Never the Strongest: Reconciling the Four Schools of Thought in System Dynamics in the Debate on Quality

Abstract: We propose a reconciliatory categorization of different schools of thought in the system dynamics field based on different mental models. We suggest these differences arise from the natural and valuable differences in understanding and studying complex systems phenomena and how these confidence-building approaches are understood. We define the four schools of thought; Empirical, Structural, Pragmatic, and Methodological, and suggest four personas that correspond to each: Scientist, Philosopher, Policy Engineer, and Artisan. We recognize that these proposed schools are useful heuristics and not strictly exclusive. We show how a reconciled approach can better serve the totality of Forrester's challenges in his 2007 System Dynamics Conference speech. We believe that by recognizing the different schools of thought - and allowing each to identify its convention on methods, approaches, definitions of quality, aesthetics, and ethical modeling practices, we can best serve the entire field and the pursuit of systems science.

Introduction

On his deathbed, Alexander the Great's generals asked him, "Who shall succeed you?" His dying words allegedly were, "To the strongest." Forty years of war followed as his generals fought each other resulting in four kingdoms; Ptolemaic Egypt, Seleucid Mesopotamia, Attalid Anatolia, and Antigonid Macedonia. All eventually fell to Rome. Likewise, the reign of Emperor Shah Jahan was considered a "Golden Age" of the Mughals in what today is India, but as he fell ill, the Mughul tradition that succession went to 'the strongest' took hold. Jahan's sons rebelled, fighting against one another and imprisoning their father, the Shah, who lived for another eight years. The Mughul Empire soon fell apart.

By contrast, the inheritor of Alexander's Aristotelian influence was the city of Alexandria - founded as a center of learning, science, and knowledge. However, Alexandria's strength was not the excellence of a single academy within it - but the dozens of philosophical and scientific pursuits studied there. Schools reconciled to the existence of one another turned that energy instead to accumulating, cataloging, and furthering philosophy, science, medicine, mathematics, and astronomy.

With the passing of Jay Forrester, the field of system dynamics exists at a similar crossroads. Debates of implicit, if not explicit, inheritance and future direction are already breaking out among competing generals. Who owns Forrester's legacy? Will we proceed down the reference mode of the Macedonian and Mughul Empires - or will we instead seek an alternative reference mode of Alexandria: integration, reconciliation, and mutually recognized co-existence of different schools within the broader field of system dynamics?

We suggest the latter path - and that begins by recognizing at least four, if not more, distinct schools of thought on how to approach system dynamics and the study of complex systems. We believe these

schools arise from differing mental models in the field and the consequences that arise in practice from these differences.

A Brief History of the Quality Debate

The authors sent a comment copy of this note to the known emails of as many living individuals cited in this section as we could identify, asking for "feedback to whether we have accurately captured its progression and details." We provided two weeks for a response and an opportunity to ask for an extension. One individual requested an extension of several weeks which we granted. We received feedback from two individuals.

Alexander at the Ganges

Appropriately enough, Alexander himself began the debate. In 2007 at the System Dynamics Conference, Jay Forrester described the field as being stuck upon an "aimless plateau" consisting of three components. A failure to impact government, "grasping for low-leverage" rather than focusing on high-leverage policies, and the quality of the work in system dynamics (Forrester, 2007, pp. 360–366). Within the context of the last item, Forrester laid out eight criteria for a high-quality paper.

It begins with a clear problem description and an endogenous model indicating the causes of the problem. The model should be of a class of systems with behaviors that fit the class. Policy analysis should be novel, defendable, and prepared to offer solutions and explain why policy resistance will form and how to overcome it (Forrester, 2007, pp. 365–366)." For a full description of the eight criteria, please see Table 3.

We note that as we review the quality debates as they occurred, increasingly, participants veered away from addressing these eight specifically, often supplying their own criteria. However, we will return to these criteria in the discussion section in Table 3.

Early Perspectives and Seeds of the Debate 2007-2017

Early response to Forrester focused on the three points he made where system dynamics was failing: impact on government, high leverage policies to solve big problems and quality of the work. Discussion on the first two points faded, and the focus on quality shifted to mean less on the criteria Forrester spoke of and more personalized takes on what should constitute quality in the field.

For example, Barlas, in 2007, agreed with Forrester on the importance of quality – but saw the ability to correctly model high-leverage policies, which he termed "big policies," as a second-order effect of high-quality creation of small models. Barlas flips the script on Forrester's example of the irrelevance of data fitting to historical time series data saying that it is imperative to "quantitatively measure and test such pattern fit and present the results as quantitative/empirical evidence of model quality(Barlas, 2007, p. 471)." Barlas also mentioned that the bottleneck to reaching Forrester's goal of improved quality was through university education(Barlas, 2007, p. 472), a theme frequently revisited in the debate.

Homer has written a series of articles on this topic. At first, he disagreed with Forrester's assertion that a radical break was needed, even while acknowledging that quality was a concern (Homer, 2007). Six years later, however, he came to accept the need for a radical break under a hypothesis that the field suffered an identity crisis of inability to project the "' sameness' as other modeling disciplines have

managed(Homer, 2013, p. 125)" and the lack of "explicit standards" that would lead to the "reject[ion] of chaff based on the strict application of the standards(Homer, 2013, p. 126)."

Warren took up the quality plank of Forrester's call but in a different vein than Homer providing an early view of the split that was to come. In contrast to narrowing the aperture of conference papers, Warren argued for including the many practitioners successfully using SD in the ways Forrester described. Warren's premise is that there was evidence that many successful practitioners existed in the field but were not publishing in academic journals or conferences because of the demands of their work (Warren, Kim, 2014, p. 2). Instead, Warren suggested the way to improve the quality perception was to create a body of knowledge of high-quality model structures, sub-structures, and existing models to allow practitioners to leverage with clients(Warren, Kim, 2014, p. 18).

In 2013 a group of 20 experts in System Dynamics, among them past Presidents of the Society, conducted a working session to identify 72 best practices sorted into six categories(Martinez-Moyano and Richardson, 2013). Moreover, based on a request for a better scientific understanding of how scientific fields grew, Richardson responded with an exploratory model on the ramifications of quality related to growing a scientific field(Richardson, 2014). Richardson and Homer joined forces in 2017 with a note in the SDR investigating accompanied by a simple model of two methods to increase membership in the field: 1) suppress low quality, 2) improve outreach, and 3) improve mentoring (Homer and Richardson, 2017, pp. 341–342) The exploratory model concluded that suppressing low-quality work might show an initial benefit but at a risk of driving away enough members to either cancel out or exceed the benefit of improved quality(Homer and Richardson, 2017, p. 343).

The Successor States Emerge: Winter Camp 2017

At the 2017 System Dynamics Society Winter Camp in Albuquerque, NM, George Richardson presented "Confidence in exploratory models." In the small audience of no more than a dozen individuals were David Keith, Asmeret Naugle, Erling Moxnews, Ignacio Martinez-Moyano, Brad Morrison, John Sterman, George Backus, Len Malczynski, Sara Pete, and Timothy Clancy. What follows is based on the notes made at the time by one of the authors as a personal observation.

Richardson prefaced his presentation by saying he intended to offer a "provocative viewpoint on the power and use of exploratory models – even if there is no data for the problem." He made the presentation believing that the field was straying from Forrester's intent, focusing on optimization and data fitting. His central premise was that exploratory models could still be high quality even if they were not numerically precise or quantitatively sophisticated(Richardson, 2017). Among many criteria presented were that clearly defined problems representative of a class of problems presented opportunities to vividly link structure, date, and behavior. Equations, parameters, sensitivity runs, and policies should be represented and explainable as real-world mechanisms recognizable to practitioners operating within the system rather than abstracted mathematical notions. After iterative modeling efforts, conclusions should be stated clearly and boldly with real-world implications and indications to look for but also humility and openness to error and improvement (Richardson, 2017).

From this presentation, a great discussion followed, which saw the articulation of three of the four schools we identified, as retained by notes taken contemporaneously at the time of the discussion. Richardson had just articulated the structuralist position. Clancy added that exploratory models should

make explicit the intended audience, the perspective, and bias of the modeler, the boundaries and reasons they were selected, and the definition of confidence. A good exploratory model would manifest many different behavior modes – encompassing the behavior modes found within the class of problems even if they include plausible counter-factual to what historically happened—agreeing with Richardson that visual structure, with graphical plausible real-world causality linked to behavior, is crucial.

Sterman pushed back strongly that models should not focus on classes of problems as that may be misleading, but instead, they should focus on a case, using real-world data and nothing more. Iterative model building has a place – but it should not stop there and must eventually confront real-world data. Moreover, to distinguish training model development, which is easy work, with rigorous testing of the model and challenging it with modern mathematical methods. In a reply that previewed his 2018 reflection (Sterman, 2018), Sterman laid out the empirical case: "We must raise the quality of our work, and this includes raising at our barriers to entry to ensure we are getting the best in the field. By conducting high-quality, well-regarded research work on meaningful problems, we will draw talent. The field has moved forward from fifty years ago and now includes data science, econometrics, statistics. We must be incorporating this hard work (pre and post modeling) into everything we do and demanding it in the papers we accept."

Malczynski offered what we would come to recognize as a pragmatist perspective that system dynamics should not ignore emulating Excel in enabling low-level employees to rise in respective organizations because they could better understand the problems facing them, frame them, and solve them. Ensuring many individuals enter their firms with system dynamics knowledge that helps them frame today's problems and solves them gives us the chance to insert leaders for the next generation amenable to system dynamics.

Backus was the only one to touch on Forrester's original three points unrelated to quality. The Winter Camp and Society should focus efforts on large global problems, not just climate change, but the associated challenges of climate change, including migration flows, violence, and instability. Sterman noted that the right topic would represent areas that individuals could dedicate their careers.

In an email that evening to Backus, Malczynski, Sterman, and Richardson, Clancy offered a potential reconciliation: circumstance matters, and one size will not fit all. We need to discuss broad profiles of who the audience is and what kind of problems they are trying to solve and give some examples ranging from executive and high-level leadership in private companies and public sector agencies to everyday managers and academics. He noted that some of these audiences might overlap needs and be collapsible. However, we should begin from their needs, as they understand them, and how we can provide that safely and effectively to them with quality and expand their understanding of the art of the possible within reason relative to that profile. It is not wrong to go big, but it is wrong to ignore small. Because if we can provide safe, quality models that fit their needs, incrementally expand the boundaries of their knowledge, ***and no more*** – we are still providing a relatively better approach to solving certain classes of problems than anything else widely available in the business. He also challenged that data is always available or obtainable within the confines of a project on what mattered, issues directly addressed by Sterman later(Sterman, 2018).

After the Winter Camp, the schools continued to form. In May 2017, Khalid Saeed released a working paper with a personal perspective on what constituted confidence in system dynamic models(Saeed,

2017). Much like Richardson, he reinforced one of Forrester's points that system dynamic models influence policy rather than simply forecasting and argued for an inherently structuralist, rather than numeric, approach to model formulation. The structural formulation of the simulation to accurately capture the dynamic interactions was more useful than numerical precision. Abstracted representations of reference mode and simplified dynamic hypotheses were precursors of quality work, followed by structurally and behaviorally valid models. Not models that merely replicate historical data or forecast but can replicate a wide range of behaviors within the system represented in the reference mode (Saeed, 2017, pp. 11–12). Saeed goes further and explicitly circumscribes system dynamics is by indicating what it is not, pulling from Forrester that models cannot be derived from "historical time series" but instead constructed from "mental the written databases" reflective of "microstructure and the governing policies of the real world" and from these models, the use should not be forecasts of specific scenarios but insights into how "changes in policies affect behavior" (Saeed, 2017, pp. 23–24).

This paper by Saeed highlights two key changes that began at Winter Camp and defined the debate on quality going forward. First, the Winter Camp would present a first clear articulation of the different schools of thought emerging, though the advocates may not see themselves as advancing these positions we now attribute to them: a structural view (Richardson & Saeed), an empirical view (Sterman), and a pragmatist view (Backus & Malczynski.) Second, Backus's proposal to direct the Society towards the organization on global problems was one of the last times the debate on quality focused on what Forrester said and wrote in his 2007 address: impact with government and high leverage policies on large problems. From the Winter Camp 2017 forward, the debate within the Society between competing schools of thought almost entirely focused on differing views of what constituted quality between these schools of thought. Left behind was any continued consideration of the three points Forrester raised or the quality elements he expanded on in 2007.

Alexander was laid to rest, the successor states were forming, and all claimed to be acting in his name despite no longer addressing the points he raised in the barriers that kept system dynamics on its aimless plateau.

The Cambridge Cleanse: System Dynamics Conference 2017

In the lead-up to the 2017 Cambridge conference, the tensions exposed at the Winter Camp continued accelerating. Homer's ideas for strict standards leading to higher conference rejection rates (Homer, 2013, p. 126) were implemented. By way of example, as a consequence, the Psychology Special Interest Group (SIG) turned their annual SIG meeting time into a rogue-parallel session after the rejection of every paper submitted. In his Presidential Address to the Society, Len Malczynski addressed the quality controversy by presenting two simple slides articulating a pragmatist perspective. Using the conference as an example, he demonstrated how constraints in conference size, scope, and budget intersecting with depending on what audience attended the conference could result in different yet equally valid criteria of what constituted quality(Malczynski, 2017).

Revenge of the Empiricists: System Dynamics at 60 and the Path Forward 2018

Building on the Cambridge conference, at the beginning of 2018, Sterman set out his vision for the next sixty years(Sterman, 2018). The view at the sixtieth anniversary had markedly shifted from the view at the fiftieth (Sterman, 2007). Of the three main thrusts of Forester's critique that included the impact of system dynamics in government, focus on high leverage policies, and the quality of work – only the quality of work remained a topic of debate. Sterman continued to define what we have come to term the

empiricist perspective and adopted the strident language of Saeed in not just indicating what empiricists stood for but also what they stood against. Among many criteria of inclusion or exclusion were that system dynamics architectures may differ in how they represent time, state variables, and uncertainty, but all modeling must be evidence-based; grounded in empirical data; and leverage state-of-the-art tools(Sterman, 2018, pp. 18–37). Rebutting Warren and Clancy, Sterman indicated that all work, regardless of circumstance, should adhere to the same scientific rigor and standard of academic work to include publication in journals. Sterman was clear not to pursue publication for publication's sake but as a means to the end of improving the field and further emphasized the importance for skilled practitioners to act as "scholars to train the next generation of doctoral students, who then go on to their own academic posts, advance the state of the art and train still more students(Sterman, 2018, p. 39) Once developed models must be tested against "evidence and through experiments in the real world" lest poorly tested models replace "a poor mental model with a diagram, archetype, or simulation that is not grounded in evidence…create[ing] more harm by providing false confidence and more deeply embedding flawed mental models(Sterman, 2018, p. 39)."

This letter provoked a wide range of responses beyond the scope of this article. However, in summary, Homer(Homer, 2019) and Schwainger(Schwaninger, 2019) agreed with Sterman; Anderson agreed but expanded to hybrid modeling(Anderson, 2019), while Morrison argued a middle ground(Morrison, 2019). Randers suggested that focusing on modeling methodology overlooked the importance of implementation methodology (Randers, 2019). Sterman himself replied to these(Sterman, 2019).

The Reykjavik Skirmish & Rapprochement 2018

At the next conference, during a parallel then-former, President Malczynski made a detailed presentation on an analysis he had conducted of quality problems found in conference submissions. During the post-presentation period, Clancy indicated that the focus on quality in the Society had been misguided and arose from two fundamental errors. "The first error is the belief that we can inspect quality into the end and treat the conference as the end.' The second error arises from the first that when we reject papers, we believe that adequate resources are available to correct the deficiencies absent society help. This leads to a controversial proposition that we should not treat the conference as an end-product but as part of infusing quality whenever we can through the conference."

The controversial hypothesis worked as advertised, drawing a strong response from Sterman that led to a frank and productive exchange during the Q&A of that session and then continued after the session. Clancy focused on the importance of improving quality, while Sterman emphasized the importance of poor-quality work not being promoted. These positions were not mutually exclusive in principle. The conversation also included an exchange with then-students attending the conference who could offer their perspectives, as students from different nationalities and SD resource perspectives to the debate. Ultimately, Clancy and Sterman agreed on the importance of quality, even if they disagreed on the best means to achieve it.

Approach

The Case for Reconciliation

However, many of the same participants in the quality debate also open the door for reconciliation. In 1999, previewing many of the topics of the debate, Richardson wrote that a "field can choose cooperation and mutual credit over controversy…and careful painstaking research that strives to settle or at least bound some of our methodological questions, rather than enjoyable but inconclusive debates on the pros and cons of various practices in the field(Richardson, 1999, p. 448)."

Even in his letter to the system dynamics field on the path forward, Sterman asserted: "Good modelers choose the model architecture, level of aggregation and simulation method that best meet the purpose of the study, taking account of computational requirements, data availability, the time and resources available, the audience for the work, and the ability to carry out sensitivity analysis, understand the behavior of the model, and communicate the results and the reasons for them to the people they seek to influence(Sterman, 2018, p. 23)."

The Root of Reconciliation – Recognizing the Mental Models that give rise to different schools of Thought in system dynamics

We propose that the primary cause of different mental models is the nature of how the understanding of complex adaptive systems is obtained. In system dynamics, we do not seek the validity of our models - believing it impossible under current methods - and thus rely on the proper application of a suite of confidence-building approaches. However, the problem being modeled and the audience for whom the problem is being modeled place different values among various confidence-building approaches. Moreover, given the essential nature of confidence-building efforts throughout the modeling process, it naturally follows that even minor variations at the beginning result in wide divergences at the end, from the selection and proper application of methods to best aid the desired form of confidence-building; to the aesthetic in which findings are presented for highest resonance with the intended audience. What constitutes "quality" as an outcome measure is crucially dependent on these input variations - and thus, different understandings of quality arise from the different schools. We believe the increasing debates over "quality" within the Society reflect the emergence of these different mental models over time, suppressed in expression until the passing of Forrester, upon which emerged the opportunity to make one or another form the "right" method for system dynamics. Instead, we propose that these differences arise as the logical conclusion of natural and useful differences in understanding and studying complex systems phenomena and how these confidence-building approaches are understood with slight variations. We arrived at these findings from observation – rather than theory.

We define the four mental models as the "empiricist", "structuralist", "pragmatist", and "methodologist." For empiricists, the primary purpose of confidence-building is to ensure that their findings are true and replicable. The primary purpose for structuralists is that the model structure has an explanatory verisimilitude to the real world. For pragmatists, it is useful to the problem their client seeks to solve within the constraints imposed by the project. Finally, for methodologists, the tools and techniques they innovate and refine are useful to system dynamicists in other schools to further their work. From these core, differences in mental models arise different schools of thought and associated criterion traits described in Table 1.

Table 1: Summary of Schools of Thought

School	Goal of Confidence Building	Relationship to & Nature of Audience	Preferred Tools of Confidence Building	Audience's Aesthetic for Model Presentation	How is quality defined?
Empirical	Findings are true and replicable.	Indirect Relationship to Scientific Community	Numerical Fit to Observed Data	Mathematical equations and scientific notation.	Publication in high-quality, rigorous academic journals.
Structural	Findings have explanatory verisimilitude to a real-world system.	Indirect Relationship to Complex Systems they are Seeking to Explain	Structural Fidelity	Vivid explanatory structural diagrams and plain language.	Increase broad understanding of complex phenomena.
Pragmatic	Findings help solve a problem within the constraints provided the sponsor works within.	Direct relationship to stakeholders whose problem they seek to solve.	Defined by stakeholder or client needs.	Day-to-day management tools, including dashboards, flight simulators, etc.	Defined by stakeholder or client needs.
Methodological	Findings improve the method of System Dynamics.	Direct relationship to systems scientists, including system dynamicists.	Making a mathematically rigorous connection between behavior and structure and the creation of software tools to facilitate methods.	It varies but includes a mix of mathematical and visual presentations.	How broad is the use of the methods and improve performance of the field?

Metaphors are pervasive in our thinking and communication and exert a formative influence on science, language, and thought (Morgan, 2006). They provide a way of understanding one element of experience in terms of another, and they can provide powerful insights into organizational life. The strength of metaphors lies in their ability to tap into familiar ways of thinking and seeing while also generating new perspectives. By using a range of complementary and competing metaphors, we can expand our understanding of organizations and build on the strengths of different points of view.

However, metaphors can also be limiting, as they provide partial views that may obscure other important aspects. They can become "ways of not seeing," as the way of seeing created through a metaphor can obscure other important aspects of organizational life. With that caution in mind, we locate the four schools as visual metaphors shown in Figure 1.

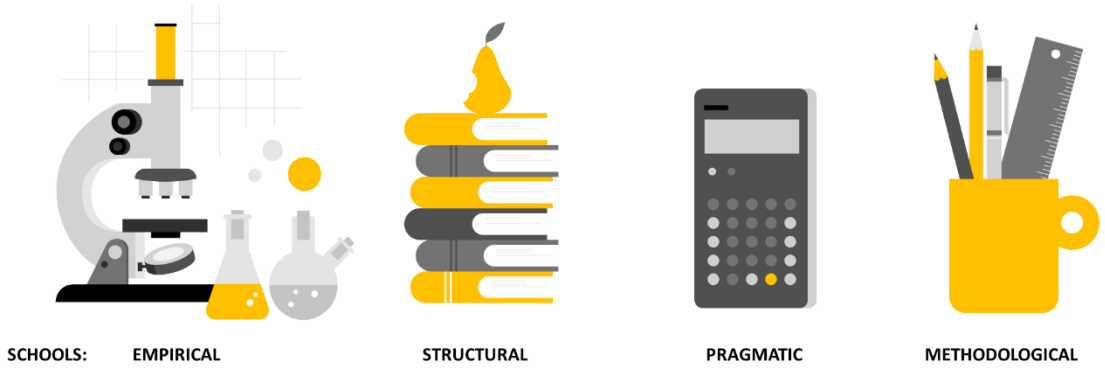

Figure 1: Visual Metaphors of the Four Schools of Thought

In the next section, we expand upon the metaphor of the schools with the metaphorical personas of those who operate in these schools. While reading this, you may discover that you do not agree with the choices of the metaphors we present and may want to introduce your own. This is desirable because the purpose is to promote dialogue and broaden our understanding rather than to arrive at a conclusion.

Empirical School – Metaphorical Persona: Scientists

Figure 2: Scientists

We propose that empiricists operate within the mental model of 'scientists' as depicted in Figure 2. They pursue confidence-building by studying complex systems to identify truth and create replicable and testable findings in the great scientific tradition. Empiricists have an indirect relationship with the larger scientific community reached by publishing peer-reviewed articles in highly regarded journals. Empiricists advance that the best methods to approach confidence-building lie in the correct and proper application of empirical observations, data collection techniques, and numerical replication of real-world behavior from the model. Precise measurement and calibration are preferred. This preference results in a blend of traditional system dynamics incorporated with and adherence to the most recent advances in data science, statistics, and advanced analytics. Because their audiences are fellow scientists and journal editors, the aesthetic best received by this audience is of analytical notations and mathematical equations. From the empiricist's perspective, quality is adherence to standards of highly-regarded journals, understanding that publication enables the testing, replicability, and dissemination of findings that most aid science.

Figure 3: Philosophers

Structural School – Metaphorical Persona: Philosophers

We propose that structuralists operate within the mental model of 'philosophers' as depicted in Figure 3. They pursue confidence-building in that it has an explanatory verisimilitude - that the findings offer a useful understanding that is as close as possible to being real, without necessarily being real itself, given that it arises from a simulation. Structuralists view their audience as the broad population seeking to understand the complex system being studied - reached indirectly through journals, think tanks, books, websites, conferences, and popularizing policy solutions through various means. Structuralists advance that the preference of confidence-building tools focuses on the fidelity of structure itself - in correctly identifying manifest and latent feedback structures and their causal method of interaction. Overall, the accurate structure is more important than precisely measuring any value within the structure. The proper methods arising from this emphasis lie mostly within the classical realm of system dynamics as they have been advanced over time: boundary selection, proper structural formulation, and the ability to pass confidence-building tests. The structuralist aesthetic is vividly clear to the lay reader in plain language. The structure is made visible and linked explicitly to behavior in visually striking ways. According to philosophers, quality provides the greatest understanding of a complex system to aid in communication and policymaking by those who must implement or live with that system's ramifications.

Pragmatic School – Metaphorical Persona: Policy Engineers

Unlike structuralists or empiricists, who often have an indirect relationship with their audience, pragmatists directly work with and for their audience, which is why they hold the mental model of policy engineers as depicted in Figure 4. Sponsors, in this case, community stakeholders on whose behalf modeling is undertaken or an even more direct internal or external client/consultant relationship within an organization. This direct relationship and the benefits and restrictions that follow distinguish the pragmatists and policy engineers from the empiricists and structuralists. The client comes to them with the problem seeking to be solved - and all selections of confidence-building, aesthetic, and quality are those that, in the pragmatists' mind, will best achieve the goal of solving the problem. Pragmatists will alternate between empiricism and structuralism and integrate with other methods based on the circumstance they find themselves in.

Figure 4: Policy Engineers

Methodological School – Metaphorical Persona: Artisan

The methodologist's audience are other system dynamicists working in the above three schools themselves as depicted in Figure 5. Artisans create better methodologies and techniques to improve

Figure 5: Artisans

capabilities in system dynamics. Once created, methodologists often seek to adopt these techniques through software design. Like the pragmatists, artisans directly connect to their audience, working within and writing for system dynamicists. Confidence building for methodologists lies in the mathematical rigor of the underlying methods and techniques and the utility and functionality of accompanying software that implements that method. Quality to a methodologist is judged by the reach of a tool across the audience of system dynamicists and that tool's overall ability to improve the field's performance.

Analysis – Categorizing Award Winners by School

As an exercise of whether these schools could prove useful, we analyzed Jay Forrester and Application WEB winners since the start of the Society. The method of analysis was qualitative, notional, and collaborative among the authors. Unlike the “Brief History” section above, we did not seek individual feedback from the authors listed. The four schools' concept is very early, and our approach was to explore the boundaries and definitions of school. Each author independently assessed the paper or corresponding work and marked it as an empiricist, structuralist, pragmatist, or methodologist. We used no rubric, which is beyond the scope of this early effort. After an independent assessment, we returned. If all three choices were the same – the school was listed as is. Where assessments differed, we used that as an opportunity to dialogue to reach a consensus, and in doing so, identified additional boundary definitions mentioned in the Discussion. The results of this analysis are provided in the Supplementary Materials. This includes a breakdown of the award year and identified school (Table 1) as well as two charts. The first chart shows the total distribution of awards within the schools (Figure 1) while the second shows the distribution of awards between schools in five year periods (Figure 2). .

Discussion

Of the 28 award winners we evaluated, we reached a unanimous consensus on the first pass in 22. Four out of the six papers requiring reconciliation involved differing judgment calls between reviewers between what was originally three schools: empirical, structuralist, and pragmatic. When we examined these works through the headings of Table 1 (e.g., relationship and nature of audience; goal and preferred tools of confidence building; audience’s preferred aesthetic, etc.), we were missing a school, which we later identified as methodological and added as a fourth school. The fifth and sixth disagreements arose on whether a paper fell into the pragmatic, empirical, or structural schools. Our resolution and analysis of these disputes are included in detail in the supplementary material. However, one key result is that we realized that when we used our but these disputes perhaps further convey that the definition of the schools is a shifting target. None of the authors of the works were contacted nor allowed to self-identify in a school; any findings at this early stage should be taken as notional. However, sheerly the exercise of categorizing the award winners into schools demonstrated the utility of such an approach. It clarified the interaction between elements of the field that were frequently in contrast and disputed during the quality debate described above.

Indeed, returning to Forrester's plateau, which began the debate, and how to move off it, we believe the four schools represent different pieces of his three challenges, as shown in Table 2.

Table 2: Schools Aligned to Forrester's Challenges to System Dynamics Society

Forrester Challenge	School of Thought within System Dynamics
Deliver impact to sponsors (e.g., government)	Pragmatic
Identify high-leverage policies	Empirical & Structural
Use high-quality methods	Methodological

And what constitutes 'high-quality' methods? We return to the eight criteria Forrester provided in Table 3 (Forrester, 2007, pp. 365–366). On the left side of the table are the eight criteria, and on the right is how the three original schools each contribute meaningfully to parts, but not the whole, of Forrester's eight criteria.

Table 3: Schools Aligned to Forrester's Criteria for Quality

Forrester Criteria of Quality	School of Thought within System Dynamics
The paper starts with a clear description of the system shortcoming to be improved.	Pragmatic
It displays a compact model that shows how the difficulty is being caused.	Empirical & Structural
It is based on a model that is completely endogenous with no external time series to drive it.	Structural
It argues for the model being generic and descriptive of other members of a class of systems to which the system at hand belongs.	Structural
It shows how the model behavior fits other members of the class as policies followed by those other members are tested.	Empirical
It arrives at recommended policies that the author is willing to defend.	Empirical & Structural
It discusses how the recommended policies differ from past practice. It examines why the proposed policies will be resisted.	Pragmatic
It recognizes how to overcome antagonism and resistance to the proposed policies. None of these require new advances in system dynamics but only a demand for higher standards of work.	Pragmatic

Where advances are made by the three schools, they are captured by the methodological school and returned in the form of new practices and tools back to practitioners in empirical, structural, or pragmatic schools. Of course, this feedback effect is notional at this point. But it shows how a reconciled approach across the schools can better serve the totality of elements Forrester presented for quality work rather than just a subset arrived at by elevating one or another school over the others.

Conclusion

Our next steps involve further research to deepen our understanding of the history of the quality debate, both in greater depth of what's presented here and other events of the history of the debate we haven't covered. Although we sought feedback from the individuals cited in the "A Brief History" section, we recognize that the group represents only a selection and not the total of all participants or perspectives on the quality debate. Additionally, we intend to seek feedback from the Jay Forrester Award winners to understand whether they agree with our assessment and challenge our boundary definitions.

We recognize that these proposed schools are useful heuristics at best and are not strictly exclusive. Philosophers of structuralism desire to be published in highly regarded journals just as scientists from within empiricism desire their works to create broad understanding. Pragmatists may guide clients to structuralism or empiricist approaches based on the studied problem. All may engage in multi-method modeling approaches. Indeed, most seasoned system dynamicists can and should know, if not the preference, how to adjust their mental model from one school to another as circumstances dictate. Therefore, our metaphor in using the term 'schools' is akin to the actual structure that serves as a place of learning that can be willingly entered, enjoyed, and left by those seeking to gain, practice, or teach knowledge. We do not intend the metaphor to be mistaken for and reject any interpretation of a prison where individuals are trapped within either because they have been confined or take it upon themselves the duty to confine others.

In conclusion, we have proposed these schools of thought as the starting point of departure for a broader discussion and dialogue on the causes of divergence within the field and whether those divergences can be beneficially recognized and encouraged or need to be suppressed. We anticipate this dialogue may range from others' observations to more theoretically grounded approaches in the nature of epistemology. We believe that by recognizing the different schools of thought - and allowing each to identify its convention on methods, approaches, definitions of quality, aesthetics, and ethical modeling practices, we can best serve the entire field and the pursuit of systems science. We believe that the most influential individual yet to emerge within system dynamics has yet to join the field. When she does - what will she find? Scattered factional kingdoms similar to the ruins of Alexander's Empire or a syncretic collection of schools reconciled to the existence of one another in the tradition of the city of Alexandria. Each school advancing its methods and forms to advance the study of complex adaptive systems and allows practitioners to move between and benefit from one, several, or all approaches.

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