. Is it simply a matter of studying a particular set of techniques or is there some epistemological approach or methodology that distinguishes the practitioner in that field from one in a neighbouring discipline. For example, is there a process of "learning to think like a computer scientist" which is different from learning to think like an engineer or a mathematician. A related question is how professionals from that discipline induct students into the broad community of practice in which the subject is studied [10]. These issues involve an explicitly epistemological perspective as they deal with what counts as knowledge in the subject domain, how such knowledge is acquired and an ability to reflect on how the process is justified to a wider community. It would be interesting to investigate the degree to which current members of the computer science community share a specific conception of knowledge and a common understanding of "ways of knowing" within the subject, and also how this is passed on to new graduates. This, in turn, may have practical implications for issues associated with identity such as curriculum development, academic and industry retention practices, and lifelong or lifewide learning [23].

B. Models of Personal Epistemology

While investigation into the development of an individual's conception of knowledge was a central part of the work of Piaget from the 1930s onwards, research into this area has increased substantially in recent decades. The first study, which specifically addressed the topic in the context of Higher Education, was that of Perry which proposed a general scheme in which epistemological understanding developed through nine stages, grouped together into three phases. In the initial phase, often categorized as absolutist thinking, an individual sees knowledge in polar terms as either right or wrong. Uncertainty is due to lack of analysis of suitable data and can be eliminated by straightforward procedures such as direct observation, appropriate introspective examination or through appeal to some expert authority. In the next phase, this naïve position shifts into a more relativist stance. There is a significant reaction against the previous dualistic view to the extent that knowledge is now perceived as inherently uncertain and idiosyncratic to the individual, with recognition of the possibility of multiple views, which may depend on context. The main feature of the final phase is an epistemological understanding in which knowledge is constructed by comparing evidence and opinion on different sides of an issue. Knowledge is seen as constructed through a process of reasonable inquiry leading to a well-informed understanding. It also recognizes the contingent nature of personal knowledge, exploring the implications of commitment to individual views. Perry, therefore, presents a model of personal epistemological development which is a linear spectrum ranging from initial "simple" or "naive" views to the more "sophisticated", evaluative stance which he saw as desirable in graduates.

Subsequent work on this type of developmental model has extended the analysis in a number of different directions but, as indicated by Hofer and Pintrich [24], a common element in such work is the retention of a movement from an initial dualistic, objectivist view of knowledge, through to a more subjective, relativistic stance to a final contextual, constructivist perspective of knowledge and its acquisition and justification. As pointed out by Kuhn [20], this evolutionary structure has practical implications for teaching as epistemological factors determine how students view the components of a theory and its relationship to reality. As an example, consider the development of high-level metacognitive skills such as those associated with critical thinking. At an initial, absolutist level, claims about knowledge are seen as facts which are either correct or incorrect. Critical thinking is therefore perceived to be a straightforward matter of comparing such statements to reality in order to determine their truth or falsity. At the more relativistic level, assertions are considered merely to be opinions, none of which is more compelling than any other, and so any may be selected on personal preference. At this stage, critical thinking is largely irrelevant as justification is limited to the statement of subjective views. It is only at the final, evaluative stage that assertions are considered to be judgements that can be appraised by argument and reference to evidence. As a consequence, it is primarily at this stage that critical thinking, seen as a method for promoting coherent, logical argument, will be considered useful.

C. Epistemological Beliefs

This concept of a single, integrated continuum of development was, however, challenged in the work of Schommer (later Schommer-Aikins) in a series of papers [8, 5, 26, 13] which drew on Perry's work but incorporated significant elements from other researchers. These included work by Schoenfeld on the speed of learning [27], beliefs about innate intelligence [28], Kitchener and King's work on reflective judgment [29], and Ryan's work on epistemology and comprehension [15]. While accepting the idea of personal epistemological development, she suggested that it was better conceptualised as a multidimensional belief system, the dimensions of which may be only weakly bound to each other. She retained the idea of a developmental continuum from what she, too, characterised as "naïve" views to more "sophisticated" ones, but applied it to each of the key epistemological beliefs and suggested that development may occur in each at different rates. Epistemological development, in this model, was therefore better described by a trajectory in a multidimensional space rather than by progression along a line.

The main instrument used by Schommer for this analysis was her Epistemological Beliefs Questionnaire. This seeks to establish the respondent's level of commitment to a range of statements which reflect a particular epistemological belief. Examples of these include "People who challenge authority are over-confident", "I try my best to combine information across chapters or even across classes", "The most successful people have discovered how to improve their ability to learn", and "Things are simpler than most professors would have you believe".

The questionnaire itself was based on the hypothesis that there were five dimensions through which epistemological development takes place: structure of knowledge, stability of knowledge, source of knowledge, speed of knowledge acquisition, and the learner's control of knowledge acquisition (see Table 1). The first three of these were influenced by Perry's original model. The speed of learning dimension was based on the work of Schoenfield, and the control of knowledge dimension was influenced by Dweck's work on implicit intelligence.

One difficulty with the study of personal epistemology is that we do not observe these beliefs directly but only infer them from behaviour so these dimensions are, in some sense, hidden. Moreover, several behaviour patterns could result from the same belief. For example, according to Schommer et al [5], if one considers the dimension for "structure of knowledge", the naive epistemological view is that knowledge is essentially simple and that complexity is due to inadequate analysis rather than any inherent conceptual ambiguity in the information or the interrelationships involved. If a person held this view, there would be a tendency to oversimplify complex information which could manifest itself in two ways: they could tend to focus on one aspect of the problem and neglect others, or else they could artificially reduce the complexity of the relationships between the constituents of the problem by a process of inappropriate compartmentalisation. The epistemological views about structure of knowledge therefore give rise to two subsets of observable behaviour. Using the naïve behaviour as a descriptor, these would be termed "Seeks single answers" and "Avoids integration" and the questionnaire was developed to elicit responses that could be tied to these behaviours. Using this type of analysis, Schommer identified twelve different observable behaviours for the five hypothesised dimensions of belief (see Table 1).

Table 1. Schommer's Dimensions of Personal Epistemology

Dimension	Explanation	Development Continuum	Subset Behaviours (labelled by "naïve" view)
Structure of Knowledge	How students think about the structure, relationship and organisation of knowledge in a particular domain.	From "*knowledge as isolated, unambiguous bits of information*" to "*knowledge as highly interrelated and integrated set of concepts*"	• Seeks single answers • Avoids integration
Stability of Knowledge	How students think about the contingency of knowledge and the way theories may change over time.	From "*knowledge as unchanging*" to "*knowledge as contingent and subject to continual revision and change*"	• Avoids ambiguity • Knowledge is certain
Source of Knowledge	Where students think domain knowledge can come from.	From "*handed down by authority*" to "*derived from empirical evidence and reasoning*"	• Don't criticise authority • Depend on authority
Speed of Knowledge Acquisition	How students think about the speed at which they acquire knowledge.	From "*learning as occurring quickly or not at all*" to "*a view of learning as a gradual process*"	• Learning is quick • Learn first time • Concentrated effort is a waste of time
Control of Knowledge Acquisition (Ability to Learn)	How students think about their capacity to control the acquisition of knowledge.	From "*a view that the ability to learn is fixed at birth*" to "*a view that it can be improved over time*"	• Can't learn how to learn • Success is unrelated to hard work • Ability to learn is innate

Given a dataset of responses to the questionnaire which measure the observable behaviours, the hypothesis that these behaviours are correlated with specific epistemological beliefs can be tested using the statistical procedure known as exploratory factor analysis, which looks for latent variables (factors) that underlie and give rise to the measured, observable data.

Schommer's conceptualisation of personal epistemology as a belief system has been extremely influential in the educational psychology literature as a model of epistemological development. It provides a methodology for quantitative analysis of epistemological data and can also accommodate instances in which students exhibit sophisticated epistemological beliefs in one dimension but less complex beliefs in another, something which is more problematic in one dimensional models. There has, however, been criticism of this approach due to reported difficulties associated with replicating the factor structure she described [27]. This leads, among other things, to ambiguity in the number of dimensions, i.e. important beliefs, that characterise an individual's personal epistemology Nevertheless, there are a relatively large number of studies that use the method and we have attempted to follow her methodology in our study.

III. Method

A. The Participants

Our study involved datasets from two groups of students. The first set of data was collected from a group of twenty-five respondents involved in a globally distributed group project [21]. The sixteen respondents from Uppsala University, Sweden, were enrolled in the IT in Society course unit while the nine respondents from Rose-Hulman Institute of Technology, USA, were following the Computing in a Global Society course unit. Both course units were taught in English. The students participating in the course in 2012 were aged between 20 and 38. The majority of students were pursuing a major in computer science or information technology, but some students were studying other technical majors. Most students had studied for at least three years at the university.

The second data-set was obtained from eighty-five respondents out of a class of one hundred and ten first year undergraduates in the School of Computing Science and Digital Media at the Robert Gordon University, U.K. These students were aged between 18 and 40 with the majority of them having entered university from secondary school. They were registered on a variety of computing degrees ranging from Computer Science to Business Information Systems.

The data for dataset 1 was collected at the beginning of the academic year at the start of the course when both Swedish and American students were in Uppsala. All students who were present completed the questionnaires during academic contact time. Dataset 2 was collected in the first week of the undergraduate term just after the Induction period. All students who were present completed the questionnaires during academic contact time.

B. The Instrument

The main investigative tool for the study was Schommer's Epistemological Beliefs Questionnaire, which seeks to investigate a range of epistemological commitments by asking respondents to indicate levels of agreement to a series of sixty-three statements on a five-point Likert scale. As described in section 2, these statements are grouped into twelve sections which describe different attitudes to learning and act as observed or measured variables for further statistical analysis (see tables 2 and 3).

Exploratory factor analysis was performed on this group of twelve averages using MINITAB. The aim of this technique is to reduce the dimensionality of the space of variables by looking for latent factors that underlie the structure of those observed variables. Eigenvalues of the correlation matrix for the measured variables were extracted using principal component analysis, in order to determine the number of factors, and a table of factor loadings for each set was produced. A loading for a particular variable with regard to a factor quantifies the variation of the measured variable that is explained by that factor and so a high loading indicates a strong correlation between the measured variable and latent factor while a low value indicates that the factor contributes little to the measured variable. Interpretation of the factors themselves proceeds by rotating the axes in the factor space so that the loadings show high values for a few variables and low values for the remaining ones. Following Schommer's original paper, orthogonal varimax rotation was used for this.

The communality for each measured variables was also calculated. This is a measure of the reliability of the number of factors used and is the variation of the observed variable that is accounted for by all the latent factors under consideration. So, for example, a communality of 0.75 for a particular measured variable indicates that 75% of the variation in that variable is accounted for by those latent factors.

IV. Discussion of Results

A. Number of Factors

Principal Component Analysis was used to extract the eigenvalues of the correlation matrix for each of the two datasets. In both cases, analysis of the eigenvalues suggested five latent factors underlying the measured variables. Exploratory factor analysis with five factors was carried out on each dataset, using MINITAB, and a table of loadings for each set was produced. These were rotated using an orthogonal varimax rotation and the results are displayed as table 2 and table 3.

The ratio of sample size to number of measured variables for dataset 1 is relatively small, but the communalities were reasonably high (for real data). In her original paper, Schommer used a loading threshold of greater than 0.5 to determine contribution to measured variables but, for this dataset, we used a higher value of 0.6. The size to number of variables ratio for the second dataset was better and so, here, we used Schommer's original loading threshold to identify factors. Schommer reported that four factors emerging from her statistical analysis. In both of our datasets, principal component analysis suggested five factors. Comparative analysis with four factors shows that there was no significant reason to reduce this to four in either case, although there did not appear to be a consistent interpretation of what these factors represented.

Table 2. Factor Loadings and Communalities for Dataset 1

Variable	F 1	F 2	F 3	F 4	F 5	Com'ity
1. Seeks single answers	**0.73**	*-0.11*	*-0.24*	*-0.21*	*0.29*	*0.73*
2. Avoids integration	*-0.04*	**-0.85**	*0.01*	*-0.11*	*0.03*	*0.73*
3. Avoids ambiguity	**0.90**	*-0.19*	*-0.04*	*-0.06*	*0.01*	*0.83*
4. Thinks knowledge is certain	*0.15*	*-0.06*	*0.13*	*-0.06*	**0.90**	*0.87*
5. Depends on authority	*0.14*	**-0.74**	*-0.08*	*0.28*	*-0.07*	*0.65*
6. Don't criticise authority	*0.46*	*0.26*	*0.56*	*0.38*	*0.12*	*0.76*
7. Ability to learn is innate	*0.19*	**-0.78**	*0.29*	*-0.14*	*0.09*	*0.75*
8. Cannot learn how to learn	*-0.34*	*-0.14*	*0.09*	**0.76**	*0.14*	*0.73*
9. Success is unrelated to hard work	*0.01*	*0.09*	*-0.01*	**0.85**	*-0.17*	*0.76*
10. Learn the first time	*-0.22*	*-0.10*	**0.77**	*0.06*	*0.20*	*0.70*
11. Learn quickly or not at all	*0.54*	*-0.04*	*0.53*	*-0.43*	*0.11*	*0.76*
12. Conc. effort is a waste of time	*-0.11*	*-0.18*	**0.70**	*-0.02*	*-0.49*	*0.71*

B. Identification and Interpretation of Factors for Dataset 1

An examination of the loadings for dataset 1 identifies a number of similarities and differences with the results reported by Schommer and others. The first factor (F1), i.e. the one associated with the largest eigenvalue, has a large contribution to the variables "*Seeking single answers*" and "*Avoiding ambiguity*". These behaviours seem intuitively to be related (even though Schommer categorised the first as referring to the structure of knowledge and assigns the latter to views on the stability of knowledge) and it seems reasonable to us that both behaviour descriptors relate to an avoidance of multiple representations of knowledge. We would therefore categorise both behaviours as indicating some kind of belief related to the Structure of knowledge dimension. The fifth factor (F5) is associated with the single variable "*Thinks knowledge is certain*" which Schommer categorises as pertaining to the Stability of knowledge. There also appears to be one factor (F3) which underlies the belief that if one is going to learn something then its should be possible to "*Learn it the first time*" and that "*Concentrated effort is a waste of time*". These, again, seem intuitively to be linked and Schommer categorises both of these variables as referring to the Speed of learning. A fourth factor (F4) is strongly associated with the view that one "*Cannot learn how to learn*" and that "*Success is unrelated to hard work*". Schommer categorised both as concerned with innate ability to learn, but the loading for the similar measured variable, "*Ability to learn is innate*", is small on this factor. A final factor (F2) is negatively correlated with the measured variables "*Avoids integration*", "*Depends on authority*" and "*Ability to learn is innate*", i.e. the group would tend to integrate knowledge from different sources, not rely on authority and trust their own ability, which we see as being associated with the Control of knowledge acquisition dimension. We thus have two factors capturing slightly different aspects of this dimension.

Two variables, one tracking the view that you should not "*Criticise Authority*" and one that "*Learning is quick or not at all*" do not have an above-threshold correlation with any of the five factors. This is the case even if the number of factors was increased to six. The main substantive change in this case is that "*Depends on authority*" would become a single-variable factor. Conversely, if we restrict to four factors, in line with Schommer's original paper, the high loading for "*Thinks knowledge is certain*" would vanish to be replaced with a moderate loading for this variable on F1 (0.56). However, the communality for this variable then decreases to 0.32 suggesting that this action would not be sensible.

C. Identification and Interpretation of Factors for Dataset 2

While principal component analysis of the second dataset also indicated that there were five factors, the pattern of (rotated) factor loadings (table 3) is quite different from the previous data, and more difficult to interpret. There is also a considerable difference between the distributions of loadings for this dataset and that reported by Schommer.

The first factor (F1) appears to underlie the variables "*Cannot learn how to learn*", "*Success is unrelated to hard work*", and that it should be possible to "*Learn [something] the first time*", which are all categorised by Schommer as referring to a naive belief about the speed of knowledge acquisition. There is also a reasonably high loading for the behaviour "*Concentrated effort is a waste of time*" which Schommer associates with the view that learning is innate, but also, perhaps, suggests a negative belief about learning as some kind time-related process. The factor (F2) has high negative loadings on "*Ability to learn is innate*" and one "*Learn(s) quickly or not at all*" which also mixes behaviour associated with a view that learning ability as innate (in the first case) and about speed of knowledge acquisition (in the second), although in a different way to the first (F1). This may suggest that the data is trying to capture two aspects of the beliefs underlying these behaviours, although not the ones reported by Schommer.

There is one factor (F3) that contributes to the variables "*Avoids ambiguity*" and "*Depends on authority*". Schommer proposed that the former behaviour was due to a belief about the stability of knowledge so this pairing may indicate that the first year students saw authority as a stabilising element for knowledge. Another factor (F4) has high loadings for the behaviours "*Avoids integration*" and "*Thinks knowledge is certain*" which seems to mix structure and stability of knowledge. The fifth factor (F5) contributes highly to behaviours "*Seeks single answers*" and "*Don't criticise authority*" which seems to mix structure and source of knowledge factors. Although there was a some degree of mixing of Schommer's factors with the first dataset, it seems much more pronounced with the first year cohort and this could perhaps be due to lower levels of academic maturity.

The interpretation of the data for the second cohort is, in general, more problematic than for dataset 1, although the sample set is bigger. It is interesting to note however that there appears to be a broad division between those factors (1 to 3) that refer to views about knowledge (which Schommer identified as coming from the developmental work of Perry et al) and those concerning knowledge acquisition (factors 4 and 5), i.e. which pertain to learning. This is found in both data sets and may reflect a basic characteristic of the results.

Table 3. Factor Loadings and Communalities for Dataset 2

Variable	F 1	F 2	F 3	F 4	F 5	Com'ity
1. Seeks single answers	*0.08*	*0.04*	*0.24*	*-0.13*	**-0.73**	*0.61*
2. Avoids integration	*0.02*	*0.07*	*0.29*	**-0.77**	*-0.23*	*0.72*
3. Avoids ambiguity	*0.08*	*-0.18*	**0.59**	*-0.33*	*-0.18*	*0.53*
4. Thinks knowledge is certain	*-0.15*	*-0.11*	*-0.31*	**-0.78**	*0.12*	*0.76*
5. Depends on authority	*-0.18*	*-0.03*	**0.78**	*0.17*	*0.04*	*0.67*
6. Don't criticise authority	*-0.18*	*-0.48*	*-0.20*	*0.05*	**-0.58**	*0.64*
7. Ability to learn is innate	*0.21*	**-0.78**	*0.01*	*-0.05*	*0.19*	*0.70*
8. Cannot learn how to learn	**0.81**	*0.09*	*0.10*	*0.09*	*-0.03*	*0.69*
9. Success is unrelated to hard work	**0.67**	*-0.05*	*-0.33*	*-0.06*	*0.15*	*0.59*
10. Learn the first time	**0.69**	*-0.23*	*-0.16*	*0.10*	*-0.24*	*0.62*
11. Learn quickly or not at all	*-0.02*	**-0.73**	*0.18*	*-0.02*	*-0.20*	*0.60*
12. Conc. effort is a waste of time	**0.63**	*-0.11*	*0.24*	*-0.05*	*0.46*	*0.68*

V. Conclusion and Further Work

Our aim in this paper has been to start to address some of the issues around personal epistemology within the discipline-specific context of Computer Science Education and the study should be seen as an initial attempt towards this goal. The main technique used is factor analysis and while this form of investigation can be quite sophisticated, we would want to emphasise the exploratory nature of the process. Our analysis does not reproduce the factor loadings described in Schommer's paper, but her work examined a much more general set of students than ours and our main interest here is not to replicate Schommer's findings but to use her work to investigate a multidimensional developmental model in a discipline-specific context. Schommer obtained four of her five hypothesised dimensions through exploratory factor analysis whereas we obtain five factors from this procedure.

We would stress some of the limitations of this study. Factor analysis requires a reasonable sample-size to variable-number ratio and the first cohort was at the very lowest limit of this. Internal consistency measures for the questions in the questionnaire were not high. Both of the groups studied were quite socially diverse and qualitative further analysis suggests that the questionnaire appears to be quite sensitive to linguistic and cultural factors. This may have contributed to rather poor internal consistency measures for the variables.

Finally, the discipline-specific nature of the group was not adequately addressed by the questionnaire. As, ultimately, one of the things we wish to investigate is whether an individual's approach to knowledge and learning contributes to a sense of subject identity and belonging to a community of practice, we believe that it is likely that an instrument with a much greater fit to the disciplinary context is needed for further work in this area.

Nevertheless, despite these issues, we anticipate that further enquiry into personal epistemology will offer significant insights into a range of problems which affect the performance of students on Computing degrees. Among the most important of these is greater understanding of the different methodologies students take when asked to solve well-structured and ill-structured problems [31, 32]. These are common across the Computing curriculum wherever there is a divergent, open-ended aspect to the solution process and some research appears to [33] indicate that different epistemological approaches are taken for each sort of problem. Further work to investigate this area is underway.

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