Jessica Lindvall
Jessica.lindvall@nbis.se
Joint head of Unit, Training coordinator
ELIXIR-SE (National Bioinformatics Infrastructure Sweden, NBIS)

INTRODUCING THE MR-BI

Applications to training & professional development

ACKNOWLEDGEMENTS

Rochelle Tractenberg, Allegra Via, Terri Attwood

  

OVERVIEW

What is the MR-Bi?

A visual tour

Two applications

WHAT IS THE MR-BI?

RESEARCH ARTICLE

The Mastery Rubric for Bioinformatics: A tool to support design and evaluation of career-spanning education and training

Rochelle E. Tractenberg[1]*, **Jessica M. Lindvall**[2], **Teresa K. Attwood**[3], **Allegra Via**[4]

1 Collaborative for Research on Outcomes and –Metrics, and Departments of Neurology, Biostatistics, Biomathematics and Bioinformatics, and Rehabilitation Medicine, Georgetown University, Washington, DC, United States of America, **2** National Bioinformatics Infrastructure Sweden (NBIS)/ELIXIR-SE, Science for Life Laboratory (SciLifeLab), Department of Biochemistry and Biophysics, Stockholm University, Stockholm, Sweden, **3** Department of Computer Science, The University of Manchester, Manchester, England, United Kingdom; The GOBLET Foundation, Radboud University, Nijmegen Medical Centre, Nijmegen, The Netherlands, **4** ELIXIR Italy, National Research Council of Italy, Institute of Molecular Biology and Pathology, Rome, Italy

* rochelle.tractenberg@gmail.com

Citation: Tractenberg RE, Lindvall JM, Attwood TK, Via A (2019) The Mastery Rubric for Bioinformatics: A tool to support design and evaluation of career-spanning education and training. PLoS ONE 14(11): e0225256. https://doi.org/10.1371/journal.pone.0225256

Editor: Nicholas J. Provart, University of Toronto, CANADA

Received: June 6, 2019

Accepted: October 24, 2019

Published: November 26, 2019

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: https://doi.org/10.1371/journal.pone.0225256

Data Availability Statement: All of the data are included in this manuscript: the data are qualitative and are included in the tables.

Abstract

As the life sciences have become more data intensive, the pressure to incorporate the requisite training into life-science education and training programs has increased. To facilitate curriculum development, various sets of (bio)informatics competencies have been articulated; however, these have proved difficult to implement in practice. Addressing this issue, we have created a curriculum-design and -evaluation tool to support the development of specific Knowledge, Skills and Abilities (KSAs) that reflect the scientific method and promote both bioinformatics practice and the achievement of competencies. Twelve KSAs were extracted via formal analysis, and stages along a developmental trajectory, from uninitiated student to independent practitioner, were identified. Demonstration of each KSA by a performer at each stage was initially described (Performance Level Descriptors, PLDs), evaluated, and revised at an international workshop. This work was subsequently extended and further refined to yield the Mastery Rubric for Bioinformatics (MR-Bi). The MR-Bi was validated by demonstrating alignment between the KSAs and competencies, and its consistency with principles of adult learning. The MR-Bi tool provides a formal framework to support curriculum building, training, and self-directed learning. It prioritizes the development of independence and scientific reasoning, and is structured to allow individuals (regardless of career stage, disciplinary background, or skill level) to locate themselves within the framework. The KSAs and their PLDs promote scientific problem formulation and problem solving, lending the MR-Bi durability and flexibility. With its explicit developmental trajectory, the tool can be used by developing or practicing scientists to direct their (and their team's) acquisition of new, or to deepen existing, bioinformatics KSAs. The MR-Bi is a tool that can contribute to the cultivation of a next generation of bioinformaticians who are able to design reproducible and rigorous research, and to critically analyze results from their own, and others', work.

https://doi.org/10.1371/journal.pone.0225256

A descriptive '3D' table

KSAs, Stages, PLDs

Performance Level:	Novice	Beginner	Apprentice	J1 Journeyman	J2 Journeyman
General description of bioinformatics practitioner	Reads, generally understands, but does not question, life science research (results). Beginning to recognise that 'facts' are actually just the best-currently-supported theory. Limited engagement with uncertainty associated with 'facts'; developing understanding of experimental design paradigms in biology, & own specific area of study.	Consolidates reading & understanding, beginning to learn how to analyze given biology problems (with software). Growing recognition that 'facts' are typically the best-currently-supported theory. Engaging consistently with uncertainty associated with 'facts'; deepening understanding of experimental design paradigms in biology, & own specific area of study.	Reads & understands; reliably identifies methods (software & programming) for given problems. Chooses & executes correct analysis, not necessarily able to identify several methods that could be equally viable, depending on given research objectives. Qualified as a fluent, but not as an independent, scientist who uses bioinformatics as a tool, but does not yet synthesise techonolgy with biology to generate new research problems.	Qualified as an independent scientist who uses bioinformatics methodologies as part of routine practice. Poses novel scientific questions, & identifies data & technology to align appropriate statistical/analytical methods to desired scientific objectives. Experienced reviewer of relevant technical features of available bioinformatics methods. Newly-independent expert in integrating bioinformatics technology/techniques into novel research problems in their area of expertise.	Independent scientist who expertly integrates bioinformatics & more traditional methodologies, as needed, to achieve desired objectives & contribute to the body of knowledge. Expert reviewer of relevant technical features of available bioinformatics options.
Considerations for evidence of performance at this level	**Bloom's 1, early 2:** remember, understand. Problems the Novice can engage with are well-defined, with solutions already known. Work does not generally reflect self-assessment.	**Bloom's 2-3**: understand & apply, **but only what they are told to apply**. Problems the Beginner can engage with are well-defined. Work reflects some self-assessment, when directed to do so.	**Bloom's 3-4, early 5:** *choose* & apply techniques to problems that have been defined (either jointly or by others). Can analyze & interpret appropriate data, identify basic limitations & conceptualise a need for next steps/contextualization of results with extant literature. Seeks guidance to improve self-assessment of own work.	**Bloom's 5, early 6:** evaluate (review) & synthesise novel life-science knowledge while developing abilities to integrate bioinformatics into research practice. Shows independent expertise in a specific life-science area, & confidently integrates current bioinformatics technology into that area. Beginning to critically evaluate experimental paradigms & their results, without knowing/requiring that there be 'one right answer'. Consistently self-assesses own work.	**Bloom's 6:** prepared for independent scientific work. Expert in design & critical evaluation of experimental paradigms & their results. Self-assesses in own work, & encourages others to develop this skill.
Ethical practice	Exhibits respect for community standards/rules for public behavior & personal interaction. Learning how to recognise, & manifest respect for, intellectual property, professional accountability, & scientific contributions.	Learning to recognise 'misconduct' in the scientific sense. Learning to avoid, & respond to, misconduct; & the importance of neither condoning nor promoting it.	Learning the principles of ethical professional & scientific conduct. Seeks guidance to strengthen applications of these principles in own practice. Learning how to respond to unethical practice.	Practices bioinformatics in an ethical way, & does not promote or tolerate any type of professional or scientific misconduct. Seeks guidance in how/when to take appropriate action when aware of unethical practices by others.	Practices, & encourages all others to practice, bioinformatics in an ethical way. Does not promote or tolerate any type of professional or scientific misconduct. Takes appropriate action when aware of unethical practices by others.
Prerequisite knowledge – biology (includes statistical inference & experimental design considerations)	Basic knowledge of biology; little-to-no awareness of the uncertainty inherent in experimental designs common in the life sciences. Thinking about the life sciences is based on uncritical acceptance of information as 'factual' or 'true'.	Advanced knowledge of biology, & basic knowledge of key bioinformatics methods. Very simple statistics/programs are run to answer pre-defined scientific questions. Learning to understand the uncertainty inherent in the scientific method, questions assumptions in the data & their relevance for given	Thinking about life sciences integrates both experimental & bioinformatics/technological sources for data & knowledge. Understands the uncertainty inherent in the scientific method, questions assumptions in the data & their relevance for given scientific problems (which typically arise from others, or with others). Experimental design & statistical	Recognises the importance of, & is able to critically evaluate, the relevant literature, & understands historical background of the relevant biological system(s). Sufficient knowledge of a biological system(s) to be able to draw functional conclusions from analytical results. Collaborates with experts to inform the next stages in the experimental design process (validating	Makes predictions to inform next stages of experimental design process. Evaluates relevant experimental methods that can be applied in any problem. Can generalise to other biological systems; independently solves biological problems that are innovative & move the field forward.

A descriptive '3D' table

KSAs, Stages, PLDs

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General description of bioinformatics practitioner	Reads, generally understands, but does not question, life science research (results). Beginning to recognise that 'facts' are actually just the best-currently-supported theory. Limited engagement with uncertainty associated with 'facts'; developing under-standing of experimental design paradigms in biology, & own specific area of study.	Consolidates reading & understanding, beginning to learn how to analyse given biology problems (with software). Growing recognition that 'facts' are typically the best-currently-supported theory. Engaging consistently with uncertainty associated with 'facts'; deepening understanding of experimental design paradigms in biology, & own specific area of study.	Reads & understands; reliably identifies methods (software & programming) for given problems. Chooses & executes correct analysis, not necessarily able to identify several methods that could be equally viable, depending on given research objectives. Qualified as a fluent, but not as an independent, scientist who uses bioinformatics as a tool, but does not yet synthesise techonolgy with biology to generate new research problems.	Qualified as an independent scientist who uses bioinformatics methodologies as part of routine practice. Poses novel scientific questions, & identifies data & technology to align appropriate statistical/analytical methods to desired scientific objectives. Experienced reviewer of relevant technical features of available bioinformatics methods. Newly-indepen-dent expert in integrating bioinformatics technology/techniques into novel research problems in their area of expertise.	Independent scientist who expertly integrates bioinformatics & more traditional method-ologies, as needed, to achieve desired objectives & contribute to the body of know-ledge. Expert reviewer of relevant technical features of available bioinformatics options.
Considerations for evidence of performance at this level	**Bloom's 1, early 2:** remember, understand. Problems the Novice can engage with are well-defined, with solutions already known. Work does not generally reflect self-assessment.	**Bloom's 2-3**: understand & apply, **but only what they are told to apply**. Problems the Beginner can engage with are well-defined. Work reflects some self-assessment, when directed to do so.	**Bloom's 3-4, early 5:** *choose* & apply techniques to problems that have been defined (either jointly or by others). Can analyse & interpret appropriate data, identify basic limitations & conceptualise a need for next steps/contextual-isation of results with extant literature. Seeks guidance to improve self-assessment of own work.	**Bloom's 5, early 6:** evaluate (review) & synthesise novel life-science knowledge while developing abilities to integrate bioinformatics into research practice. Shows independent expertise in a specific life-science area, & confidently integrates current bioinformatics technology into that area. Beginning to critically evaluate experimental paradigms & their results, without knowing/requiring that there be 'one right answer'. Consistently self-assesses own work.	**Bloom's 6:** prepared for independent scientific work. Expert in design & critical evaluation of experimental paradigms & their results. Self-assesses in own work, & encourages others to develop this skill.
Ethical practice	Exhibits respect for community standards/rules for public behavior & personal interaction. Learning how to recognise, & manifest respect for, intellectual property, professional accountability, & scientific contributions.	Learning to recognise 'misconduct' in the scientific sense. Learning to avoid, & respond to, misconduct; & the importance of neither condoning nor promoting it.	Learning the principles of ethical professional & scientific conduct. Seeks guidance to strengthen applications of these principles in own practice. Learning how to respond to unethical practice.	Practices bioinformatics in an ethical way, & does not promote or tolerate any type of professional or scientific misconduct. Seeks guidance in how/when to take appropriate action when aware of unethical practices by others.	Practices, & encourages all others to practice, bioinformatics in an ethical way. Does not promote or tolerate any type of professional or scientific misconduct. Takes appropriate action when aware of unethical practices by others.
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A descriptive '3D' table
KSAs, Stages, PLDs

	not even contextualise conclusions with the protocol that was followed. Not aware of the difference between conclusions about the null hypothesis & those about the research hypothesis. Conclusions may over- or under-state results & be driven by p-values or other superficial cues. Does not recognise the importance of identifying & acknowledging methodological limitations, or their implications, for conclusions. Does not or cannot apply rules of logic to scientific arguments, & commits logical fallacies when drawing conclusions.	not be able to draw those conclusions from given results themselves. Learning to differentiate between conclusions about the null hypothesis & those about the research hypothesis. Learning why p-value-driven conclusions, & the lack of FDR controls, are not conducive to reproducible work. Conclusions are generally aligned with given results, but when multiple methods are used, does not recognise the dependencies among methods that appear to reinforce, but actually replicate, results. Conclusions are neither fully contextualised with the rest of a document (write-up, paper, *etc.*) or study/experiments/paradigm (contextualisation for *coherence*), nor with the literature (*critical contextualisation*).	hypothesis/hypotheses & across the entire manuscript/writeup (as appropriate). Learning to critically contextualise results; is able to draw the most obvious conclusions, but struggles to see patterns, or draw more subtle conclusions. Learning that 'full' contextualisation of conclusions requires consideration of limitations deriving from methods & their applications, & their effects on results & conclusions. Learning to recognise how independence of multiple methods applied to similar data/problems supports reproducible conclusions.	statistical & biological significance. In their own & others' work, seeks competing, plausible alternative conclusions. Can judge the scientific importance of their results, & draws conclusions accordingly. Can draw conclusions & contextualise results with respect to an entire manuscript/writeup in a given project or study, or with literature (as appropriate). Can detect when conclusions are not aligned with other aspects of the work (*e.g.*, introduction/background, methods &/or results, or other experiments in the project). Gives careful consideration to limitations deriving from the method & its application in a specific study. Sees patterns, & perceives more subtle conclusions than earlier-stage scientists, & collaborates to fully articulate & motivate them. Writes the Discussion & Conclusions sections, including limitations, of own articles, with collaboration.	within any given document (*e.g.*, manuscript, writeup, *etc.*). Strives to fully contextualise conclusions in own work, & also requires this in others' work. Draws & contextualises more subtle conclusions than at earlier stages. Can conceptualise new experiments based on the lack of robust &/or defensible conclusions in others' work. Carefully considers consistency of conclusions with the other parts of own or others' work.
Communication	Does not communicate scientific information clearly or consistently; is unaware of community standards for scientific communication. Generally relies on lay summaries to support own communication; does not recognise that using original literature strengthens scientific communication. Does not differentiate appropriate & inappropriate scientific communication, nor understand the ethical implications of each.	Learning both to recognise the value of clear communication, & about the role of communication in sharing & publishing research, data, code, data management, tools & resources. Developing an awareness of community standards for scientific communication, & that these include documenting code, annotating data, & adding appropriate metadata. Does not adapt communication to fit the receiver. Learning to differentiate appropriate & inappropriate scientific communication, but does not yet understand that transparency in all communication represents ethical practice, *even when* the desired results have not been achieved.	Understands the roles of sharing & publishing research, data, code, data management, tools & resources in scientific communication. Seeks guidance so that own communication is coherent, accurate & consistent with community standards (*e.g.*, following FAIR‡ principles; ensuring socially responsible science). Learning to document code, annotate data, & add appropriate metadata – & the importance of these (as appropriate given their research/context) for sharing & integration. Learning the importance of adapting communication to fit the receiver, seeking opportunities to practice this. Learning that transparency in all communication represents ethical practice, even when the desired results have not been achieved.	Consistently & proficiently uses technical language to correctly describe what was done, why, & how. Sufficient consideration given to limitations, with explicit contextualisation of results consistently included in the communication of results & their interpretation. Can adapt communication to fit the receiver; recognises that sometimes communication must be consistent with community standards beyond their own discipline. Appropriately documents/annotates all data, code, tools, & resources for sharing, integration, & re-use. Understands that transparency in all communication represents ethical practice.	Is an expert communicator & reviewer of scientific communication; adheres to & promotes disciplinary standards for communication. Communicates in a manner that is consistent with standards across communities beyond their own discipline, as appropriate. Ensures communication is appropriate for target audience, expertly adapting to fit the receiver(s). Communication is transparent, & appropriate to support reproducibility – & thereby, ethical practice – in every context.

*Framework of the workflow supports decisions; workflow is not necessarily linear and can be multidirectional and iterative; any point can be re-iterated, or new starts from within the workflow can be made. A pipeline is unidirectional, not iterative within its structure (it is ballistic: once initiated, it runs), and has no decision points. Pipelines can exist within workflows, but workflows do not exist in pipelines.
‡ FAIR: Findable, Accessible, Interoperable, Reusable.

KSA	Novice	Beginner	Apprentice	J1 Journeyman	J2 Journeyman
PK biology	Basic knowledge of biology	Advanced knowledge of biology & basic knowledge of bioinformatics methods	Integrates experimental & bioinformatics sources for data & knowledge	Sufficient knowledge of biological systems to be able to draw functional conclusions from results	Independently solves biological problems that are innovative & move the field forward
PK computational methods	Basic knowledge of computational methods				
Integrate interdisciplinarity	Doesn't recognise that life sciences require integration of experimental & computational approaches				
Define a literature-based problem	Can recognise a problem that is explicitly articulated but can't derive one				
Hypothesis generation	Doesn't generate hypotheses & may not recognise them without explanation				
Experimental design	Can't design data collection or experiments				
Identify relevant data	Can't describe what makes data relevant to a problem				
Identify & use appropriate methods	Doesn't identify methods relevant to a problem				
Interpretation of results	Treats the output of programs as the final result, without interpretation				
Draw & contextualise conclusions	Doesn't draw appropriate conclusions from results				
Communication	Doesn't communicate scientific results clearly or consistently				
Ethical practice	Learning how to recognise intellectual property & scientific contributions				

Stages (*columns*)
Developmental trajectory, from less (novice) to more expert (journeyman)

Knowledge, Skills & Abilities (KSAs) (*rows*)

Performance Level Descriptors (PLDs) (cells) Describe performance at each stage

A VISUAL TOUR

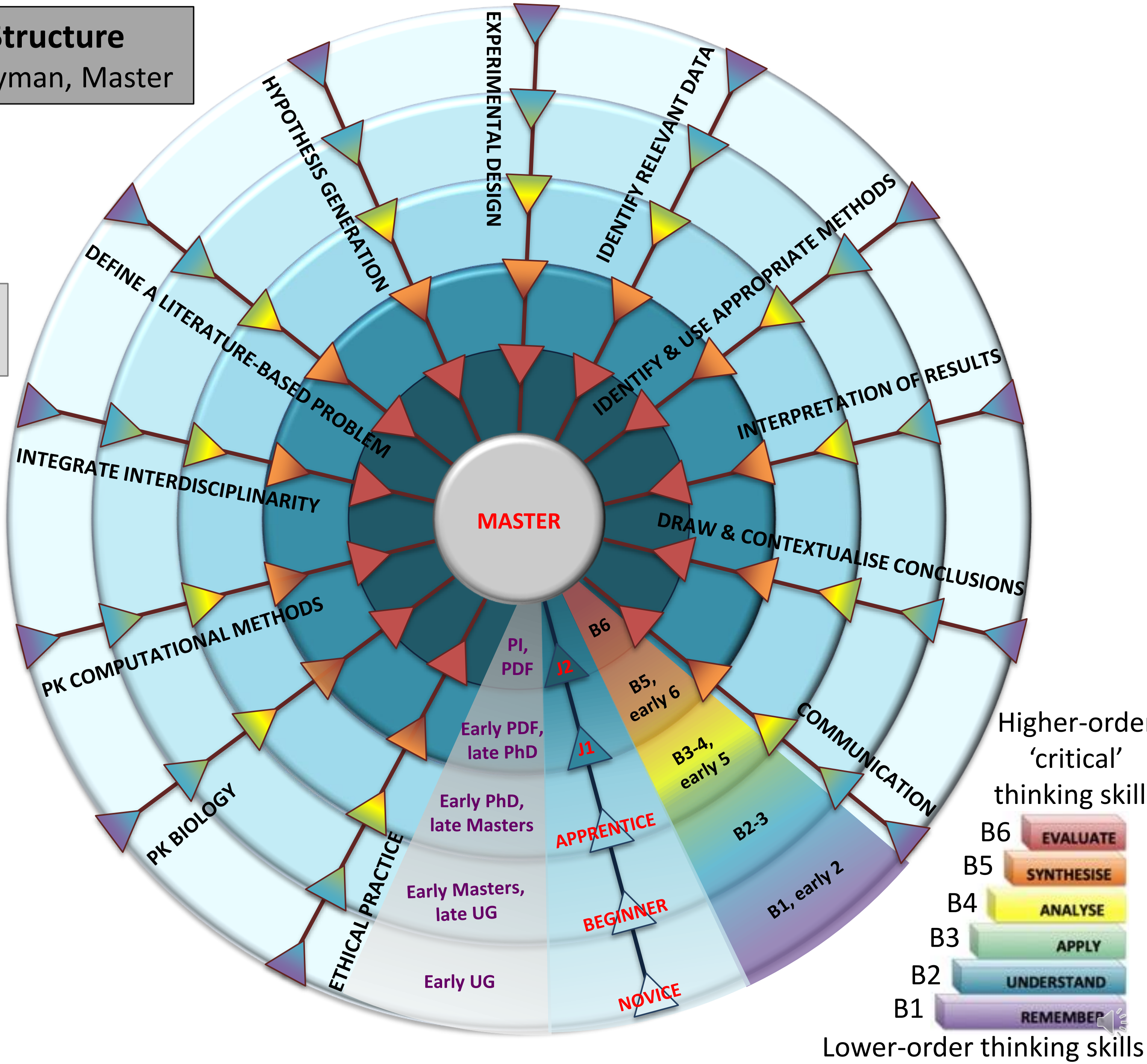
European Guild Structure

Apprentice, Journeyman, Master

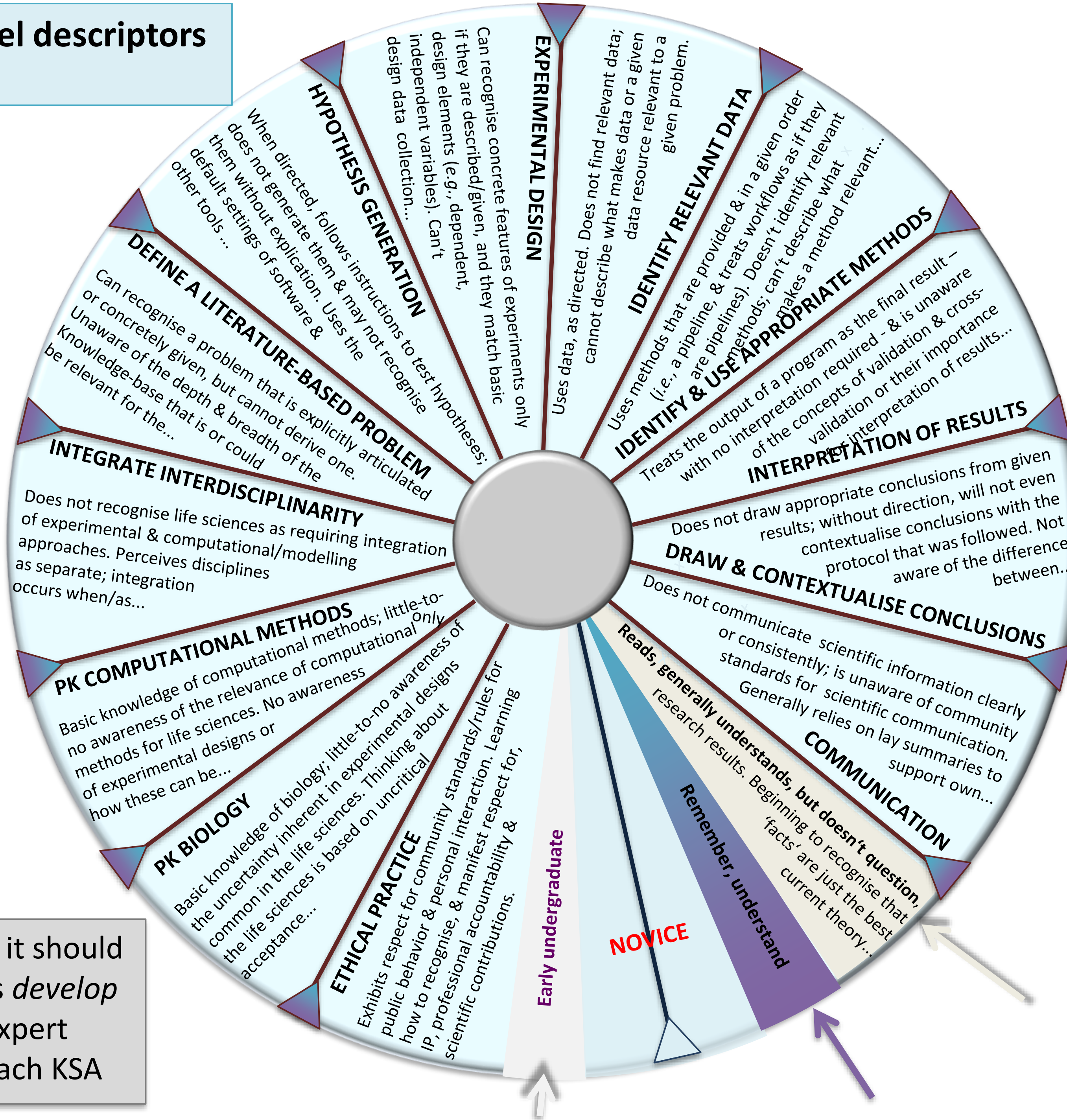
KSAs based on the scientific-method

Foundational discipline-specific KSAs

Ethics

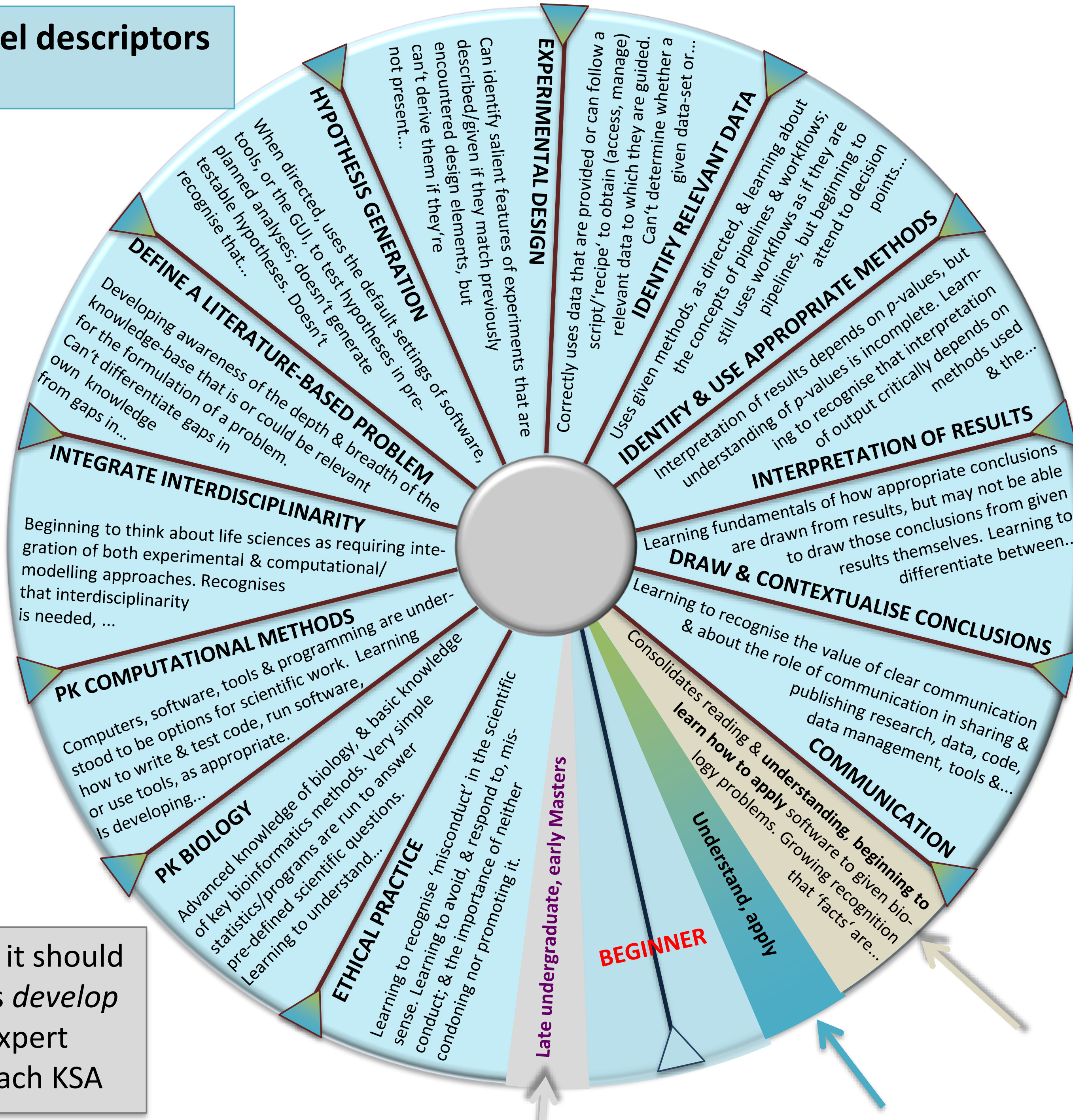


Performance-level descriptors
Novice



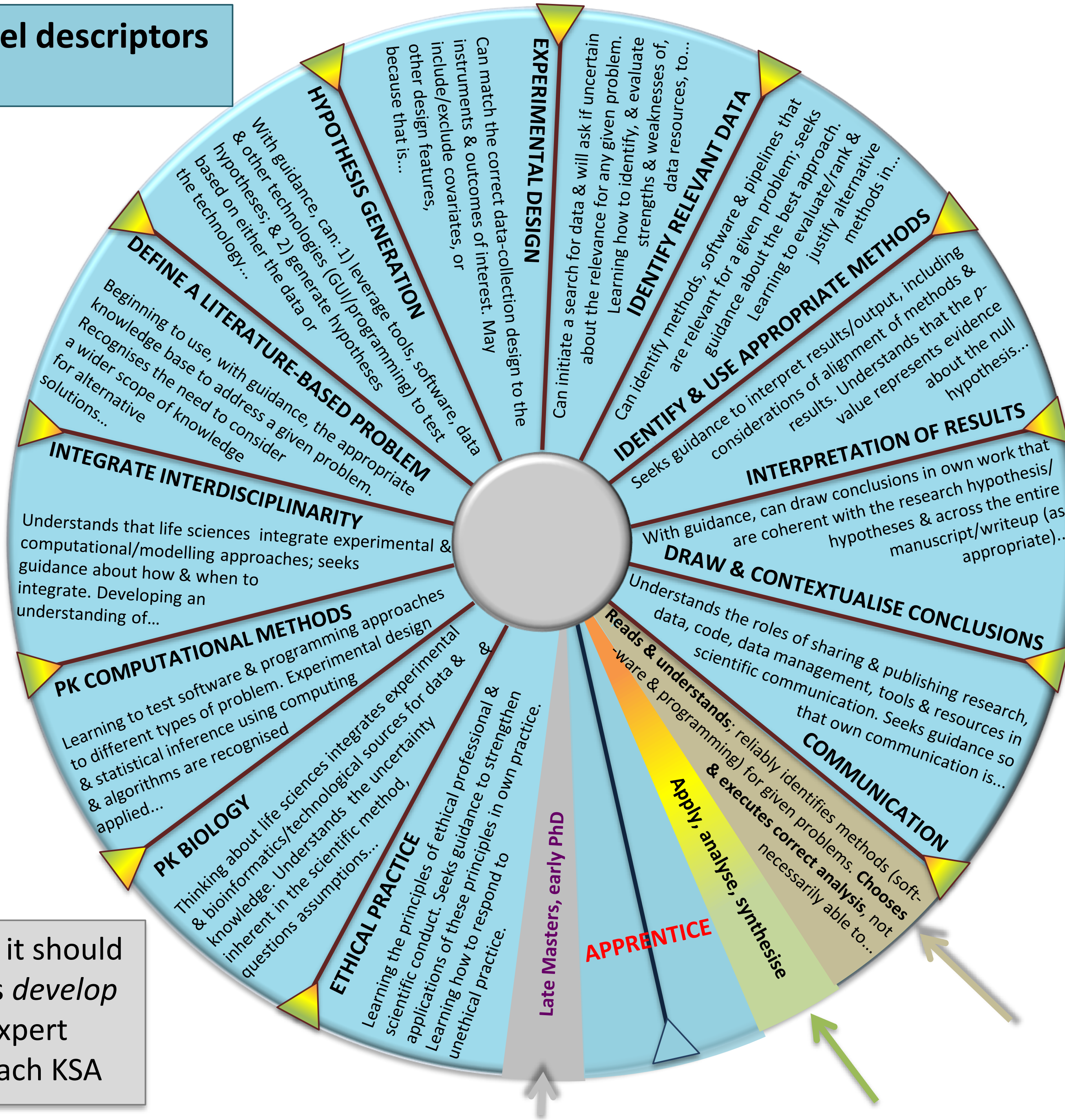
PLDs describe what it should ***look like*** as learners *develop* from *less* to *more* expert demonstration of each KSA

Performance-level descriptors
Beginner



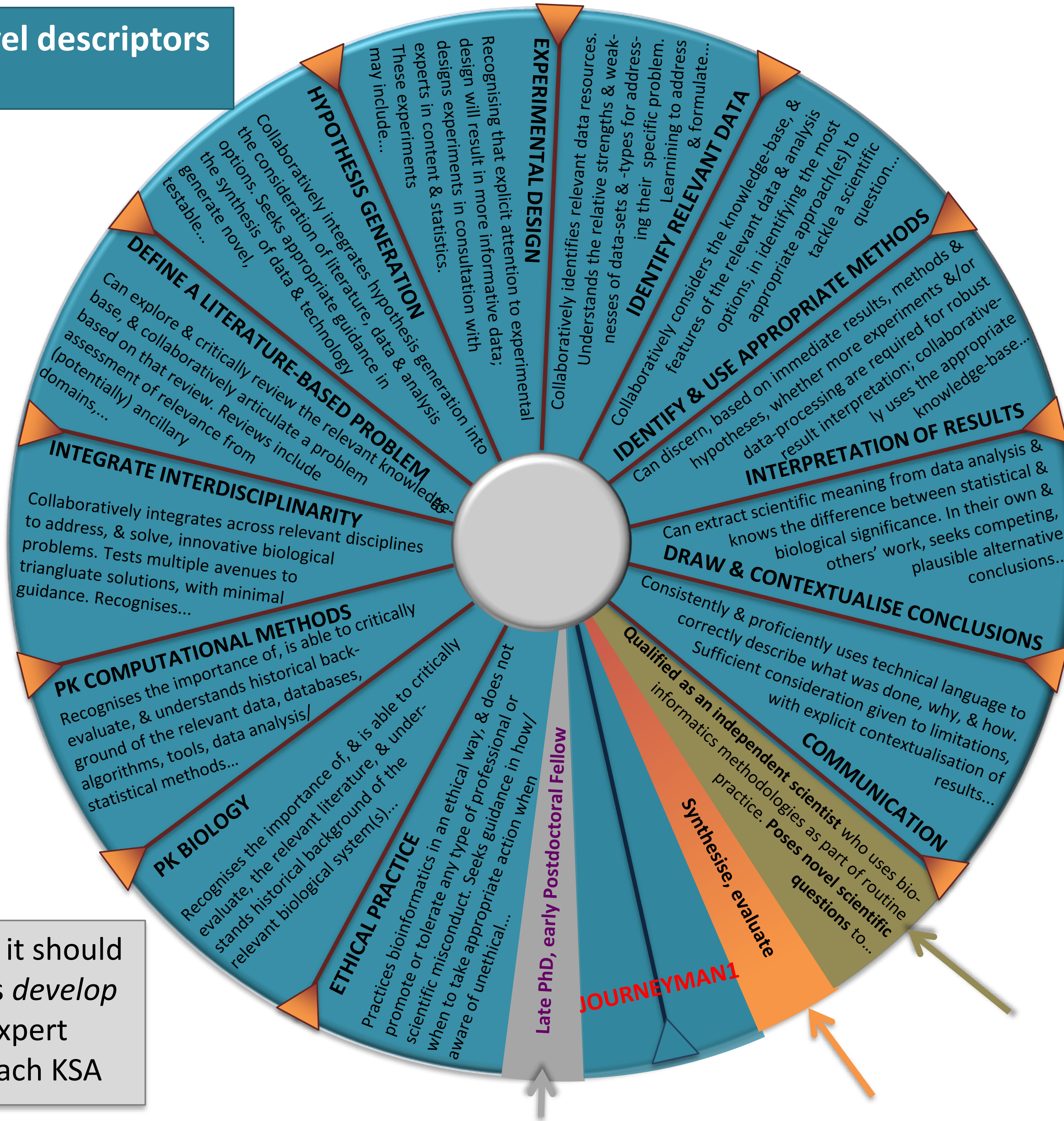
PLDs describe what it should ***look like*** as learners *develop* from *less* to *more* expert demonstration of each KSA

Performance-level descriptors
Apprentice



PLDs describe what it should ***look like*** as learners *develop* from *less* to *more* expert demonstration of each KSA

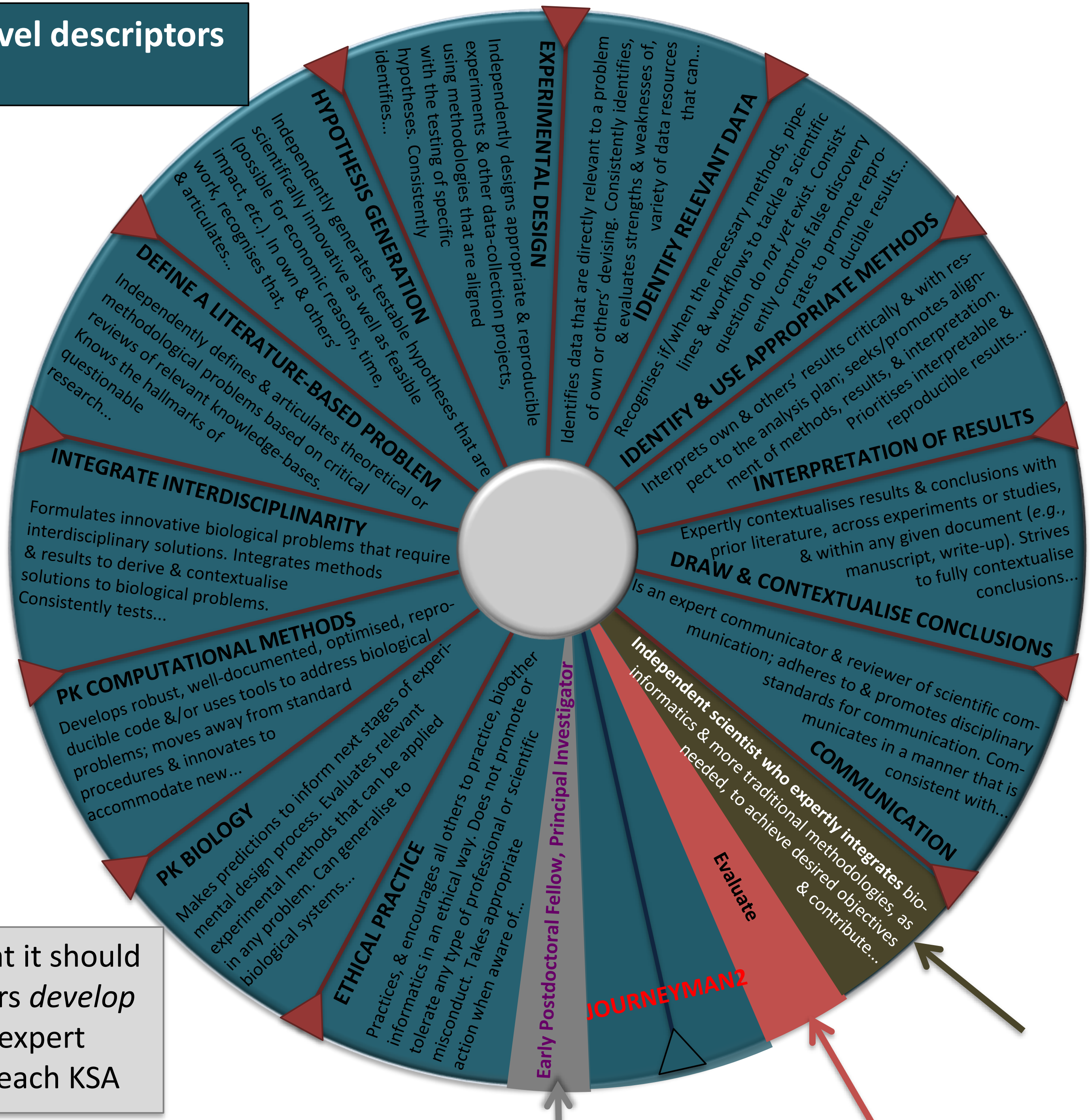
Performance-level descriptors
Journeyman 1



PLDs describe what it should ***look like*** as learners *develop* from *less* to *more* expert demonstration of each KSA

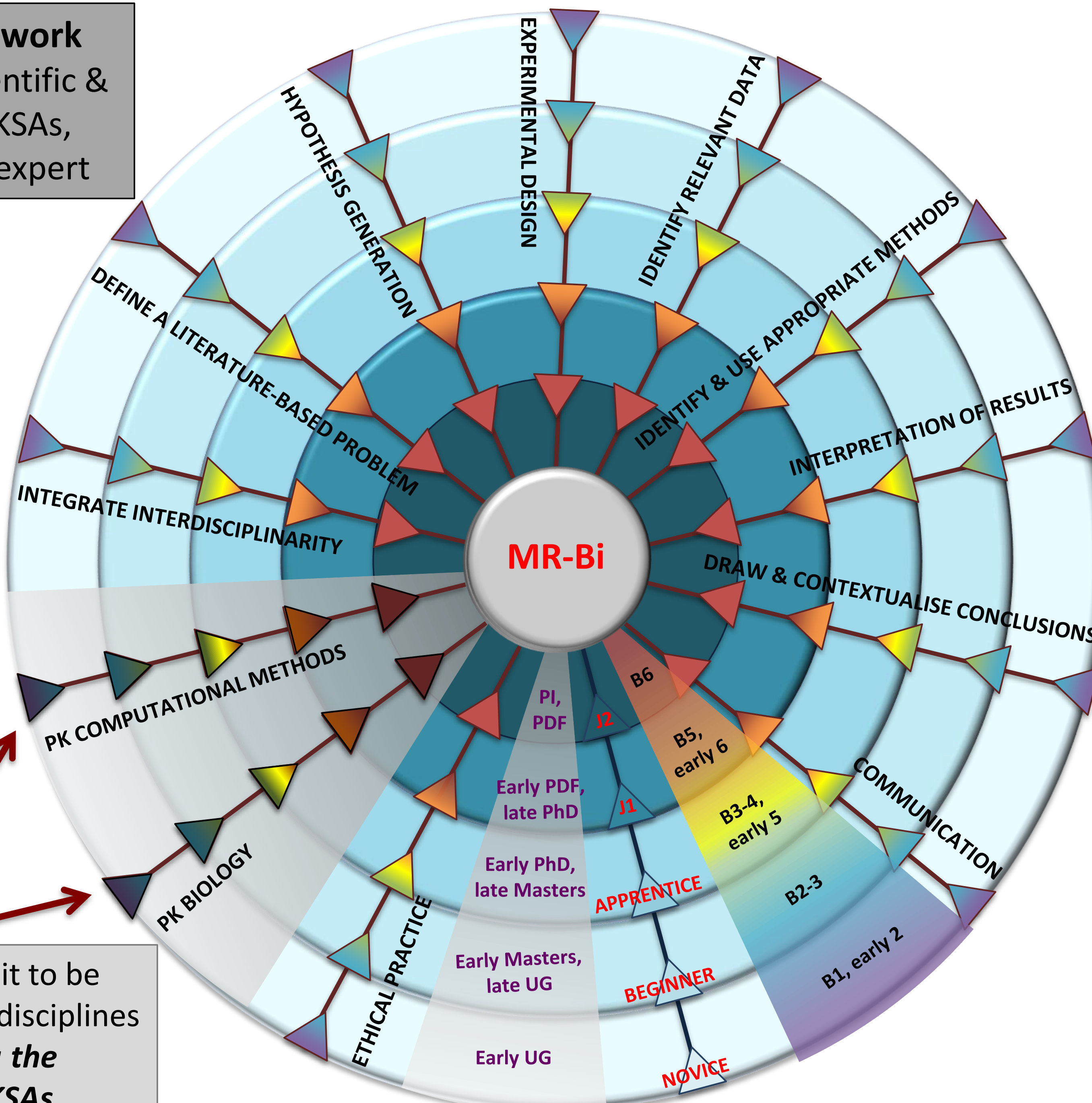
Performance-level descriptors

Journeyman 2



PLDs describe what it should ***look like*** as learners *develop* from *less* to *more* expert demonstration of each KSA

A standard framework for developing scientific & discipline-specific KSAs, from less to more expert



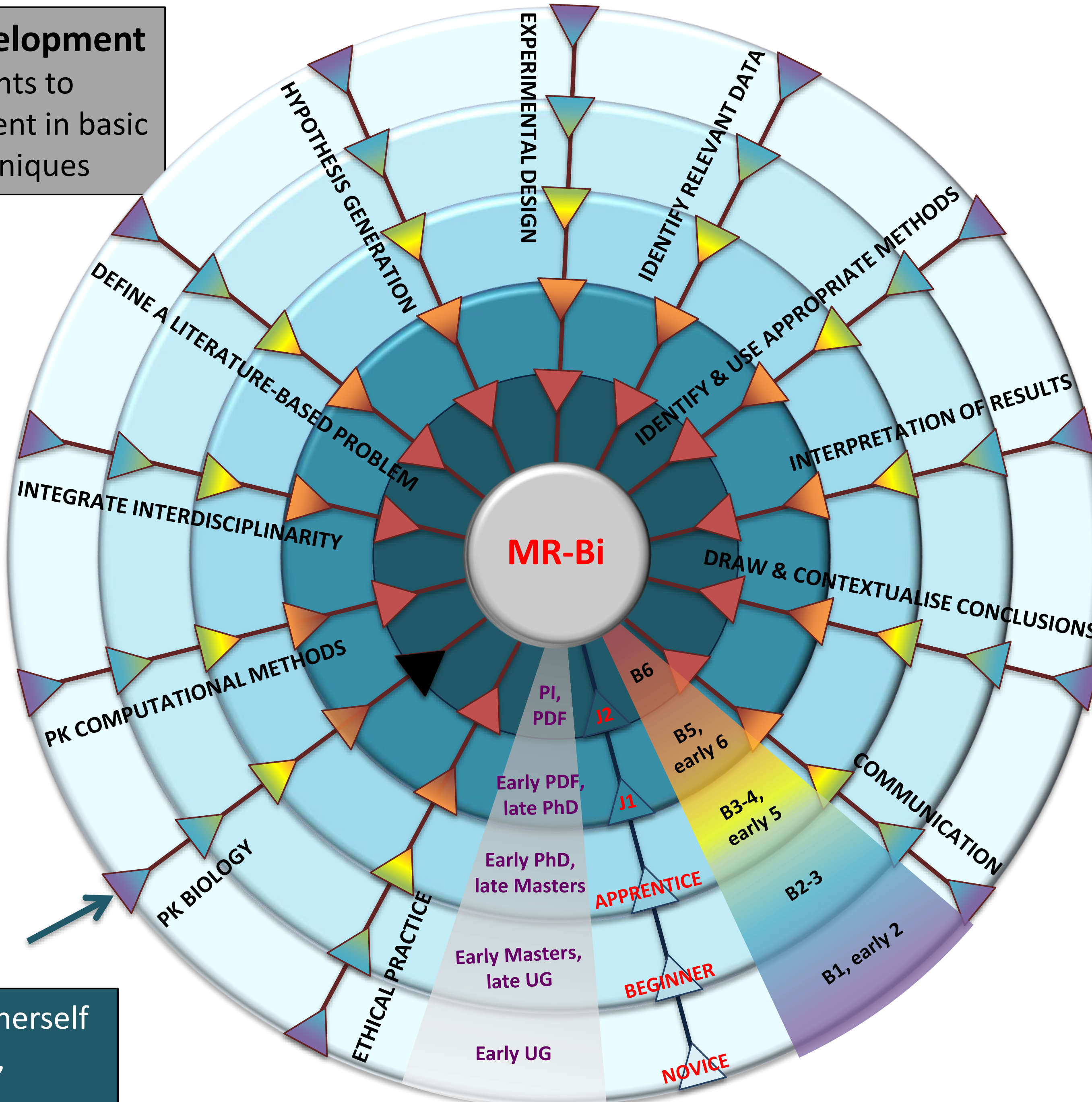
Its structure allows it to be adapted to related disciplines ***simply by changing the discipline-specific KSAs***

APPLICATION 1

Professional development

Professional development

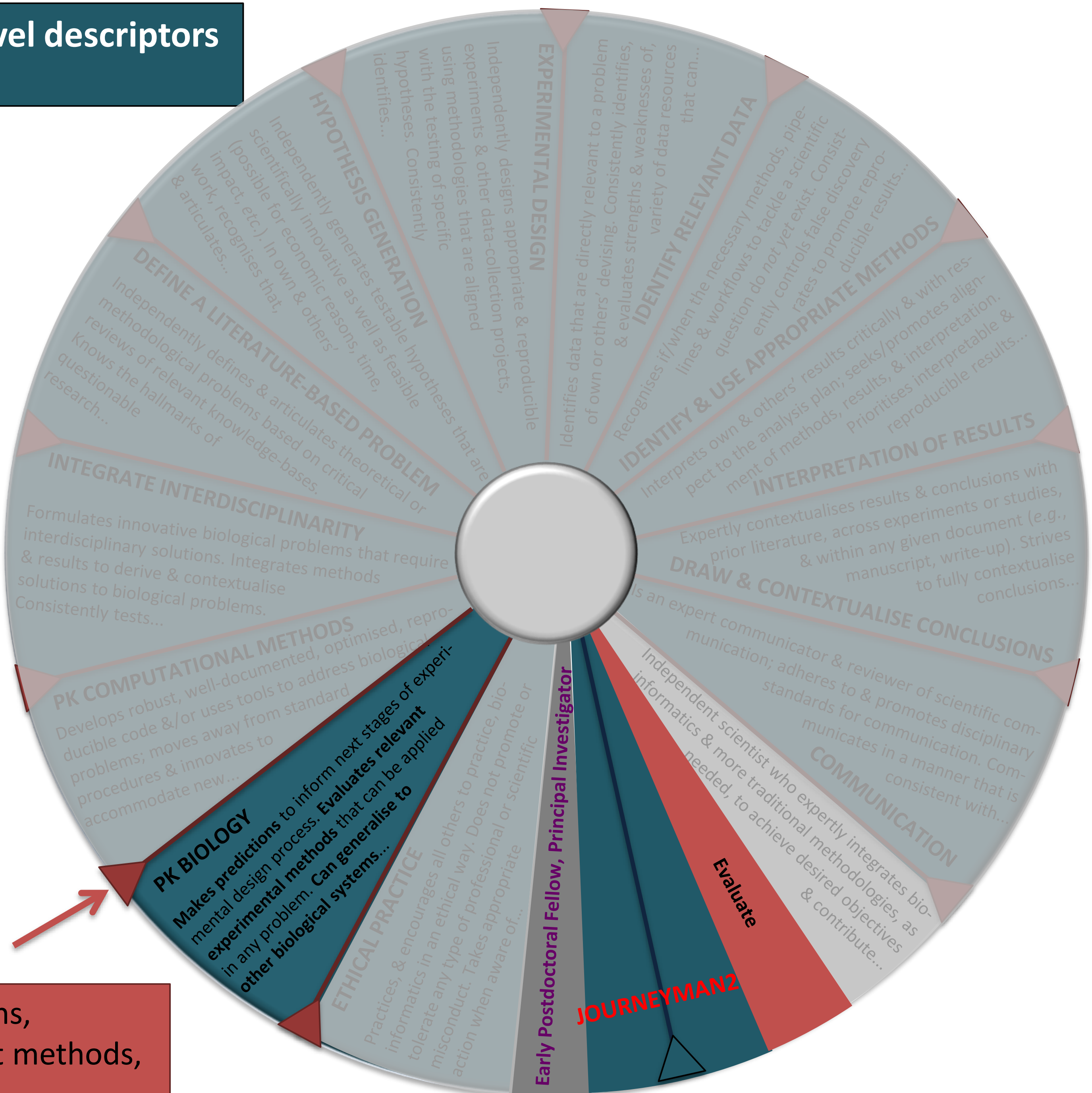
A life-science PI wants to become self-sufficient in basic bioinformatics techniques



Recognises him or herself as a ***J2*** life scientist, someone who…

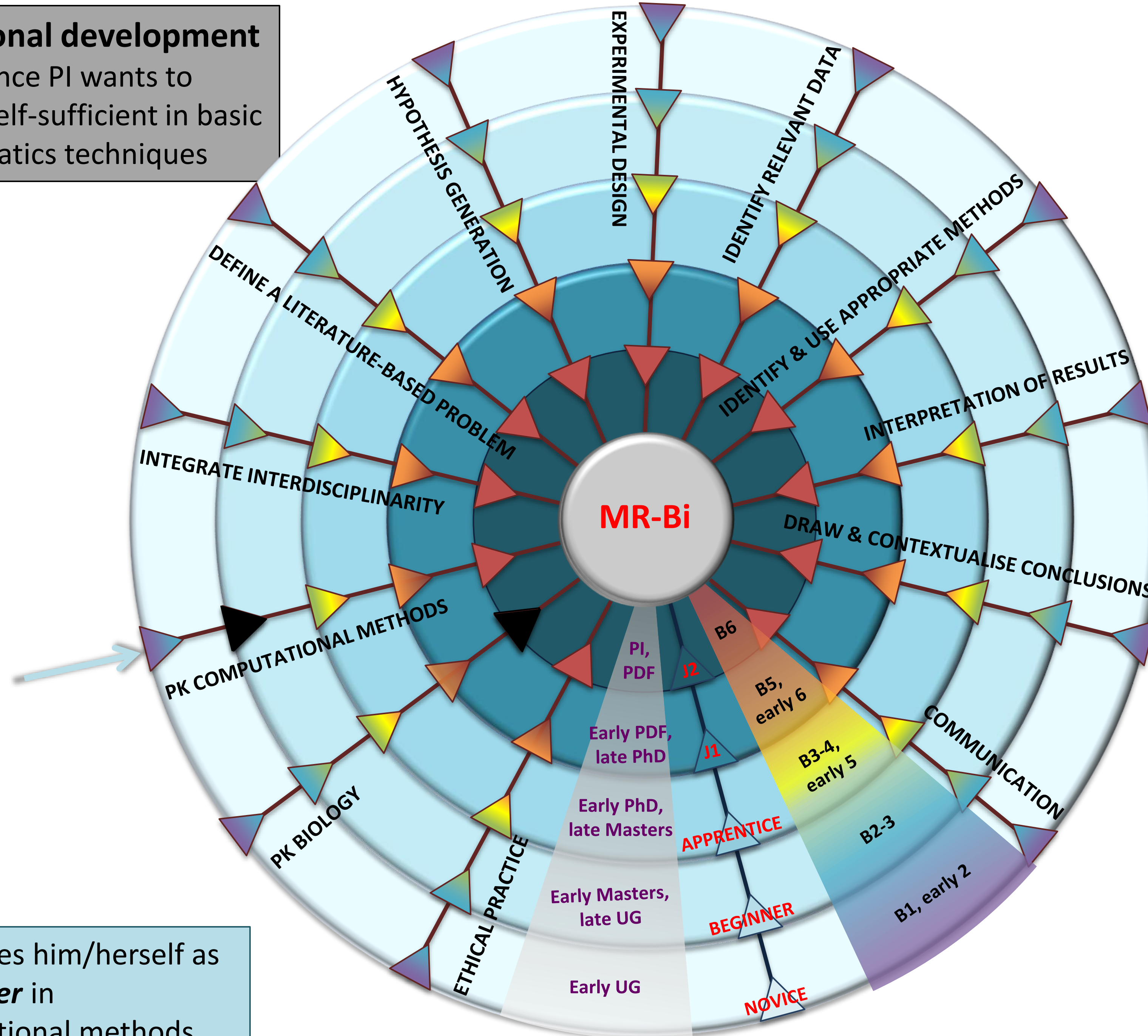
Performance-level descriptors

Journeyman 2



…makes predictions, **evaluates** relevant methods, & can generalise…

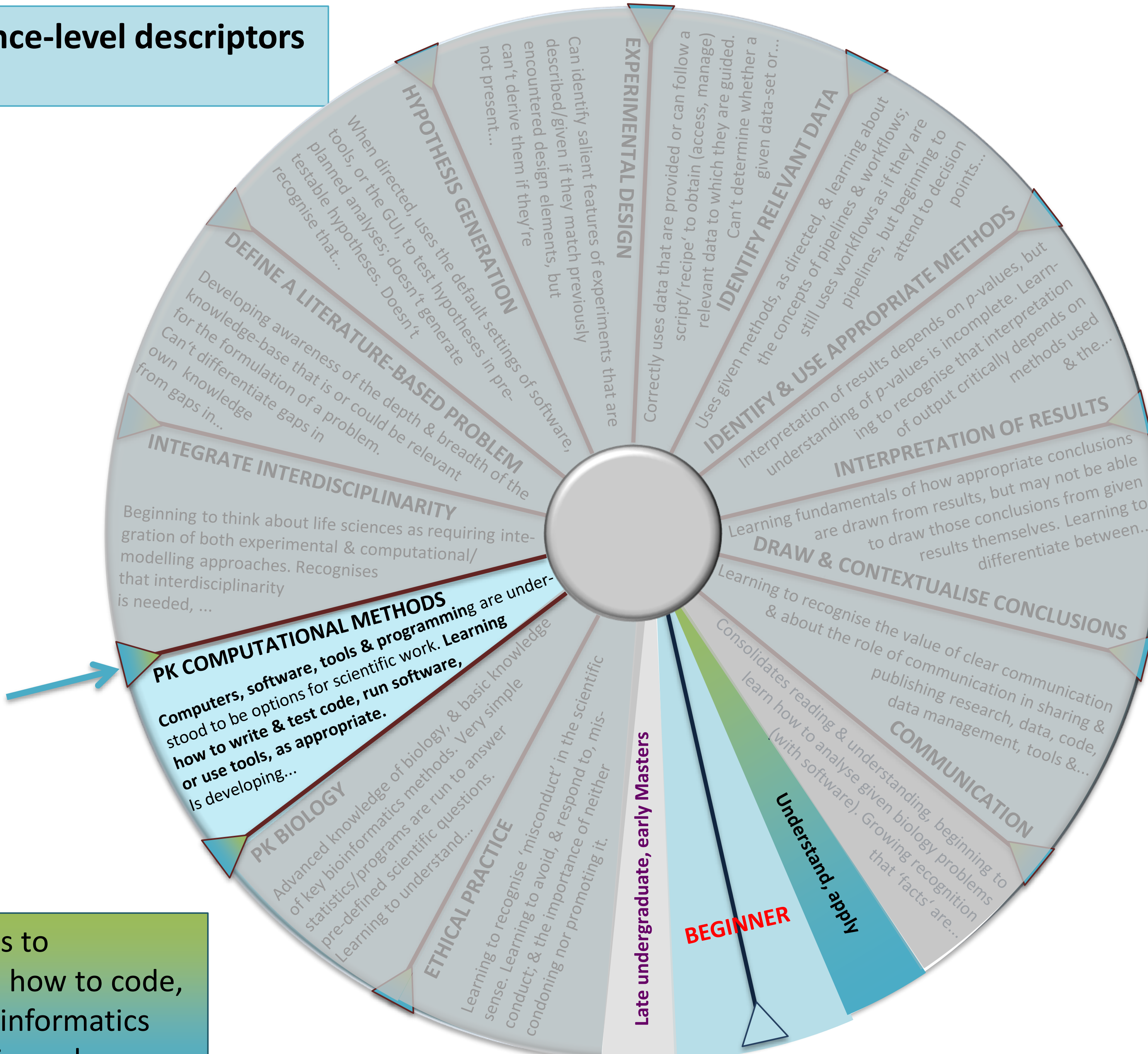
Professional development
A life-science PI wants to become self-sufficient in basic bioinformatics techniques



Recognises him/herself as a ***beginner*** in computational methods…

Performance-level descriptors

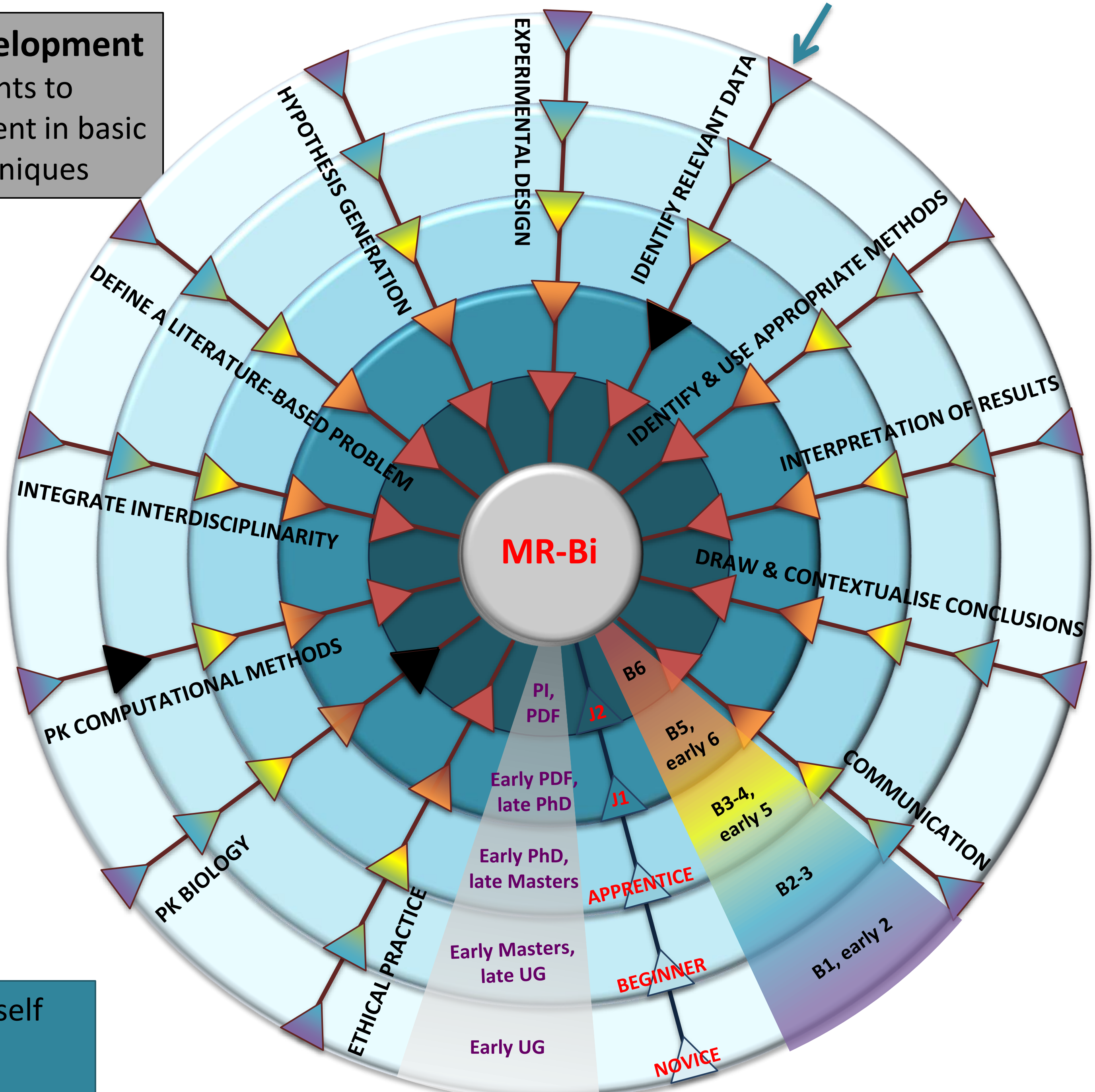
Beginner



…who wants to **understand** how to code, & **apply** bioinformatics tools in their work…

Professional development

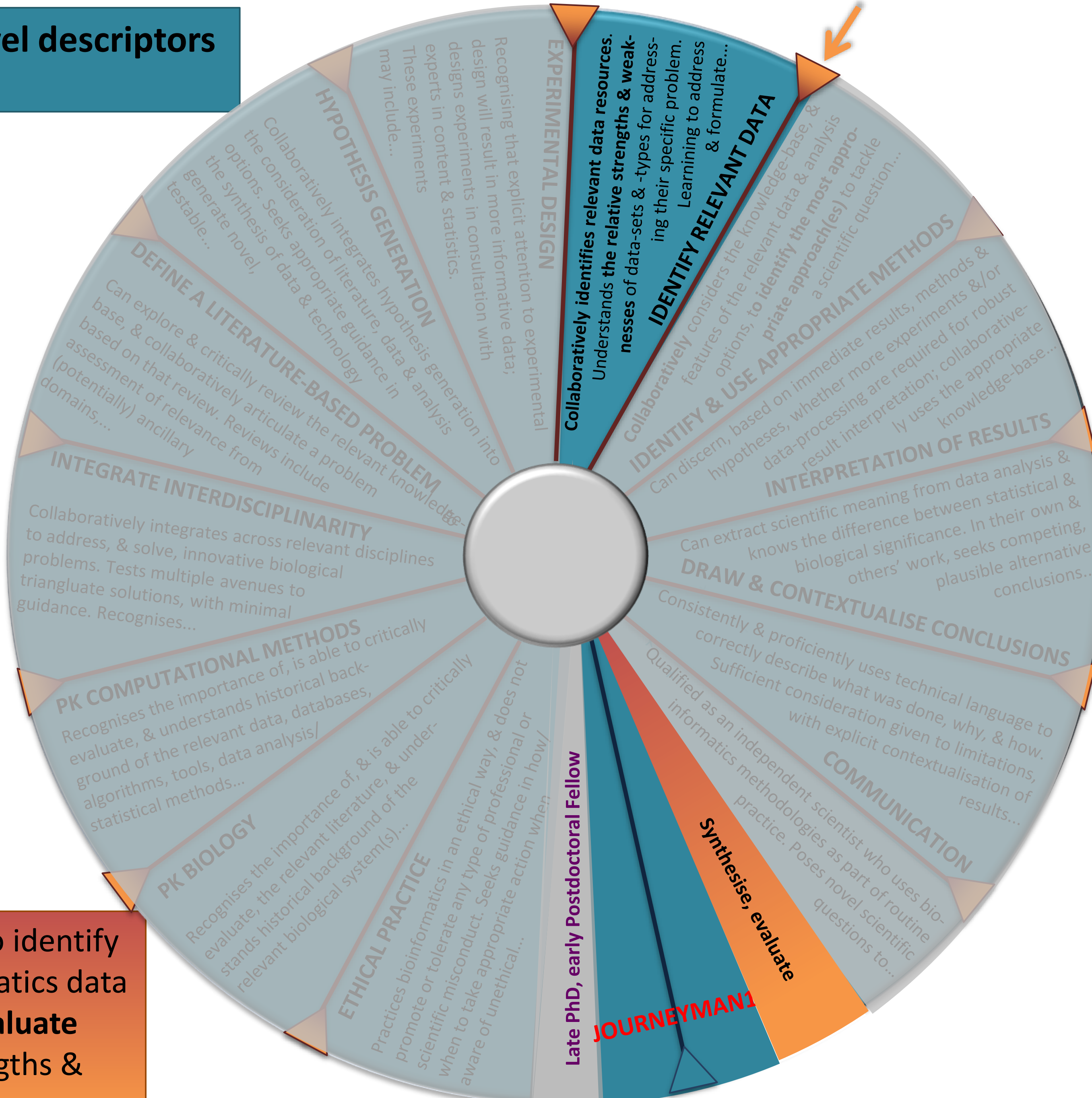
A life-science PI wants to become self-sufficient in basic bioinformatics techniques



Considers him/herself as ***J1*** in identifying relevant data…

Performance-level descriptors

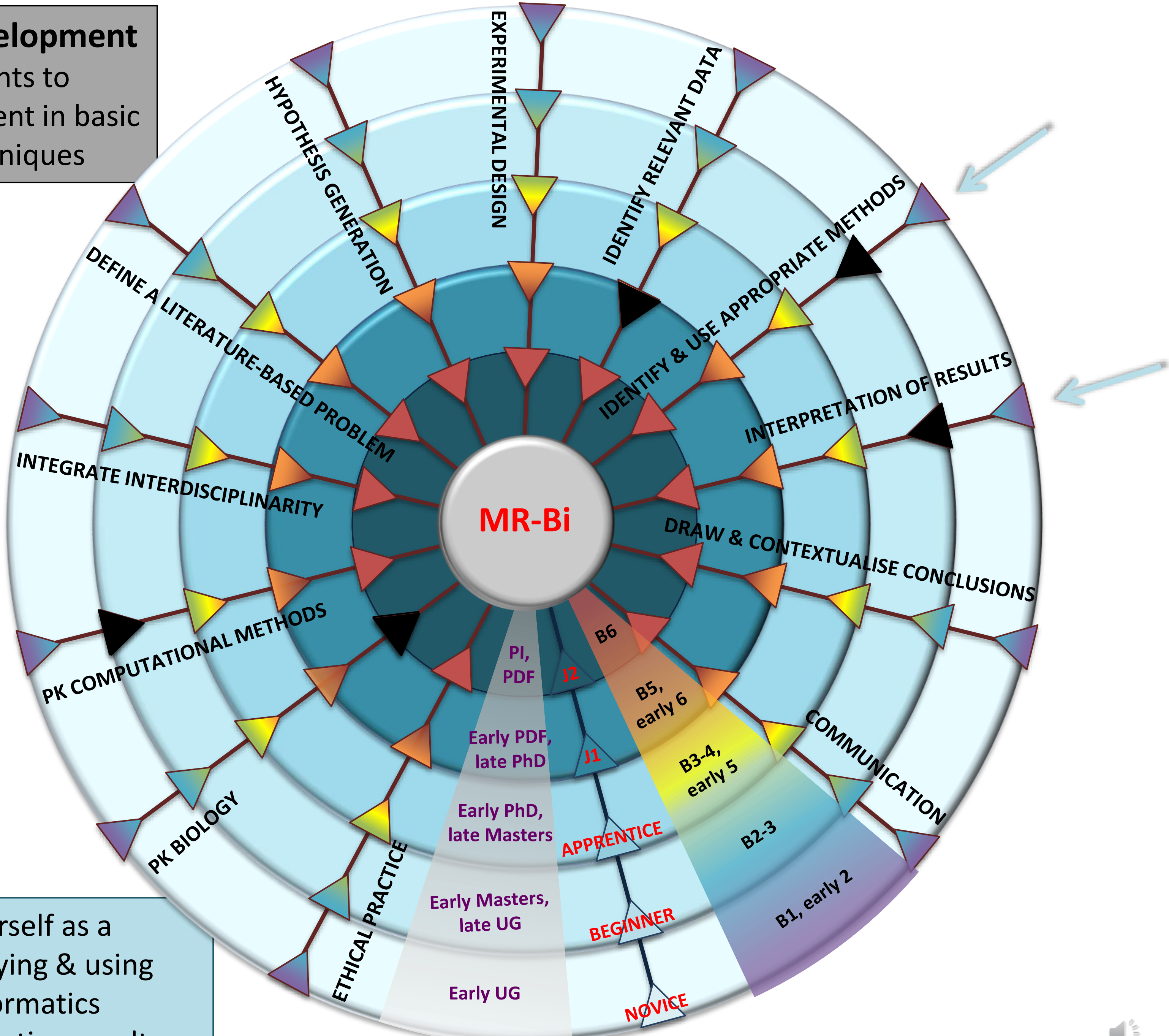
Journeyman 1



…but needs help to identify relevant bioinformatics data resources, & to **evaluate** their relative strengths & weaknesses…

Professional development

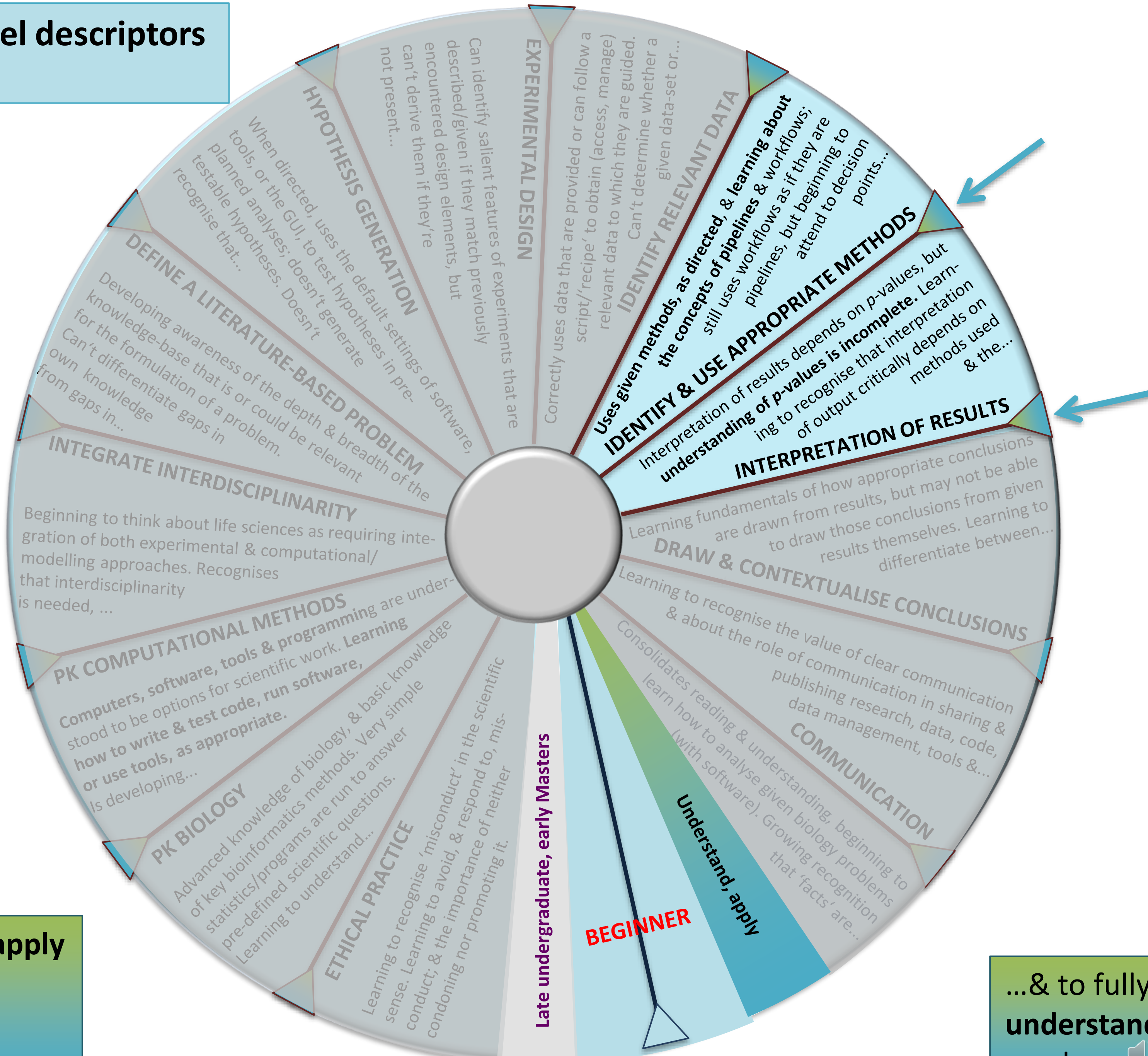
A life-science PI wants to become self-sufficient in basic bioinformatics techniques



Recognises him/herself as a ***beginner*** in identifying & using appropriate bioinformatics methods, & interpreting results…

Performance-level descriptors

Beginner

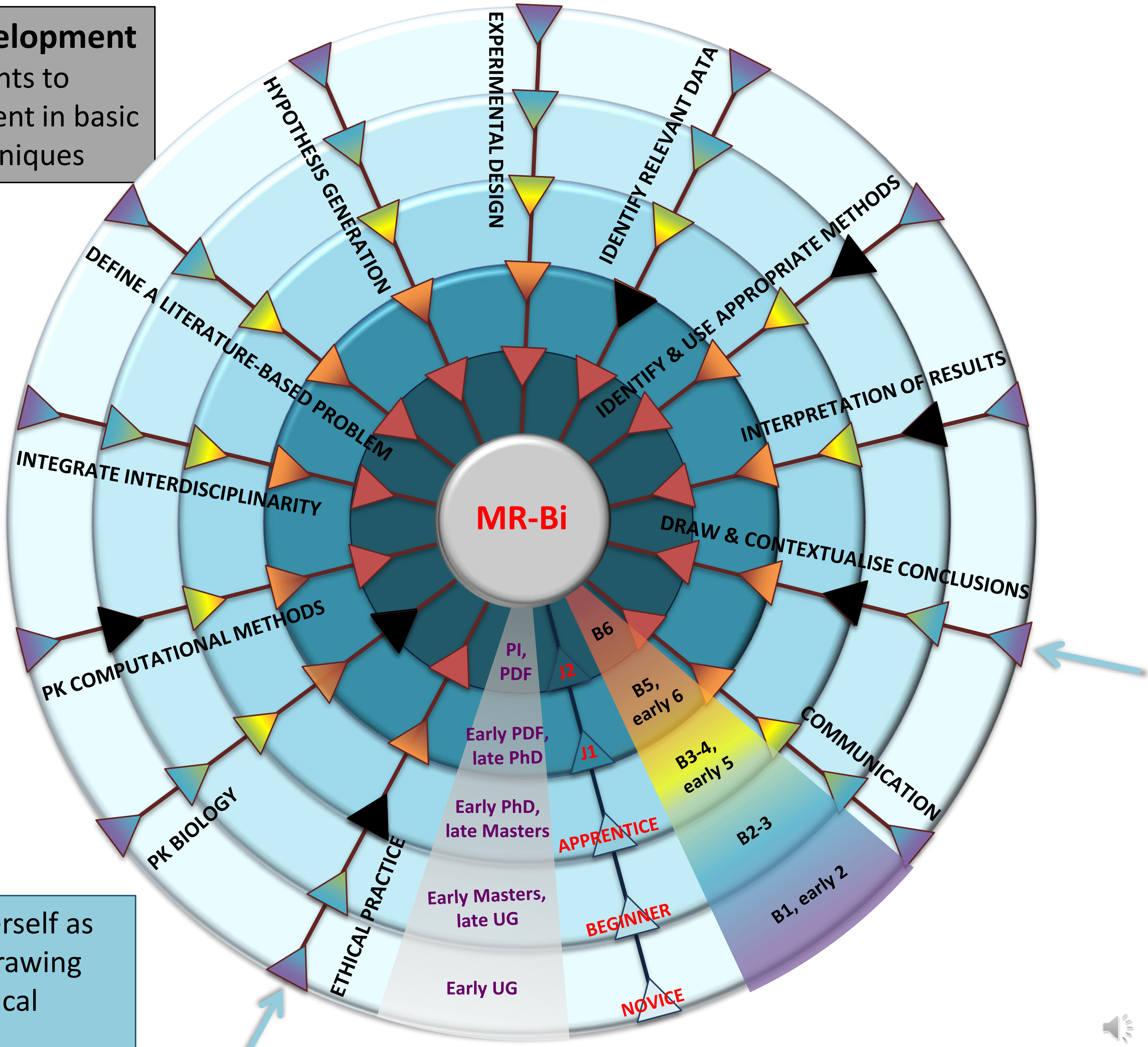


…needing help to **apply** bioinformatics methods & to **understand** pipelines…

…& to fully **understand** *p*-values…

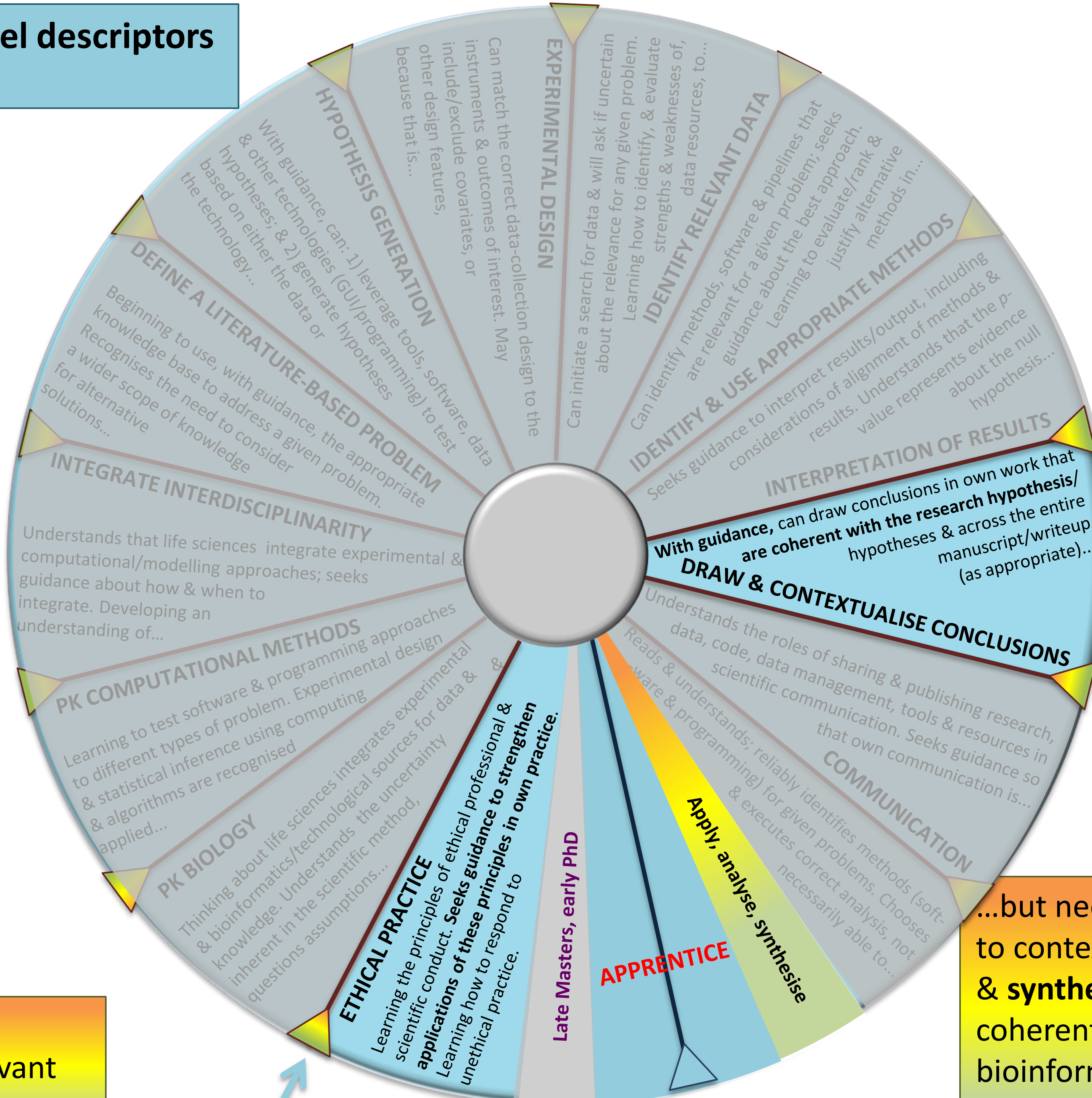
Professional development

A life-science PI wants to become self-sufficient in basic bioinformatics techniques



Recognises him/herself as an ***apprentice*** in drawing conclusions, & ethical practice…

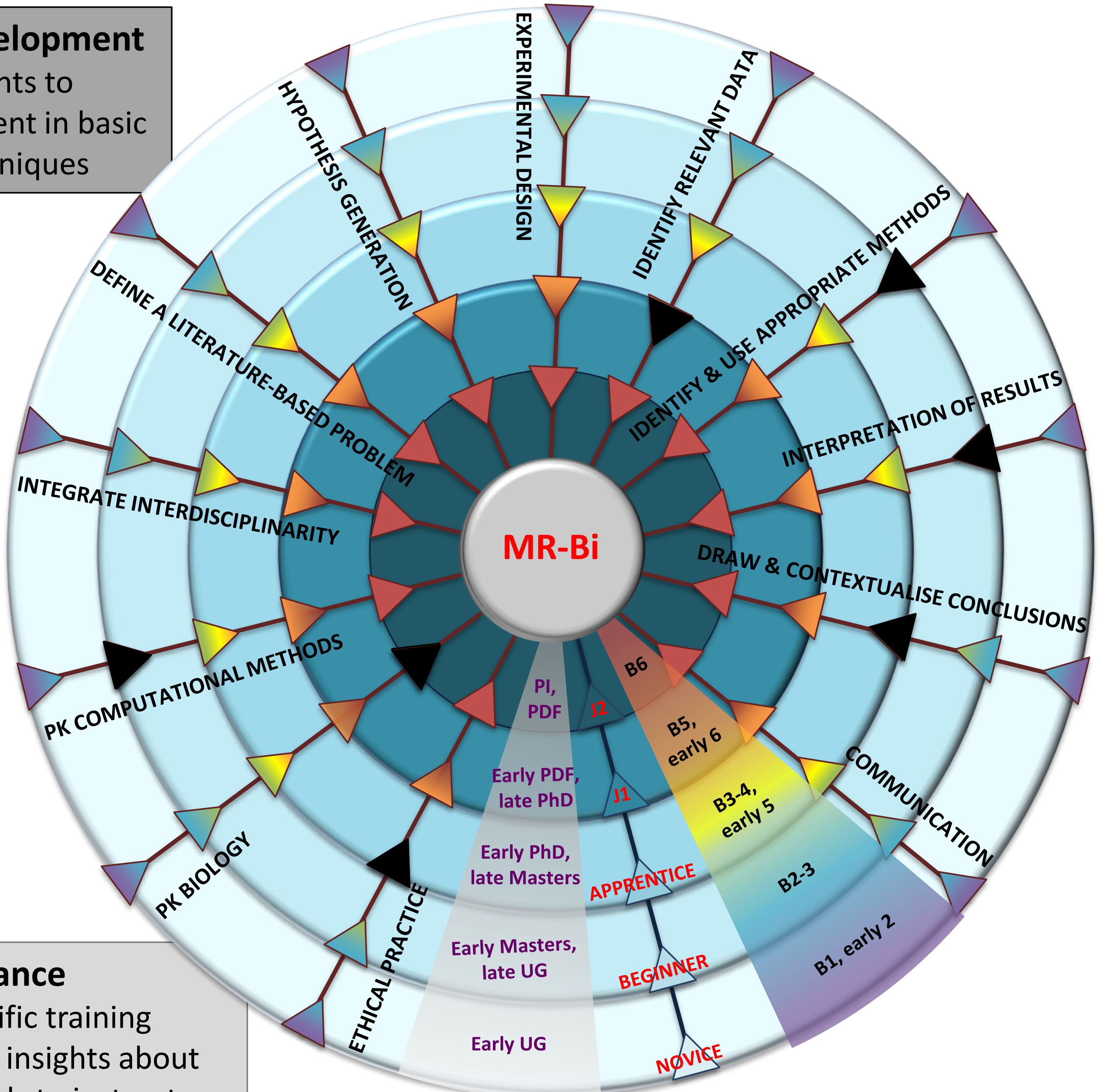
Performance-level descriptors
Apprentice



…but needs help to contextualise & **synthesise** coherent bioinformatics conclusions…

…& to **apply** bioinformatics-relevant ethical practices…

Professional development
A life-science PI wants to become self-sufficient in basic bioinformatics techniques



Tool for self-guidance
Helps focus on specific training needs; provides key insights about this individual's needs to instructor

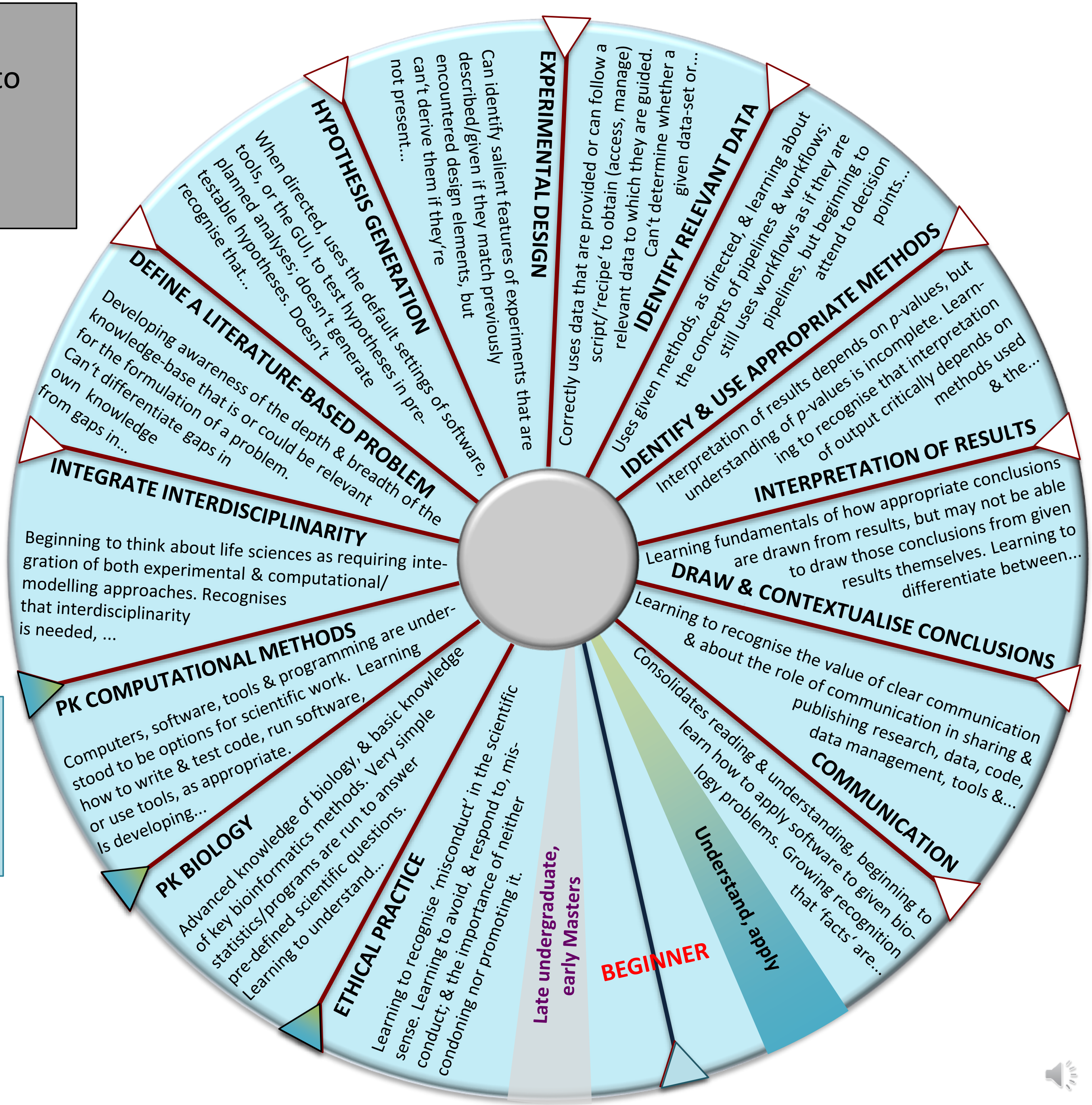
APPLICATION 2

Course design

Course design
A university teacher wants to develop an introductory module for a basic bioinformatics MSc course

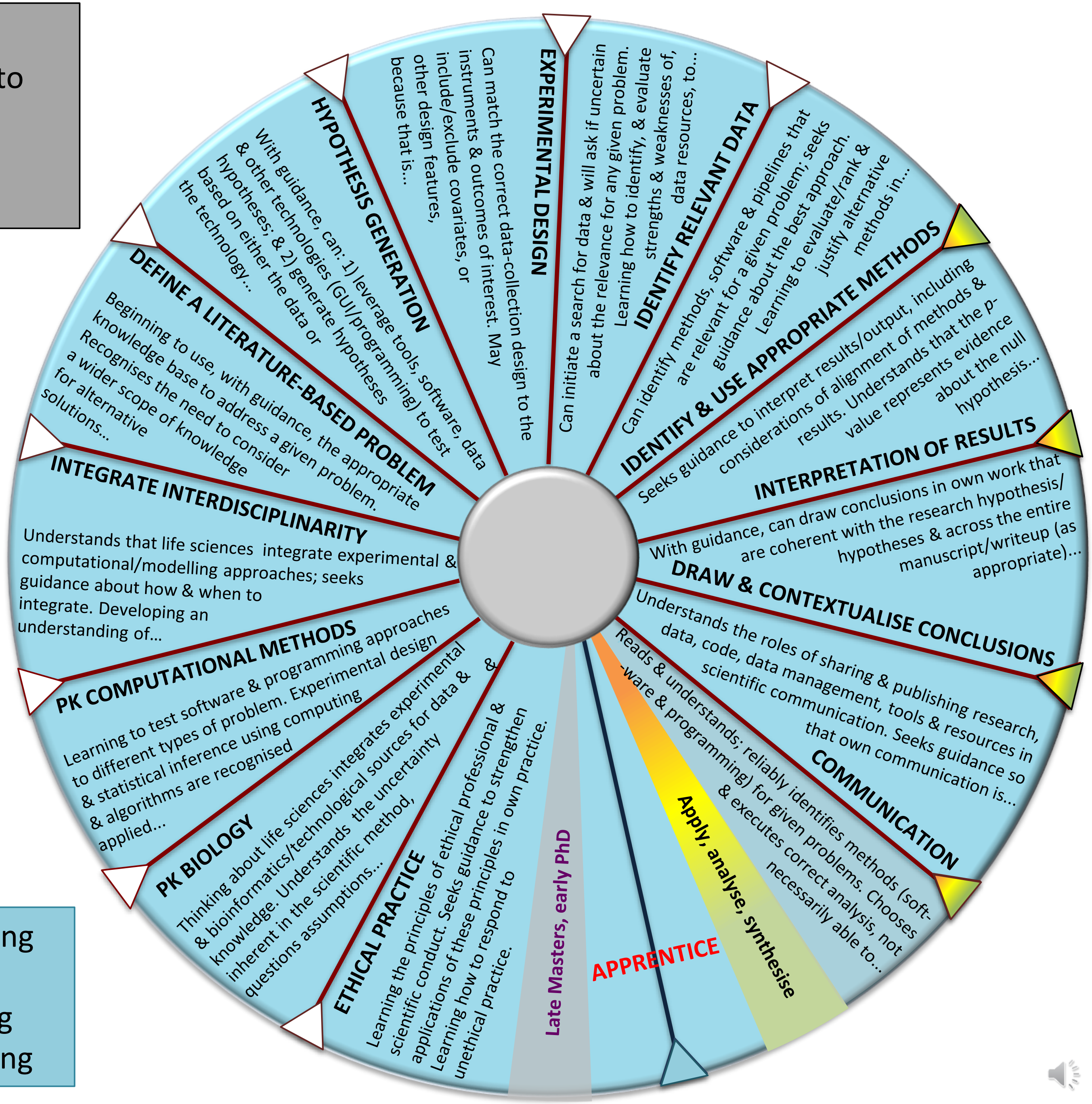
Identify the ***KSAs*** relevant to the course & appropriate ***developmental stages***

Say, from foundational – ***beginner-level*** – biology, computational methods & ethical practice…



Course design

A university teacher wants to develop an introductory module for a basic bioinformatics MSc course

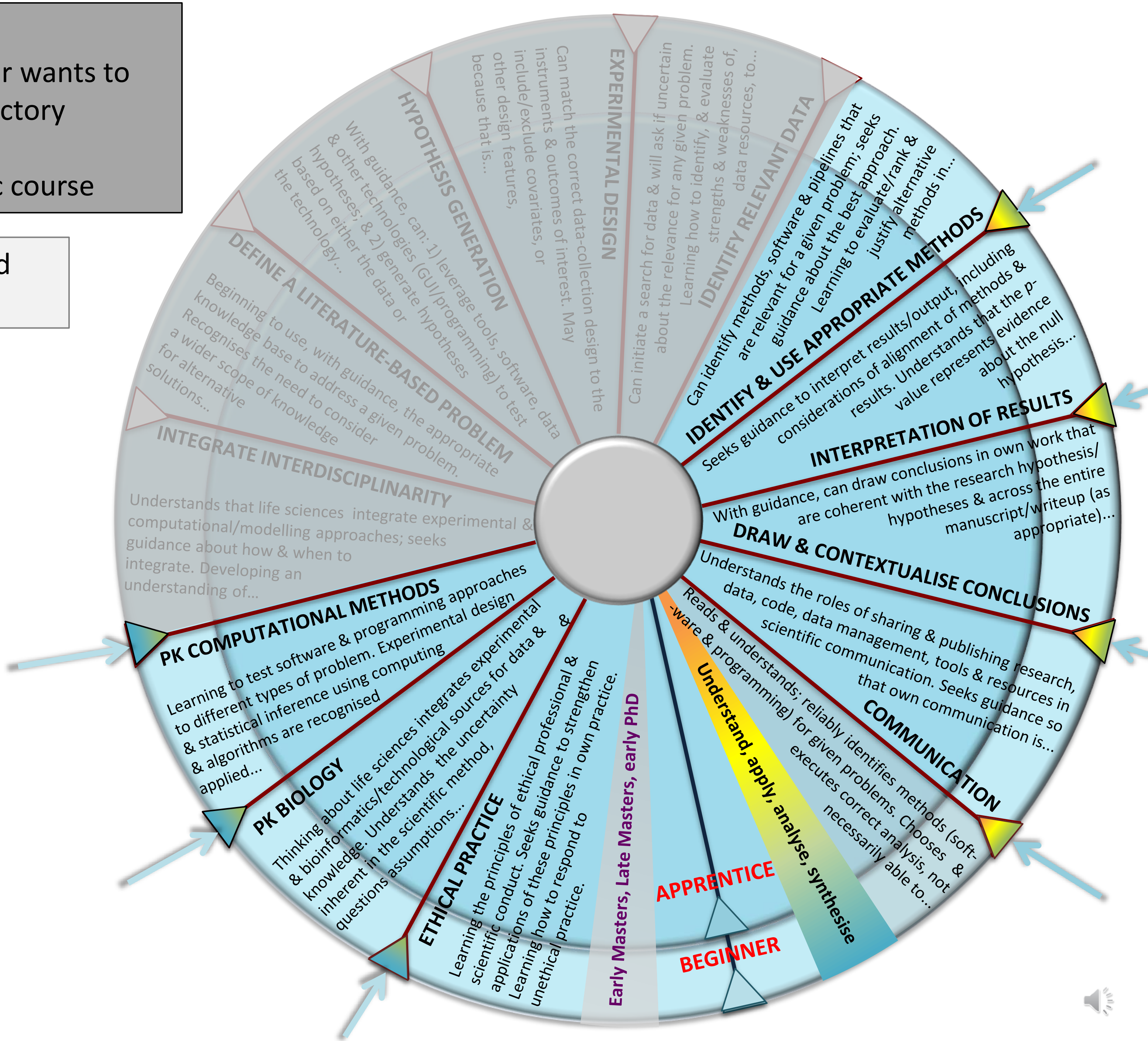


…to ***apprentice-level*** applying appropriate methods, interpreting results, drawing conclusions & communicating

Course design

A university teacher wants to develop an introductory module for a basic bioinformatics MSc course

Follow a structured paradigm…



Course Design
Considerations for trainers

PROFESSIONAL GUIDE

https://doi.org/10.7490/f1000research.1118395.1

Version: 18 November 2020

4 Nicholls' five phases of curriculum design

The backdrop for our considerations of course design is Nicholls' paradigm for curriculum development, illustrated in Figure 2. Its five-phase structure has been briefly summarised by Tractenberg et al.[2], as follows:

1. Select LOs;
2. Select or develop LEs that will help learners achieve the LOs;
3. Select or develop content relevant to LOs;
4. Develop assessments to ensure learners progress toward LOs;
5. Evaluate the effectiveness of LEs for leading learners to LOs.

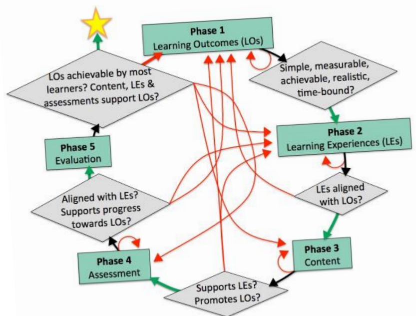


Figure 2. Nicholls' phases of curriculum design & their dependencies. Where these considerations are shown (diamonds). Where these For each phase, key considerations are shown (diamonds). Where these aren't satisfied, that or previous phases should be revisited (red arrows). When all otherwise it is safe to move to the next phase(s) (green arrows). When all considerations are satisfied, the curriculum or course can be characterised, with concrete evidence, as successful (star).

As can be seen from Figure 2, the model's phases are inter-dependent; all are ultimately dependent on the first – defining LOs. Moreover, the phases are iterative: this means that LOs influence later decisions, but later decisions may also reflect backwards, thereby providing opportunities to check for alignment of each phase to the target LOs (in other words, to ensure that successive phases are mutually consistent with, and supportive of, the LOs). Thus, the role of LOs is pivotal: they must have specific characteristics to function, and support each of the other phases as they do. Figure 2 illuminates an important feature of the model: that *LOs are the starting point, and drive all decision-making*. This is just as true for courses as it is for programmes[7]. Missing from the model, however, is the dependence of LOs on a hierarchy of cognitive complexity that establishes a developmental trajectory, like that seen in Bloom's taxonomy. We reflect on this crucial point, and its relevance for course design, in the discussion of each of the five phases below.

4.1 Define intended LOs

Just as for curricula, Phase 1 of course design begins with stating the LOs (as already noted, LOs are explicit statements of the KSAs – and requisite level of cognitive complexity – that learners are expected to achieve, and be able to demonstrate, on completion of a period of instruction). To help formulate LOs, it's important to take a step back and think about what you aim to achieve (*i.e.*, what are your TGs and the KSAs you intend to be achieved?), how you

propose to get there, and how you'll know y…
encapsulated this process in the form of thre…

1. What KSAs are the targets of instruc…
2. What learner actions/behaviours wi…
3. What tasks will elicit these specific…

These questions were originally posed… assessment. Their focus on KSAs – the LOs… creation of relevant tasks (to reveal the… rational development of *appropriate* asse… a framework for, and clarify, *what to ass*… support all phases of course developme… tion of intended KSAs stated in a set of L…

Writing coherent LOs is challenging: … ate (Bloom's) verbs (Figure 1) that exp… and assessable actions, accurately des… ers will be able to do – *and at what*… after instruction.

Various characteristics of, and princ… been published[16,17]: some of these are… (further information and additional… tive LOs is given in other Guides fro… Given their detail and complexity, … the instructional inputs you devise… you intend, it can be hard to kn… explains why it may feel easier t… selecting its content rather than fi… on student learning. Nevertheless, … are consistent with, the characte… helps to promote better alignmen… er outcomes.

In short, when defining LOs, … Specific, Measurable, Achievabl… are they SMART? If they don't t… vised; only when they meet th… Phase 2, as shown in Figure 2. … *structure and context for decis… ers), hence their primary role…*

Learning outcomes

LOs should:

- *be specific & well defin…* KSAs that learners sho…
- *be realistic*: LOs mus… sources available for… abilities, developmen… needed vs. time avai…
- *rely on active verbs*, stated in terms of w… a result of instructi…
- *focus on learning*… not state what ins… learners will be ab…
- *be simple, not c…* statements that…
- *be appropriate*… sessable within…
- *support assessm…* actionable mea… tion by a learne…

EXERCISES

1. Think of a course you currently run, plan to run or have run in the past. Are its intended LOs stated? If not, try to jot a few down.
2. Now consider, are your LOs SMART? If any of them don't meet the SMART criteria, try revising them as follows: select an active verb that can (in principle) be observed & assessed, & complete the sentence, '*At the end of this course, learners will be able to…*' (if it helps, review the verbs listed in Figure 1). It's important to focus here on what learners will be able to do at the end of instruction: *e.g.*, will they be able to describe its content? Explain a concept? Implement an algorithm? Solve a problem? Evaluate results?
3. To determine how well you've structured your LO, visit the Intended Learning Outcome Advisor: https://web.cs.manchester.ac.uk/iloadvisor & paste your phrase into the input box. Press the '*SUBMIT*' button. How well did you do?
4. Consider revising your phrase if the Advisor identified any issues. Consider writing further LOs; test each using the Advisor.

4.2 Select LEs that will lead to the LOs

Phase 2 involves identifying the most appropriate LEs to lead learners to the intended LOs. It's important to appreciate that different LEs can lead learners to demonstrate different Bloom's-level accomplishments: *e.g.*, lectures differ from problem-sets – solving problems helps learners to work with, and manipulate, information rather than passively listening to it; similarly, lab exercises differ from writing computer programs – writing original code affords learners the opportunity to create something new rather than simply following instructions. Some example LEs are listed in Table 1, together with the Bloom's level and the kinds of TG and LO that each may support.

Having defined SMART LOs in Phase 1, Phase 2 thus hinges on choosing the most appropriate LEs to best lead learners towards them: if LOs include, for example, being able *to write a computer program*, then the LEs must allow learners to apply the knowledge they've acquired and to demonstrate that they've written a piece of functional code: *i.e.*, LEs and LOs must be aligned (if they aren't, this

Table 1. *Sample learning experiences & the highest Bloom's level that each may support. Examples of the kinds of teaching goal that such LEs may underpin & the kinds of learning outcomes they may promote are also shown.*

Learning experience	Highest Bloom's levels supported	Example TG(s) *This LE will allow me to…*	Example LO(s) *Learners will be able to…*
Lecture, webinar	Remember, Comprehend	Inspire learners, ignite learners' enthusiasm, clarify/explain a concept, provide an overview, give context, summarise content	· *list* the key points of the lecture/webinar · *summarise* take-home message(s)
Exercise, practical	Apply, Analyse	Help learners digest course materials, solve typical problems, apply knowledge, show how to do things with appropriate guidance, give an idea of how a tool works	· *follow* a set of instructions or protocol · *calculate* a set of results or outcomes from a given protocol
Flipped class	Apply, Analyse	Teach learners how to formulate questions, help learners to memorise new information & concepts, or analyse & understand course materials	· *summarise* the content material · *ask* appropriate questions
Peer instruction	Synthesise, Evaluate	Prepare learners to defend an argument, give learners opportunities to explain things, thereby helping to develop critical thinking & awareness	· *explain* how they solved an exercise · *evaluate* others' choices/decisions · *diagnose* errors in the exercise-solving task
Group discussion	Synthesise, Evaluate	Give learners opportunities to practice questioning, develop new ideas & critical thinking	· *communicate* their own ideas · *defend* their own opinions
Group work	Synthesise, Evaluate	Promote collaborative work & peer instruction, provide opportunities for giving/receiving feedback, & digesting course materials	· *provide feedback* on their peers' work · *share* ideas · *explain the advantages* of team-work
Problem-solving	Synthesise, Evaluate	Promote learner abilities to identify & evaluate solutions, develop new ideas, make decisions, evaluate decision effectiveness, troubleshoot	· *diagnose* faulty reasoning or an underperforming result · *correct* errors

can lead directly to a gap between instructional inputs and intended outcomes, which is one reason why course evaluation to detect such misalignments is so crucial). If LEs don't satisfy this criterion, alternative LEs should be found, or the LOs should be revisited and revised before progressing to Phase 3 (as shown in Figure 2).

KEY TERMS

Exercise: an activity designed to help learners to mentally put into practice learned skills & knowledge

Flipped class: a learner-centred approach in which students are introduced to new topics prior to class; class time is then used to explore those topics in greater depth via interactive activities

Group discussion: an in-class, learner-centred approach in which students discuss ideas, solve problems &/or answer questions, guided by the instructor

Group work: a learner-centred approach in which students are organised into groups (& perhaps assigned specific roles) & are given tasks to perform collaboratively

Lecture: a didactic approach in which oral presentation is used to describe & explain concepts & to impart facts

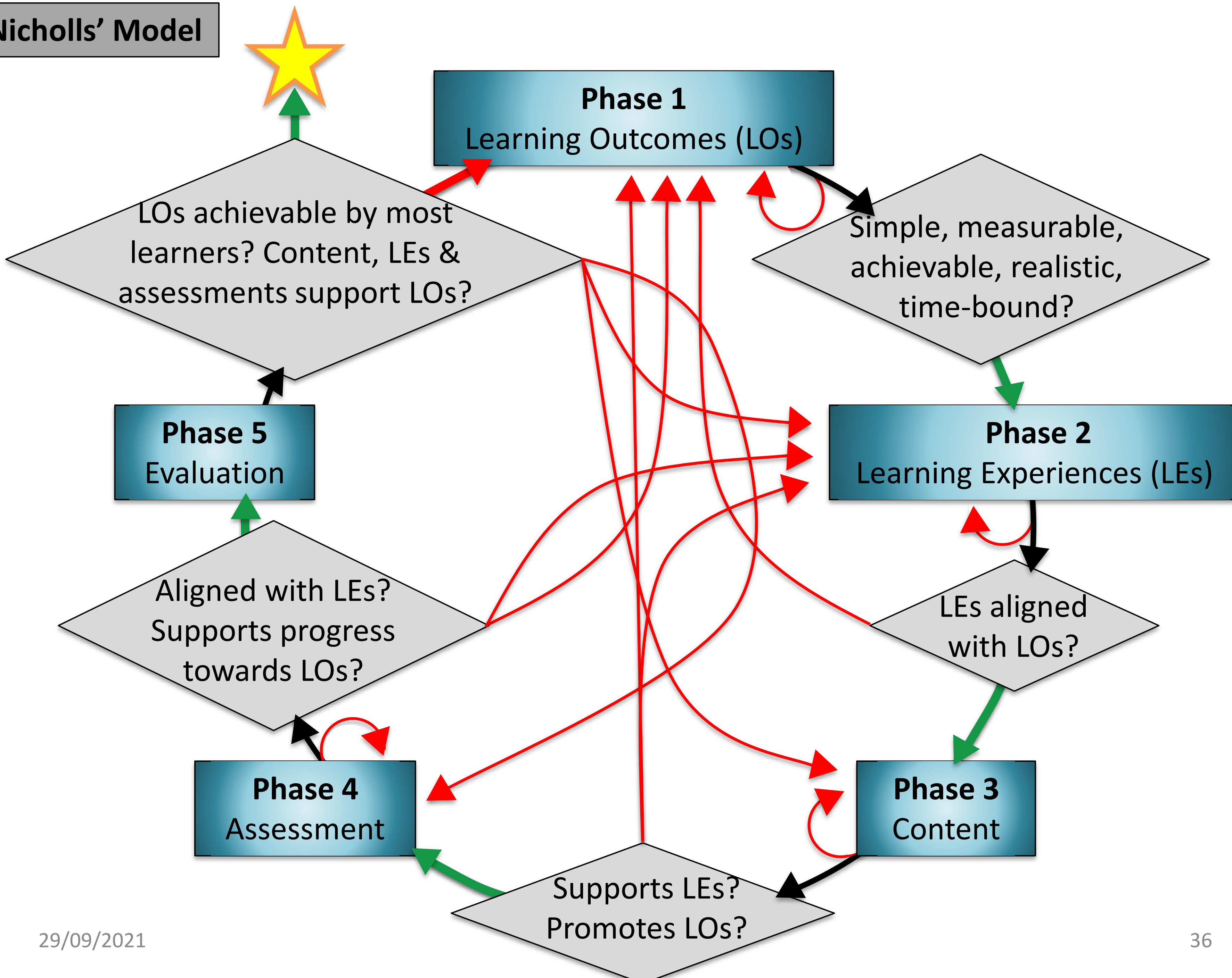
Peer-instruction: an interactive, in-class, learner-centred approach in which groups of two or more students briefly discuss a question or assignment given by the instructor

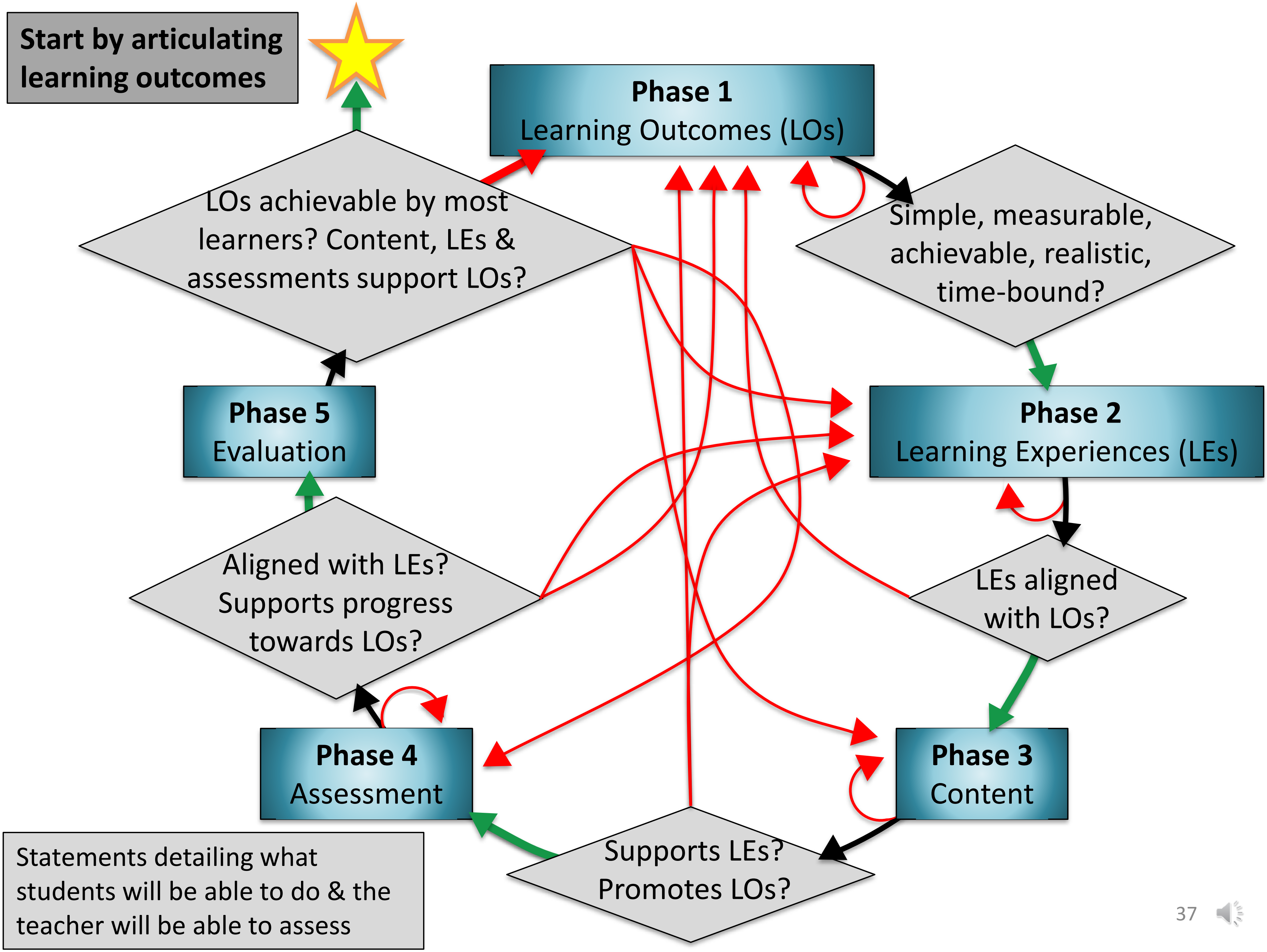
Practical: an activity to put into practice learned skills & knowledge, generally in a lab setting

Problem-solving: a learner-centred approach in which students are required to systematically investigate a problem by building or determining the best strategy to solve it (using what is known to discover what is not known)

Webinar: a lecture delivered online

Nicholls' Model




Start by articulating learning outcomes
Phase 1
Learning Outcomes (LOs)
LOs achievable by most learners? Content, LEs & assessments support LOs?
Simple, measurable, achievable, realistic, time-bound?
Phase 5
Evaluation
Phase 2
Learning Experiences (LEs)
Aligned with LEs? Supports progress towards LOs?
LEs aligned with LOs?
Phase 4
Assessment
Phase 3
Content
Supports LEs? Promotes LOs?
Statements detailing what students will be able to do & the teacher will be able to assess

Learning outcomes
are phrased actively

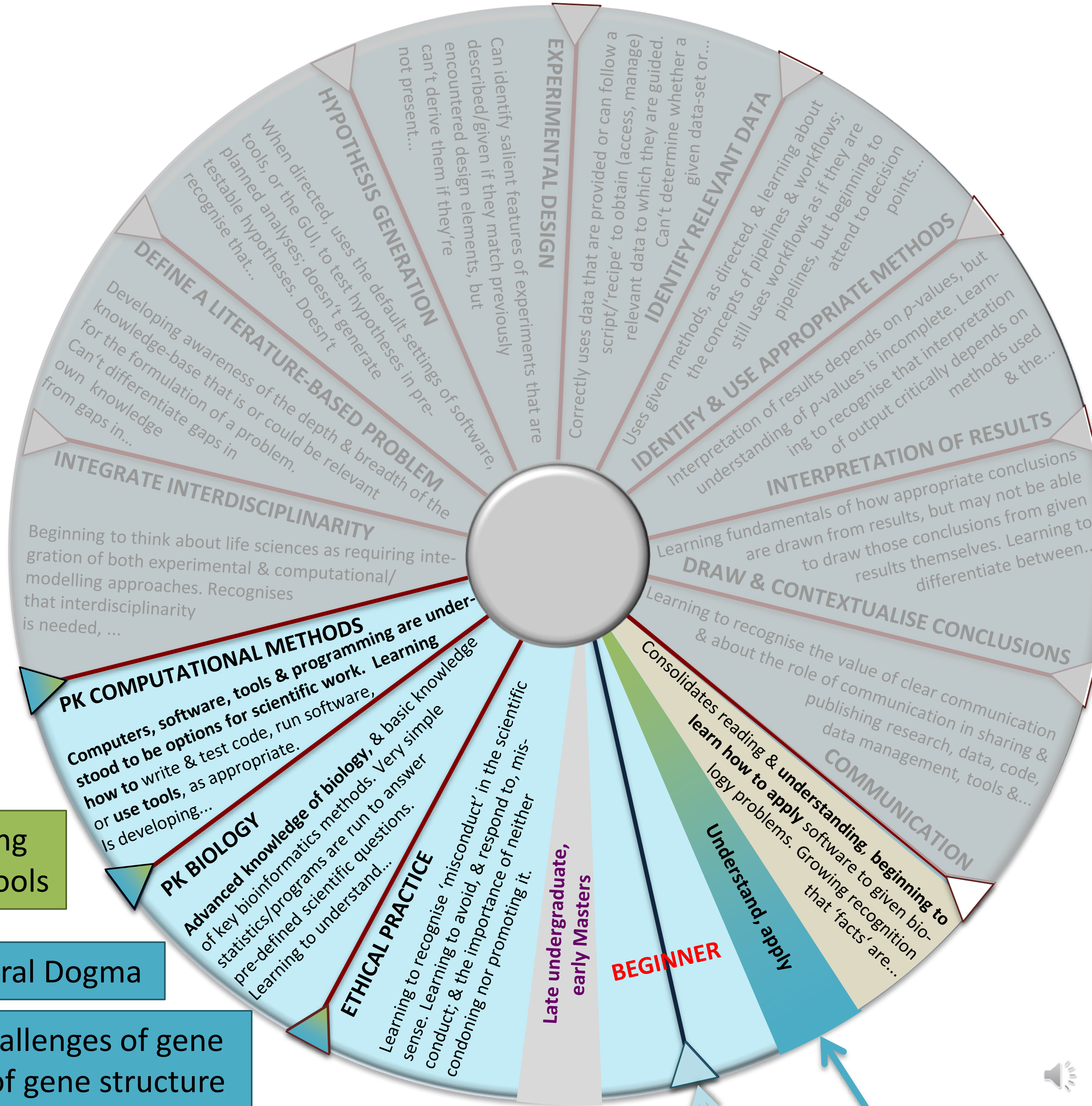
By the end of this course, students ***will be able to***:

LO3: ***list*** popular databases & protein sequence/3D structure analysis tools

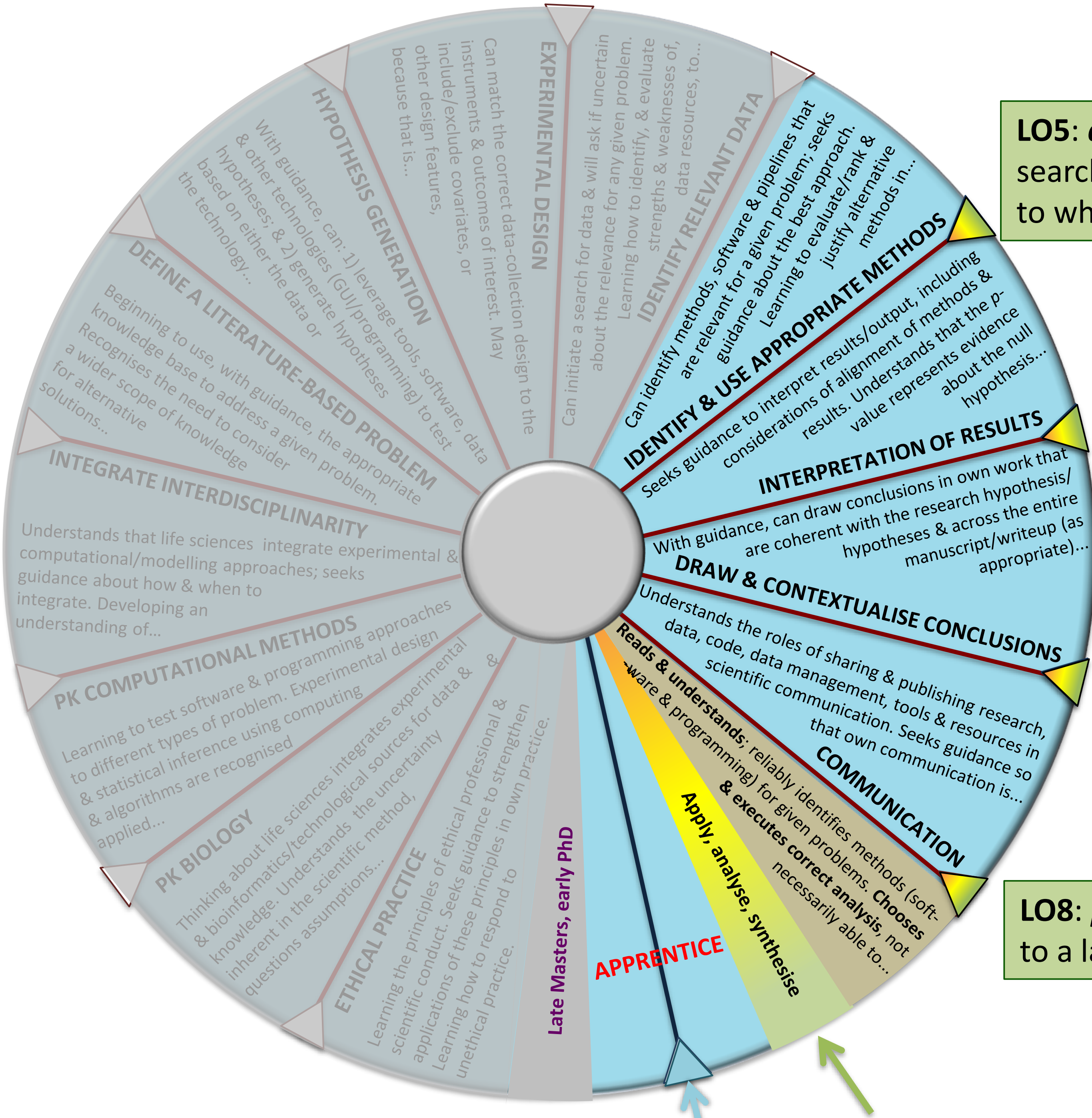
LO4: ***search*** databases using BLAST or other software tools

LO1: ***explain*** the Central Dogma

LO2: ***describe*** the challenges of gene prediction in terms of gene structure



By the end of this course, students ***will be able to***:



LO5: ***apply*** fingerprint & HMM search tools to identify the family to which protein sequences belong

LO6: ***analyse*** search outputs to determine the biological significance of results

LO7: ***synthesise*** results from different analyses to draw preliminary conclusions about the likely functions of protein sequences

LO8: ***present*** results to a lay audience

CONCLUSIONS

- The MR-Bi provides a standard framework for developing scientific & discipline-specific KSAs, from less to more expert
- Its structure allows it to be adapted to related disciplines simply by changing its discipline-specific KSAs
- It's a multi-layered tool with applications in professional development & course design
- It's not as scary as it looks – why not try it?!

THANKS FOR YOUR ATTENTION!

MR-Bi paper, *PLoS ONE*: doi.org/10.1371/journal.pone.0225256

Curriculum Guidelines, *SocArXiv*: osf.io/preprints/socarxiv/7qeht/

Curriculum Guidelines, *F1000R*: doi.org/10.7490/f1000research.1118395.1

MR-Bi slides: drive.google.com/file/d/18fnjKbtzCxHx5ooByHoZ-htFZ6u8eLRu/view

Terri Attwood
teresa.k.attwood@manchester.ac.uk

Allegra Via
allegra.via@cnr.it

Rochelle Tractenberg
rochelle.tractenberg@gmail.com

Jessica Lindvall
jessica.lindvall@nbis.se