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Physics identity development: A snapshot of the stages of development of upper-level physics students

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Abstract: As part of a longitudinal study into identity development in upper-level physics students a phenomenographic research method is employed to assess the stages of identity development of a group of upper-level students. Three categories of description were discovered which indicate the three different stages of identity development for this group of students: Student, Aspiring Physicist, and Physicist. The stages of identity development were distinguishable by the variation in their career definitiveness, their metacognitive level, and their assessment of when has become a physicist.

Keywords: identity development, STEM students, phenomenography, professional development

I. Introduction.

The majority of papers that focus on identity development in the realm of physics have in the past focused on gender differences in identity development or on the lack of people of various ethnic backgrounds choosing to take physics as a major (Hazari et al., 2010, Basu, 2008; Buck et al., 2006). Recently the focus of identity research in the domain of physics has shifted to focus specifically on how a student transforms from a physics student to a physicist. This development of the professional identity of a physicist is a fundamental part of student development and has been asserted to be a strong influence on retention of students in a discipline (Pierrakos et al., 2009). Understanding identity development and encouraging ones perceived association with a particular community has been touted as a possible solution (Barton & Yang, 2000) to the problem identified by the National Science Board (National Science Board, 2006, 2008) that physics has an underdeveloped growth rate when compared to all other fields. Both understanding how and helping students to develop an identity within the social world of physicists may stimulate this stagnant growth rate. In this paper, "identity" refers to both one's self understanding about and actual ways in which one is positioned - both by others and by institutional representations - within some social world. The social world in this case is the social world of physicists. The research presented in this study is primarily interested in exploring the major influences from the experiences of upper-level physics students that affect identity development.

II. Identity.

In a review of previous literature on identity development it is apparent that there are many factors that have been indicated to affect identity development. According to Hazari et al. (2010) the primary influencing components of a student's identity are "(i) interest (personal desire to

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learn/understand more physics and voluntary activities in this area), (ii) competence (belief in ability to understand physics content), (iii) performance (belief in ability to perform required physics tasks), and (iv) recognition (being recognized by others as a physics person)." Hazari et al. (2010) indicate that there are four categories of factors that can influence identity development: curriculum elements (Crouch, Fagen, Callan, & Mazur, 2004; Adams et al., 2006); learning environment characteristics (Sadler & Tai, 2001; Haussler & Hoffmann, 2002); teacher characteristics (Sadler & Tai, 2001; Haussler & Hoffmann, 2002); student characteristics (Cleaves, 2005; Tai et al., 2005; Hazari et al., 2007) and out of school experiences (Stake & Mares, 2001; Jones et al., 2000).

Rather than attempting to focus an investigation into all previously identified elements this study instead focused on using the phenomenographic research method to ascertain upper-level physics students' own experiences and the factors more specifically applicable to them as upper-level physics students. For example, career choice and the effect of career aspirations on a student's identity was a topic that came up in students' descriptions of why they chose to major in physics. It has been found in the past that college students were of the opinion that a career in the physical sciences is likely to affect one's ability to achieve interpersonal goals due to the perceived commitment needed for such a career path (Morgan et al., 2001). It has also been found that there is a strong link between level of identification with being a physicist and whether or not a student had chosen a physical science career (Barton & Yang, 2000; Chinn, 2002; Cleaves, 2005; Shanahan, 2007). In a longitudinal study that examined national data on identity development in the subject of Math, it was found that students' eighth grade career interests were a very strong predictor as to their chances of receiving a bachelor's degree in the physical sciences (Tai, Liu, Maltese, & Fan, 2006). In engineering, students' career intentions have demonstrated to be an influence on self-identification (Meyers et al., 2012). Personal interest in physics (Adams et al., 2006) and having significant subject-related experiences such as projects or research experience (Meyers et al., 2010; Pierrakos et al., 2009) has also been found to affect student identity development.

III. Metacognition.

Biggs (1985) describes metacognition as making sense of one's experience of learning. Ramsden (1985) has argued that raising students' awareness of approaches to learning is an integral part of teaching and Entwistle (1987) argues that students may develop a deeper approach to learning through the application of metacognition. Metacognition involves two separate but inter-related processes. One of these is concerned with the students' own knowledge about their cognitive processes as well as an awareness of how compatible these processes are with a given learning situation. The other process involves the regulatory component consisting of the array of actions and activities in which individuals engage when performing a task, and are commonly grouped into planning, monitoring, and evaluating (Sandi-Urena et al., 2012).

Case and Gunstone (2002) make the argument that metacognitive development can be viewed as a shift in the approach to learning of a student. They also argue that metacognitive development can be identified as developments in students' conceptions of learning, improvements in the organization of their own learning, and a move towards self-assessment and personal development with regard to views on the purpose of learning and long term career goals (Case et al., 2001). Metacognition is also considered a common characteristic of expertise across domains (Lasry et al., 2009). So, personal development and expertise across domains relate to identity development, although it has also been posited that metacognitive development is a necessary precursor to professional identity development (Brown, 2009). If so, this indicates a relationship between one's level of metacognitive development and one's identity development within a social world. Metacognition also has an obvious relationship to Perry's Model of Intellectual Development (Perry, 1970, 1981). Perry's model characterizes the transition stages through which college students evolve as they progress through their academic career. Since metacognitive development is the process of increasing one's awareness about learning and understanding and one's own cognitive processes, it makes sense that the way students transition through Perry's stages is the process of metacognitive development. Perry's Model of Intellectual Development and progression through the various stages could be tied to an individual's identity development.

IV. Phenomenographic Research Methodology.

The phenomenographic research methodology shares its origins with approaches to learning research, which started in Marton and Saljo's seminal research study (Marton & Saljo, 1976a, 1976b). Since then, the phenomenographic methodology has become a widely used methodology for research on learning and teaching (Bowden et al., 1992; Dall'Alba et al., 1993; Walsh et al., 1993; Ramsden, 2002; Entwistle & Ramsden, 1983; Prosser & Trigwell, 1999; Laurillard, 2002; Ramsden et al., 1993; Olympiou & Zacharia, 2012; Lee et al., 2008). A phenomenographic study usually focuses on a relatively small number of subjects and identifies a limited number of qualitatively different and logically interrelated ways in which a phenomenon or a situation is experienced.

This idea of qualitatively different ways of experiencing a phenomenon has been validated and reinforced by the theory of variation and awareness (Marton & Booth, 1997; Trigwell & Prosser, 1997; Bowden & Marton, 2004; Marton & Tsui, 2004; Marton & Pong, 2005). This theory is the basis for 'new' phenomenography and states that there are a limited number of qualitatively different ways in which something that is experienced can be understood. The limit is set by the constituent parts or aspects of the experience that are discerned and appear simultaneously in people's awareness. A particular way of experiencing something reflects a simultaneous awareness of particular aspects of the phenomenon. Another way of experiencing it reflects a simultaneous awareness of what aspects (more aspects or fewer aspects) of the same phenomenon are experienced (Marton & Booth, 1997). Therefore, it is the variation in the way in which aspects of a particular phenomenon or object are discerned, that constitutes an individual's experience of that phenomenon (Linder & Marshall, 2003).

If learning is the discernment of the variation of critical aspects of an experience and it can be divided into the sub-categories of how (approach) and what (concept) with each of these sub-categories having both structural (what is done) and referential (and why) aspects, then an investigation into students' identity development would be an examination of the variation in the critical aspects of the elements that influence identity development (structural) and the critical aspects of the intention underlining these elements (referential). A common practice in phenomenographic research is to present the 'themes of expanding awareness' which are structural groupings of aspects of variation discerned through analysis (Akerlind, 2005).

V. Objective.

The objective of this study is to qualitatively assess the different stages of development students occupy in regard to identity development at a particular instance in their course progression and to identify the elements that influence student identity development that students are most aware of.

VI. Design of Study.

The primary data for this analysis comes from semi-structured interviews with students who were recruited from upper-level physics courses in electromagnetism or mechanics. The students were recruited via a sign-up sheet that was sent around in both the electromagnetism and mechanics classes and were told that they would receive the monetary reward of $10 if they participated in a study which involved being interviewed about some of their thoughts about physics. This method of recruitment reduced the risk of selection bias. We developed a 45-minute semi-structured interview protocol drawing on identity formation, epistemological sophistication, and metacognition literature. By epistemological sophistication we use Elby and Hammer's definition (2001) in that we "believe that students should come to understand scientific knowledge as fundamentally tentative and evolving...subjective in the sense that it reflects scientists' perspectives...individually or socially constructed...see scientific knowledge as a coherent, hierarchical system of ideas...view learning science as making sense of new ideas for themselves." The initial protocol was adapted from the literature outlined in sections II-IV, however, the interview was piloted on several occasions before employing it on the cohort of students that the results of the study originate from. This was an attempt to make the interview more focused on particular aspects of identity development. The interview started by asking the students to describe their history with physics starting with when they first got interested in the subject. This type of question is broad enough that it gets the students talking about their previous experiences and often offers the interviewer several opportunities to ask follow-up questions based on the interviewees responses. Follow-up questions for each broad question are part of the protocol but the phenomenographic interview approach often allows these questions to occur organically from interviewees' responses. Other examples of lead questions are: could you describe the characteristics of a physicist? or could you describe the expected career path you intend to take? Interviews, which were videotaped, began with a discussion of the student's prior history with physics up to the time of the interview and segued into questions about present physics experiences in class and attitudes in physics, future career plans, research history, and finally a discussion about knowledge, learning, understanding, and how truth is defined. Thirty students chose to participate in the study. The interviews were carried out over a two-week period near the end of the second semester. The sample was comprised of 10 female and 20 male interviewees. All respondents were over the age 18 and we obtained approval to conduct our research from the Institutional Review Board (IRB) of our university and all interviewees signed consent forms to participate in the study.

VII. Data Analysis.

The responses to the questions were analyzed initially by an individual researcher and the robustness of the categories was tested by a fellow member of the research team. The robustness testing and the analysis process are discussed in detail below:

- Each transcript was read repeatedly, often in one sitting, in order to become acquainted with the transcript set as a whole.
- For each sitting of the transcript the focus of awareness was on one particular aspect of the video. For example, on one occasion the focus may have been on how the students described their first experiences with physics, on another occasion careful attention would be paid to aspects of physics that the students liked that was focused on and on yet another occasion, the focus would be on students' conceptions of understanding.
- The next step was to make a set of notes that recorded all information that was perceived to be critical to the students' stage of identity development.
- The analysis moved to seeking out the critical similarities and differences between the notes. However, the focus was not solely on the notes and instead involved working concurrently with the notes, transcripts, and videos as the notes often lacked the depth of completeness that the videos contained.
- Cases of agreement and variation of discerned critical aspects within the notes/transcripts pertaining to the students' stage of identity development were identified.
- The variation of critical aspects was then utilized to preliminarily form descriptions (an outcome space) of the different stages of identity development.
- Once tentative categories had been constituted, the categories and the transcripts were examined for structure of the categories. In searching for the structural aspects of the approaches, it was important to identify what was focused upon within each overall meaning. In other words, the themes of expanding awareness that were present in each preliminary category were sought, which served to distinguish between the categories and further identified the hierarchical structure.
- For each category constituted, the groupings of notes were re-examined to find cases of both agreement and contrast within the notes. This was to ensure that the categories actually did describe the variations in the stages of identity development of this set of students faithfully and empirically.
- The last step was to give the transcripts and preliminary categories to another member of the research group who then examined the robustness of the categories with discussion and further development of the categories resulting.
- Extracts and statements were taken from the transcripts which would give substance and support to the categories.
- Finally, once the categories were felt to be robust, the researchers returned to the interview transcripts and placed each individual student into one of the three categories based on how well they fit into each category. In cases of disagreement the researchers engaged in a negotiating process in order justify a student's inclusion in one category over the other, however, this only occurred on one occasion and overall the researchers were in agreement over the allocation of students in each category.

VIII. Results.

A description of each of the categories of the stages of identity development in upper-level students is shown below. Table 1 presents the hierarchy of the categories and the themes of expanding awareness. The themes of expanding awareness are the commonalities that relate the categories together but it is the different ways in which the students describe and experience these commonalities that distinguishes between the levels of the categories. So the categories are inherently related given the commonalities between them but are distinguishable via the variation within the themes of expanding awareness. For example: the variation in metacognitive level highlights the increasing level of sophistication of each category and also distinguishes each category from the others in a critical manner. The analysis of the interviews revealed three categories that describe the variations in the stages of identity of upper-level physics students.

Table 1. Table of category of stage of identity development (horizontal) and themes of expanding awareness (vertical) and also indicates number of students that occupy each category at the time of interview. With all of the stages discerned from the data they were titled with appropriate names and are described in detail below.

	Student	Aspiring Physicist	Physicist
Career Definitiveness	No specific career chosen	Plan that lacks specifics	Specific job chosen
One is a physicist when...	Obtaining an amount of knowledge	Contributing to generation of new physics knowledge or practicing physicist	I am a physicist
Metacognitive Level	Lack in self awareness	Evolved sense of awareness	Complete self-awareness
No. of Students	12	13	5

A. Student.

Overall this categorizes students who are only at the beginning stages of identity development in physics. They do not identify themselves as physicists and are unsure about what it is that physicists do or what it would mean to be a part of this cultural group. In regards to the themes of expanding awareness for this group of students, the different elements and the relationship between them display a pattern of lack of definitiveness on their part about their career choice. This lack of definitiveness manifests in their unspecified future plans:

> Interviewer: From that research experience did your perception of physics change?
> Jeff: Yeah, yeah, perception of how it's done. When I first came I tried to get with [a cosmologist]…
> Interviewer: Uh huh.
> Jeff: and he was having me read books and derive derivations. It was the first time I ever… I ever really understood a derivation. Talking to him about the reality of the field and you know, the reality of a lot of the physics fields, is what turns me off. I don't want to be cooped up in a lab or in front of a computer. I want to be

outdoors more. Really, I want to be a musician. If I did it again, I'm not sure I would do it.

In regards to their metacognitive level the students are less evolved than the other stages of identity development. They also have an unsophisticated conception of understanding when compared to the other categories often resorting to the anecdote of 'you understand a concept when you have the ability to explain it to someone else' with little expansion on this explanation when pressed.

Pierce: To kinda, be able to explain it to someone who doesn't have that knowledge, they can kind of take something else away from it too.

Interviewer: So to understand something in physics is to be able to explain it?

Pierce: Yeah.

(Pierce was probed further in regards to this concept of understanding but was unable to give any more detail of his process of gaining an understanding or elaborate on how understanding is being able to explain a concept to another.)

A clear indicator that can be used to ascertain one's metacognitive level is the capacity to identify the need for different approaches to learning in different learning scenarios but the "I am student" stage of identity development offers no evidence of having this ability. One area that they are definitive in is that is takes some level of completed course work or obtainment of a certain amount of knowledge before one is a physicist often indicating getting a PhD. For example:

Interviewer: And what makes him a physicist?

Will: The mastery of it. We just did electricity and just seeing my professor doing it up on the board and how much he knew about it... just the amount of knowledge.

Similarly it is the obtainment of a qualification:

Interviewer: The way you talked about a PhD… that seems as if it's a long term ambition that you have held. So why do you think that is?

Troy: Um, I don't know. I don't see myself as a physicist yet, um, I sort of feel that if I don't get a PhD I'll never, you know I want to learn all that stuff. I want to learn the higher level physics.

Interviewer: Right.

Troy: And I want to be a physicist and that's part of being a physicist. You get a graduate degree.

In summation these students are missing an overall awareness of their place in a society of physicists and a lack of metacognitive development as well as determining that to become a physicist one must gain a certain amount of knowledge.

B. Aspiring Physicist.

This category of stage of identity development in physics is characterized by students who identify themselves to be on the path to being a physicist but are not yet there in their opinion. These students do not identify themselves as physicists because of the conceptions of what it means to be a physicist that they have developed from their past experiences.

Sam: I like to say I am an aspiring physicist, not a physicist. I'm still in classes... if they are doing research of some sort… whether it is experimental or theory... if you're not practicing, you're not a physicist anymore.

They often describe experiences they have ascertained from working in research groups, summer internships, or summer research programs. In essence they are of the opinion that one is not a physicist until you are doing research or contributing new knowledge to the physics community. This is evidenced in their career definitiveness as opposed to the "Student" category where they are unsure of their next step after obtaining their degree and the "I am Physics Student" category of students who are definitive in that they want to obtain a PhD level of education but have not yet narrowed down the area of physics in which they wish to obtain this qualification.

In regards to the metacognitive level of these students, they are much more aware of the approach that they take to their exams and classes, indicating that they have the ability to ascertain either what a lecturer is looking for in an exam or expects from them in class and adjust accordingly. They have the ability to adopt a surface approach to a learning environment or exam but also indicate that they would much prefer to gain an understanding. They indicate a preference for gaining an understanding but if it is not rewarded or if they do not have enough time to do so they will resort to a more rote learning-based approach.

> Shirley: The EP1 and EP2 exam approach is kind of… there are a lot of old tests circulating for those classes and the old tests are very similar to the new/ You have your hands on old tests studying for the exams, it's pretty straightforward what you should do. Uh, physics 3 and mechanics were a very different experience for me. The tests that they had was not at all representative of the test that they give. And in mechanics class he doesn't even give us old tests to look at so I would approach that by going over all the homework, reading through the notes, and… um… trying to make sure I understand.

These students also have a more sophisticated conception of understanding than the "I am student" category, indicating that understanding of a concept is relating it to other concepts, being able to apply it in different situations, and also being able to look at it from multiple perspectives.

In this section Abed is talking about understanding in physics:

> Abed: I think to understand something, a lot of it has to do with understanding how it relates to some other things.
> Interviewer: Okay.
> Abed: That would be a very big part, you know. You can understand if you know how to use it. That's just one example.
> Interviewer: Right.
> Abed: But I think knowing how to use something is not understanding it completely. For example, I know how to use that camera, but that doesn't mean I understand it in a deep sense. But in a deeper sense you understand how the thing relates to the other thing or you can understand how it can be derived from simpler principles. Or if… you know… you get.. you can see it, maybe from a variety of different ways.

In summation this category of students believe that being a physicist involves doing research and contributing new knowledge to the physics community and since they are not doing this yet, they cannot classify themselves as physicists but they are much more self-aware of how they learn and more definitive about what they want to do.

C. Physicist.

This stage of identity is at the top of the hierarchy of categories and hence is the highest level of identity development found amongst this group. That is not to say that it is definitive in its completeness in regards to a description of what it entails to have achieved complete inclusion into the society of physicists as it based on just this group of students. Not all of the students in this category outwardly admit to being a physicist but their descriptions of physics and what being a physicist entails would match those of experts. These students do not describe or attribute that their conceptions of physicists necessarily come from previous experiences; however, they do (unlike the other categories) display a very concrete definitiveness in career choice which they have held for a very long time.

Annie outlines that she wishes to use her physics degree to become a meteorologist and is very interested in the science-based aspects of meteorology.

> Interviewer: So that seems to be a very clear plan. It seems like you decided on this a long time ago.
> Annie: Yeah.
> Interviewer: So when did that decision actually happen?
> Annie: I did… When I was little, my mom tells this story all the time… she makes fun of me. Like when I was little, on mornings, on Saturday mornings, I would be up and watching the weather channel and I would have my crayons out and I would draw warm fronts and cold fronts and the stuff that they were putting on the screen. I knew all about it, so my mom was just... And when I was in middle school, I did Science Olympiad and I did meteorology. And it's funny cause... we did an awards ceremony… at the end I got most likely to be a meteorologist.

In regards to the metacognitive level of these students it is very similar to "I am Physics Student" in that they can identify that different approaches may be needed for different exams and classes and ascertain what different lecturers are looking for but maintain that they are always looking to obtain a deep understanding of the material.

> Craig in discussing exams and his philosophy in regards to them.
> Craig: I think I knew less how to study for an exam in [physics 1] and [physics 2] than I do now. I would say that in EP1 and EP2 I just worked as many problems as I could so that I would know how to work. So if I see… say I see a weird problem on a test that is a hybrid of two problems, I can still apply my knowledge of having solved such a vast amount of problems. It's an engineering approach... take a couple of data points and hope your curve encompasses everything. In this class (mechanics) I have been more focused on, okay understand the basic concepts that we have covered... I was always trying to understand. There's no shortcuts.

Interestingly, these students describe that they may not have possessed this ability before beginning college and they may not have identified or known how to strategically study for an exam. This indicates a sort of awareness of one's own learning, the identification of problems with one's own approach, which indicates the high level of metacognition that students in this category possess. At several points they indicate times where they have evaluated their learning and emphasized the importance of the ability to self-assess.

Craig is talking about what he interprets as the lecturer's expectations of him in his mechanics class:

> Craig: He's trying to actually get us to where we're critically thinking about the solutions that we get, because sometimes I think you believe whatever you get. But… but he'll ask "why do you think this is good? Does it solve your initial conditions?"

In regards to their opinion on what makes one a physicist these students have a much more inclusive or simplistic view of what it means to be a physicist. Anyone can be a physicist as long as they are interested in it.

> Interviewer: Why are they a physicist?
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> Jed: Why are they a physicist? Just liking it really, I mean anyone can be a physicist if they show interest in it. I mean people think you need a lot of schooling to be a physicist but anyone can be a physicist, anyone can be a scientist really it's just whether or not you have that interest in it in my opinion..
>
> Interviewer: Given that definition you must consider yourself a physicist.
>
> Jed: Yes, I definitely do.

IX. Discussion.

For this cohort of upper-level physics students, the three factors that influence their identity development distinguished from their discussions on identity are: career definitiveness, idea of when one is a physicist, and metacognitive level. The different levels of metacognition as an influencing factor in identity development correlate with previous research of Brown (2009) and Lasry et al. (2009). In many ways metacognition is, in essence, an indicator of the amount of awareness one has. It makes sense then that the more aware a student is, the more they may have examined what it means to be a physicist and hence become more attuned to what being a physicist means and when and how one reaches that level. In regards to practical application, metacognition has been shown to improve through instruction (Schraw et al., 2005; Schraw et al., 2006; Kipnis & Hofstein, 2008). So, course designers should attempt to integrate metacognitive instruction/self-reflection into a physics course to aid in the development of students' awareness that could encourage identity development and their study skills. The quality of learning has been indicated to improve when students are in a learning environment that promotes the development of metacognition (Davidowitz & Rollnick, 2003; Larkin, 2006).

Of the other two influences on identity development that were discovered in this paper, career definitiveness can also be encouraged by a physics department. Helping students to identify early on or even giving them enough experience and information on potential careers may help them to form a professional physics identity faster. Becoming attached to a particular field of physics at the earliest stage possible may result in the development of one's identity as a physicist. What this means for colleges is that perhaps if students are encouraged to explore and are educated on the different areas and facets of physics that they could choose to have a career/study in, they may develop an identity as a physicist earlier. Giving students the opportunity to experience subjects in a research capacity or offering the opportunity to upper-level physics students to join research groups will undoubtedly help them develop their identities as physicists as they are exposed to the reality of what being an experimental physicist actually entails. The "Aspiring Physicist" category of students began their interest in high school and referenced having good teachers who bred life into the subject. This indicates the importance of a good teacher and that outreach programs to middle schools and high schools by university physics departments should be encouraged in order to facilitate a positive interaction with physics as early as possible.

The different levels also clearly distinguished between different levels of ideas as to when one becomes a physicist. The student conception of gaining a certain amount of knowledge correlates well with their metacognitive level of believing that knowledge is bestowed by lecturers. It is also clear why research would be the point at which one becomes a physicist for the "aspiring physicists" as they are definitive in their belief that they want to go to graduate school and contribute new ideas in that capacity. It would seem that the students who are already physicists at this point in their academic career have firm ideas of where they want their career to go but that getting there does not mean they will be a physicist. They already believe themselves to be physicists, and therefore they do not need to become physicists at a future date.

As previously attested, Kroger (2007) outlined that identity development studies should be carried out longitudinally in order to fully understand the process one goes through in developing an identity. As indicated in the introduction of this paper this is just the first part of a longitudinal study with this group of students as they continue through upper-level physics classes and into their careers as physicists. When this group of students is revisited in the future, the different stages of identity development that they occupy may have completely evolved. Eventually, we argue that by examining upper-level physics students and identifying how they form their identities in the future it is hoped that we can understand how to encourage more students into taking physics as a major. Future work should also include an investigation into how the experiences of these physics students and how the categories that they occupy influence them over the course of their studies.

X. Conclusion.

The stages of identity development for a group of upper-level physics students were identified resulting in three primary stages. The main differentiation between stages is: career definitiveness, level of interest, and metacognitive level. These stages were found to not correlate with epistemological sophistication as students exhibited a uniform level at this stage in their physics career.

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